



Examining Pre-Service Science Teachers' Personal and Enacted Pedagogical Content Knowledge About Seasons

Fen Bilimleri Öğretmen Adaylarının Mevsimler Konusundaki Pedagojik Alan Bilgilerinin İncelenmesi

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ABSTRACT: This study examined pre-service science teachers' pedagogical content knowledge (PCK) about seasons. The framework of this study was based on the Refined Consensus Model (RCM), and pre-service teachers' topic-specific PCK was also discussed in two dimensions: personal PCK (pPCK) and enacted PCK (ePCK), which are included in this model. The pPCK of the pre-service teachers represents their declarative PCK, and their ePCK represents their dynamic PCK. This qualitative descriptive research included 18 pre-service science teachers. In the study, knowledge of pre-service teachers' pPCK was collected in vignette-based individual semi-structured interviews, and data on their competencies regarding their ePCK, which they revealed in a real classroom environment, were collected through field observations and teaching video recordings. The study's qualitative data were evaluated using two separate rubrics developed by the author using the literature. Accordingly, it was determined that the pre-service teachers who participated in the research had limited pPCK and ePCK on the seasons and that their topic-specific pPCK was partially better quality than their topic-specific ePCK. Moreover, pre-service teachers' ePCK was observed to be different from their pPCK, but their ePCK was based on their pPCK. In this context, it was seen that the results of this research are consistent with RCM.

Keywords: Pedagogical content knowledge (PCK), personal PCK, enacted PCK, teacher education.

ÖZ: Bu çalışmada fen bilimleri öğretmen adaylarının mevsimler konusuna ilişkin Pedagojik Alan Bilgileri (PABları) araştırılmıştır. Bu çalışma rafine fikir birliği modeline dayanmaktadır ve öğretmen adaylarının konuya özgü PABları bu modelin içerdiği kişisel PAB ve uygulanan PAB olmak üzere iki şekilde ele alınmıştır. Öğretmen adaylarının kişisel PABları sahip olduğu PABa ilişkin bilgilerini ve uygulanan PABları ise sınıf ortamında uygulanarak ortaya konulan PABa ilişkin yeterliklerini temsil etmektedir. Nitel betimsel metodun kullanıldığı bu araştırmaya 18 fen bilimleri öğretmen adayı katılmıştır. Araştırmada öğretmen adaylarının kişisel PABlarına ilişkin bilgileri vignetteye dayalı bireysel yarı-yapılandırılmış mülakatlar kullanılarak ve gerçek sınıf ortamında uygulayarak ortaya koydukları PABlarına ilişkin yeterlikleri de ders gözlemleri ve sınıf içi ders video kayıtları kullanılarak toplanmıştır. Araştırmada elde edilen nitel veriler, literatürden yararlanarak yazar tarafından geliştirilen iki ayrı rubrik kullanılarak analiz edilmiştir. Buna göre, araştırmaya katılan öğretmen adaylarının mevsimler konusuna ilişkin kişisel ve uygulanan PABlarının sınırlı olduğu ve konuya özgü kişisel PABlarının konuya özgü uygulanan PABlarına göre kısmen daha iyi kalitede olduğu tespit edilmiştir. Ayrıca, öğretmen adaylarının gerçek sınıf ortamında uygulayarak ortaya koyduğu PABlarının mülakatlarda bildirdiği kişisel PABlarından farklı olduğu, fakat uygulanan PABlarının kişisel PABlarına da dayalı olduğu belirlenmiştir. Bu bağlamda, bu araştırma sonuçlarının rafine fikir birliği modeli ile uyumlu olduğu görülmüştür.

Anahtar kelimeler: Pedagojik alan bilgisi (PAB), kişisel PAB, uygulanan PAB, öğretmen eğitimi.

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In the literature on teacher education, it has been stated that content knowledge and pedagogical knowledge should be addressed not separately or as competing elements but as components that need to be integrated into teacher education programs to train more qualified teachers or pre-service teachers (Shulman, 1986). In other words, it has been stated that knowing the concepts and procedures related to any science topic very well is not enough for a teacher to teach that topic effectively in the classroom environment (Shulman, 1987). In this context, the concept of Pedagogical Content Knowledge (PCK) has come into prominence as a type of knowledge that is formed by blending content knowledge and pedagogical knowledge. PCK provides the basis of many studies on teacher education in recent years (e.g., Carlson & Daehler, 2019; Gess-Newsome, 2015; Kim, 2020; Mavhunga & Rollnick, 2013; Mazibe, 2020), and many science educators have expressed PCK as an important factor that supports the performance of teachers who improve over time and experience (Eames et al., 2011). Many studies have emphasized that PCK is an important type of knowledge that teachers and pre-service teachers should acquire (e.g., Chan & Hume, 2019; Magnusson et al., 1999; van Driel & Abell, 2010). In these studies, it has also been stated that there is a need to measure and determine the knowledge and skills of teachers and pre-service teachers to confirm whether the practices carried out in teacher education programs and professional development activities are effective (Chan et al., 2019; Coetzee et al., 2022). In this context, it is important to examine pre-service teachers' PCK and classroom teaching practices in terms of basic needs in teacher education.

Different researchers have conceptualized PCK, which teachers should have, in different ways (Mazibe et al., 2020), such as declarative PCK and procedural PCK (Schmelzing et al., 2013), PCK-in-action and PCK-on-action (Park & Oliver, 2008), and dynamic PCK (Alonzo & Kim, 2016). For example, in declarative PCK and PCK-on-action, a teacher expresses conceptual knowledge of students' misconceptions about a science topic in sentences (Schmelzing et al., 2013). Procedural PCK, Dynamic PCK, and PCK-in-action are the practical knowledge of a teacher on activities performed during the lesson (Alonzo & Kim, 2016; Schmelzing et al., 2013). The reasons underlying the conceptualization of PCK in such ways are to emphasize the understanding of the relationship between teachers' knowledge and teaching practices (Alonzo & Kim, 2016) and the importance of how teachers translate their PCK into practice (Park & Suh, 2015). Abell (2008) stated that "PCK is not merely the amount of knowledge in a number of component categories, it is also about the quality of that knowledge and how it is put into action" (p. 1410). In this context, the present study aimed to determine the personal PCK (pPCK) that represents the pre-service science teachers' declarative knowledge of a science topic and the enacted PCK (ePCK) that they revealed in the classroom environment. The theoretical framework of this study was based on the Refined Consensus Model (RCM), which includes these two PCK forms (pPCK and ePCK) (Carlson & Daehler, 2019), and detailed information on this model is presented in the section of the theoretical framework.

Because PCK has been defined as a topic-specific and teacher-specific professional knowledge form (Eames et al., 2011; Lee & Luft, 2008), it is predicted that each teacher and/or pre-service teacher will have a different PCK in each topic (Aydm, 2012; Lankford, 2010; Lee & Luft, 2008). Therefore, in the literature, it has been recommended to conduct studies on topic-specific PCK of teachers and/or pre-service teachers on different science

topics (Abell, 2008; Mazibe, 2020; van Driel et al., 2002). Many researchers have examined and emphasized the topic-specific PCK of science teachers and pre-service teachers using different approaches. For instance, Lankford (2010) has examined PCK on diffusion and osmosis; Mavhunga (2014) on chemical equilibrium; Kim (2020) on force and motion; Mazibe et al. (2020) on graphs of motion; Henze et al. (2008) on models of the solar system and the universe; Coetzee et al. (2022) on electromagnetism. Many PCK studies have been conducted on chemistry, physics, and biology; however, the number of studies examining pre-service teachers' PCK on astronomy-oriented science topics (for example, seasons), which is a separate learning area of the elementary school science program, is quite limited. Nonetheless, it is important to evaluate the PCK of elementary school science teachers and/or pre-service teachers on essential astronomy topics encountered in daily life, such as seasons. In addition, it was emphasized in the literature that learning and teaching this science topic is essential for many reasons, such as misconceptions among students about this topic and the difficulties students face in learning this topic (Sneider et al., 2011; Tsai & Chang, 2005). In this regard, it is thought that the present study will contribute to the literature regarding pre-service science teachers' PCK on the topic of seasons.

Theoretical Framework

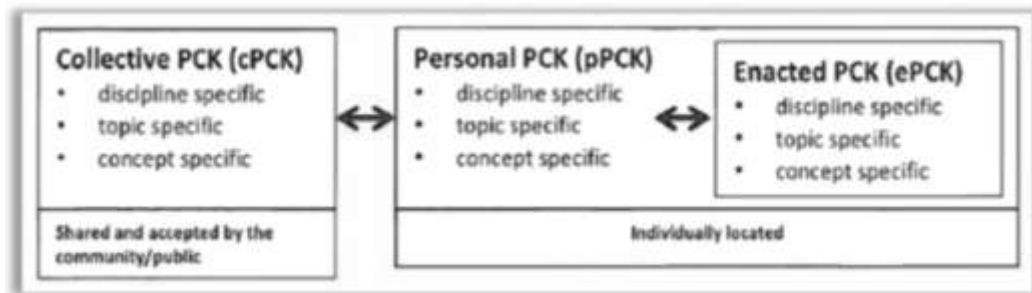
The concept of PCK was first proposed by Shulman (1986) (van Driel et al., 2002). After Shulman (1986), many researchers have introduced various definitions for PCK and its components (e.g., Gess-Newsome, 1999; Magnusson et al., 1999; Mavhunga & Rollnick, 2013; Park & Oliver, 2008; Veal & MaKinster, 1999). For example, Veal and MaKinster (1999) proposed a model, the General Taxonomy of PCK, for future studies on teacher education. In this model, teachers' knowledge is defined at three levels: general (discipline-specific) PCK (e.g., science), domain-specific PCK (e.g., chemistry), and topic-specific PCK (e.g., solubility) (p. 8). Magnusson et al. (1999) defined the concept of PCK with a model of five components: "orientation to teaching science, knowledge of science curricula, knowledge of students' understanding of science, knowledge of instructional strategies, and knowledge of assessment of scientific literacy" (p. 97). Magnusson et al. (1999) explained the topic-specific PCK as (a) curricular knowledge of a specific science topic, (b) knowledge of students' prior knowledge and learning difficulties on a specific science topic, (c) knowledge of instructional strategies and representations used in teaching a specific science topic, and (d) knowledge of assessment strategies and tools used in revealing students' understanding of a specific science topic (Lankford, 2010). In the PCK model of Magnusson et al. (1999), which has been cited the most, it has been stated that "these four elements are universal in the sense that they appear in a variety of general pedagogical models in literature and in teacher education materials" (Barendsen & Henze, 2019, p. 1143). In the present study, pre-service science teachers' PCK on the topic of seasons was examined through these components included in various PCK models in the literature (e.g., Carlson & Daehler, 2019; Gess-Newsome, 2015; Magnusson et al., 1999).

In the last ten years, new models of PCK and its components have been proposed, and many international researchers have organized various PCK summits. In the first PAB summit held in 2012, Gess-Newsome (2015) introduced the Teacher Professional Knowledge and Skill (TPK&S) model with the participants' contributions. This consensus PCK model describes "the overarching role of teacher professional knowledge" (Gess-

Newsome, 2015, p. 30). In the second PCK summit held in 2016, a group of international researchers gathered to examine the differences between different conceptualizations of PCK and review the literature studies on science teachers' PCK (Kim, 2020). As a result of this summit, the Refined Consensus Model (RCM) was revealed (Carlson & Daehler, 2019, p. 83). This latest model recognizes teachers' professional knowledge bases more extensively compared to the TPK&S model and clearly states that subject matter knowledge plays an essential role in teaching (Mazibe, 2020).

Figure 1

Different Components of PCK in the RCM



Note. (Mavhunga, 2019, p. 131)

Figure 1 presents the multi-dimensional nature of PCK in the RCM (Coetzee et al., 2022). Accordingly, three different realms of PCK have been proposed in the RCM: collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK). The cPCK is “a specialized knowledge base for science teaching that has been articulated and is shared among a group of professionals, which is related to teaching that particular subject matter knowledge to particular students in a particular learning context” (Carlson & Daehler, 2019, p. 88). The pPCK is unique for each teacher and/or pre-service teacher, and it is described as “a specialized form of personal knowledge that includes different knowledge resources related to the teaching and learning of specific science topics” (Alonzo et al., 2019, p. 273). pPCK is different from cPCK (Alonzo et al., 2019); however, cPCK transforms into pPCK when it is amplified and/or filtered by a teacher (Mazibe, 2020). The ePCK is “the specific knowledge and skills utilized by an individual teacher in a particular setting, with a particular student or group of students, with a goal for those students to learn a particular concept, collection of concepts” (Carlson & Daehler, 2019, p. 83). Teachers use the ePCK, which consists of knowledge and skills that guide all aspects of instruction in their classroom teaching practice (Singh, 2021). In other words, ePCK can be expressed as the PCK that is observable during the teaching practices of teachers or pre-service teachers (Aydeniz & Kirbulut, 2014). According to RCM, ePCK is specific to a particular science teaching and does not fully represent teachers' PCK; therefore, it is a subset of pPCK in the model (Carlson & Daehler, 2019). However, it has also been stated that regardless of the level of pPCK of a teacher or pre-service teacher, only some of this existing knowledge informs ePCK in a given situation (Kim, 2020). At the same time, according to RCM, the teaching experience that teachers acquire also shapes their pPCK (Coetzee et al., 2022). This shows that pPCK and ePCK mutually inform each other (Carlson & Daehler, 2019). In RCM, pPCK corresponds to static or declarative PCK, whereas ePCK is associated with dynamic PCK (Chan et al., 2019). In this regard, the

conceptual framework that will guide the current study is the RCM of PCK, and this current study is conceptualized within pPCK and ePCK (Carlson & Daehler, 2019). In this research, pPCK (i.e., declarative PCK) was used as a guide in examining what pre-service science teachers knew or thought about teaching the topic of seasons, and ePCK (i.e., dynamic PCK) was used as a guide to examine their classroom teaching practices.

Literature Review

The pPCK and ePCK in RCM, which are associated with the definition of PCK in the recent literature, are important as they include both the understanding and the enactment of teachers' PCK (Carlson & Daehler, 2019). They also play an essential role in the development of teachers' PCK (Mazibe et al., 2020), as the acquisition and enactment of learned PCK represent two intertwined situations (Park & Oliver, 2008). However, both PCK forms have not yet been researched enough as they have just entered the relevant research literature (e.g., Alonzo & Kim, 2016; Kim, 2020; Mazibe et al., 2020). It is also stated in the literature that pPCK and ePCK should be investigated for reasons such as (1) to explore the knowledge and competencies of teachers in terms of pPCK and ePCK in different science topics (Coetzee et al., 2022), (2) to understand the relationship between teachers' PCK and their teaching practices (Kim, 2020), and (3) to investigate the importance of the gap between pPCK and ePCK (Mazibe et al., 2020). In addition, in the literature, very few studies have been conducted on PCK (i.e., ePCK) captured from classroom teaching observations of teachers and/or pre-service teachers (Chan & Hume, 2019; Gess-Newsome, 2015). Park and Oliver (2008) emphasized that both types of PCK (pPCK and ePCK) are necessary for effective science teaching. In this regard, in the current study, it can be suggested that it is important to examine the knowledge and competencies of pre-service science teachers regarding both PCK types within the scope of a specific science topic.

In most of the studies in the relevant literature, it has been seen that one or multiple PCK components (such as knowledge of students' prior knowledge and learning difficulties and knowledge of instructional strategies and methods) were examined in teachers and/or pre-service teachers (e.g., Belge Can, 2021; Carpendale & Hume, 2019; Chan et al., 2019; Park et al., 2011). However, it has been emphasized that the determination of teachers' topic-specific PCK components is important for a well-developed PCK and effective teaching and that it is necessary to search for the detection of PCK components that teachers have or lack (Akın, 2017; Lee & Luft, 2008). In this context, in the current study, the pre-service science teachers' pPCK and ePCK on the topic of seasons were examined in line with four topic-specific PCK components: Science curriculum, Students' understanding, Instructional strategy and method, and Assessment.

In the literature, there are studies on the description of PCK that teachers and/or pre-service teachers have. In these studies, researchers have used data sources such as lesson plans (Van der Valk & Broekman, 1999), topic-specific PCK tests (Mavhunga & Rollnick, 2013), and content representation (CoRe) (Loughran et al., 2004) to determine teachers' PCK (Chan & Hume, 2019). It is seen that paper and pencil tests have been mostly used to capture teachers' PCK in studies. In most of the recent studies, interviews (Alonzo & Kim, 2016) and lesson observations (Park & Chen, 2012; Park et al., 2011) have also been used in addition to these data sources to capture teachers' PCK. Furthermore, it has been emphasized that it is important to use these two data sources in

the determination of PCK in these studies. However, in the studies, mostly 3-7 pre-service teachers have been interviewed and classroom lessons have been observed (e.g., Park & Oliver, 2008; Sağbilge, 2022). In this case, it can be suggested that the findings of these studies are limited in making a judgment about the levels/quality of PCK of teachers or pre-service teachers. In the current study, individual semi-structured interviews, field observations, and teaching video recordings were used to describe the PCK (pPCK and ePCK) of 18 pre-service science teachers. Accordingly, the vignette was employed in the creation of the interview protocol which was used to determine the pre-service teachers' pPCK (i.e., declarative knowledge). Vignettes are short stories that are developed based on real-life stories (Jeffries & Maeder, 2004) or the findings of previous scientific research (Carlson, 1996) in different formats such as open or closed-ended, fixed or interactive, and in text or video format (Simon & Tierney, 2011). In the literature, it has been stated that the vignette is a good data source to examine the developmental levels (Brovelli et al., 2014) or PCK (McNeill et al., 2015) of teachers and can be used in interviews (Simon & Tierney, 2011). It has also been suggested that the quality of the teachers' PCK would be determined by not only the pPCK they articulate in the interviews but also by how they were put into practice during teaching in the classroom setting (Abell, 2008). In this regard, field observations and teaching video recordings were used to capture pre-service teachers' PCK (i.e., enacted PCK) in the classroom setting. In this direction, it is thought that the current research is important in presenting concrete examples for the studies to be done on the effective development of pre-service teachers' science teaching competencies.

This study aimed to describe the pre-service science teachers' (PSTs') pPCK (i.e., declarative PCK) and ePCK (i.e., dynamic PCK) about the topic of seasons, which is a scientific phenomenon in the curriculum. For this purpose, firstly, the PSTs' knowledge of pPCK and its components was examined. Then, the competencies of PSTs regarding ePCK and its components revealed during teaching practices in the classroom environment were captured. Accordingly, the research questions of this study are as follows:

1. What is the PSTs' knowledge of pPCK and its components involving the topic of seasons?
2. What are the competencies of the PSTs regarding the ePCK and its components involving the topic of seasons?

Method

This qualitative descriptive study examines the pPCK and ePCK of PSTs about the seasons. The purpose of employing this methodology in this study is to provide a direct description of individuals' knowledge and skills regarding an event or circumstance (Lambert & Lambert, 2012; Sandelowski, 2010; Willis et al., 2016). Participants in the study were 18 volunteer PSTs (13 females and 5 males) in their last year of the Science Teacher Education program at the Faculty of Education of a state university in Turkey. These pre-service teachers have never experienced classroom teaching practice in an elementary school until this study.

Data Collection Tools

In this study, interviews, field observations, and teaching video recordings were used as data collection instruments to examine the pPCK and ePCK of PSTs about seasons. pPCKs of PSTs about the seasons were investigated using individual semi-structured

interviews based on vignettes. The interview protocol based on the vignette was developed utilizing relevant literature (e.g., Bailey et al., 2004; Kılıç, 2015; Sneider et al., 2011; Sung & Oh, 2018; Tsai & Chang, 2005) to examine the PSTs' knowledge of the four components of the pPCK in depth. This vignette was created by the researcher from successive stages of the lesson, each containing different events or situations that can occur in a classroom environment during one lesson hour (40 minutes). During the interviews, PSTs were asked open-ended questions about situations such as evaluating teacher-student behaviors and knowledge/opinions in a lesson on seasons based on the vignette, providing alternative suggestions on what the teacher should do in the next lesson, or questioning a specific event presented in the vignette (Schuster et al., 2007). In line with the answers given by PSTs, alternative questions were asked to them when necessary (such as explaining their views with reasons or expressing more clearly why they think the way they do). As a result, it was attempted to investigate PSTs' knowledge of each component of pPCK in depth by allowing PSTs to think more deeply about the concrete situations that can be encountered in the real classroom environment in the vignette and obtain more realistic data. The interview protocol based on this vignette was reviewed by two science educators and edited in line with their suggestions. Pilot interviews were then conducted with two PSTs who did not participate in the study, and the content of the interview protocol was finalized by editing some questions based on the PSTs' responses. All dialogues in the interviews with the PSTs participating in the study were recorded on a voice recorder and then transcribed and analyzed. A part of the vignette provided to PSTs during the interviews in the research is given in Figure 2.

Figure 2

The Vignette on PSTs' Knowledge of Students' Understanding

In the science lesson, teacher Sancar asked his students, "How do you think the seasons are formed?" to determine their prior knowledge of the formation of seasons, and received the following responses:

Student A: Teacher, there are four seasons in a year: spring, summer, fall, and winter... I think the seasons are formed by the Sun revolving around the Earth...

Student B: I think the Earth is the cause of the seasons... The Earth revolves around the Sun, which creates the seasons because the Sun does not move.

Student C: I think that the Earth's rotation around the Sun and its axis creates the seasons...

Student D: Teacher, I think the Sun has a lot to do with how the seasons change... For example, when the Sun is close to the Earth, it is summer and very hot outside. When the Sun moves away from the Earth, it is winter and very cold outside.

Student E: Seasons, I believe, are caused by the tilt of the Earth's axis... Because the Earth's axis is tilted, the distance between the Sun and the Northern and Southern hemispheres changes. This creates seasons...

Student F: Teacher, I think that summer happens on the side of the Earth that faces the Sun, and winter happens on the side that faces away from the Sun... I don't know what causes the other seasons...

After the interviews, the ePCKs of the PSTs were examined about the seasons in their real classrooms while they were teaching. PSTs' ePCKs were analyzed using written notes of field observations and lesson videos. The participant observation method was used in the research process so that the author could directly observe the classroom as it was and keep detailed observation notes on the classroom teaching practice of PSTs. Also, video

recordings of the lessons were used so that the events that happened in the classroom related to the lessons taught by the PSTs could be looked at and described in detail and so that each pre-service teacher's non-verbal actions, such as facial expressions and body movements, could be recorded exactly as they were. The teaching video recordings can also be watched again and again if needed. All of the pre-service teachers who took part in the study and the school administrators who needed to give permission did so. These data collection tools are among the data sources that have been frequently used to determine the PCK of teachers and/or pre-service teachers in recent years (Chan & Hume, 2019). Each PST participating in the study was given one lesson hour (40 minutes) for classroom teaching practices.

Data Analysis

The data were analyzed in a way that was similar to what was done in other studies (e.g., Chan et al., 2019; Mavhunga & Rollnick, 2013; Mazibe, 2020; Park et al., 2011). Since the literature usually uses qualitative data sources to measure the PCK of teachers and/or pre-service teachers, it has become common to use rubrics to analyze qualitative data (Chan et al., 2019). Accordingly, in the present study, the two forms of PCK given in the theoretical framework, pPCK and ePCK, were used as guides and two assessment rubrics were created for both pPCK (Appendix 1) and ePCK (Appendix 2) regarding the seasons, taking into account the four topic-specific components of PCK. These rubrics were designed by the author by examining many scales used in the literature to assess teachers' PCK (e.g., Mazibe, 2020; Mazibe et al., 2020). The answers given to the questions in the interviews used to evaluate the knowledge of PSTs about the pPCKs in relation to the seasons and the competencies of PSTs about the ePCKs in relation to the seasons were evaluated in four categories: limited, basic, developing, and exemplary (Mavhunga & Rollnick, 2013; Mazibe et al., 2020). For this process to be reliable, the items on both evaluation lists were reviewed and changed by a science educator who is an expert on the topic, and the changes were made based on his suggestions. As a result, rubrics with seven items for topic-specific pPCK and seven items for topic-specific ePCK were created to be used in analyzing the data from this study. The transcripts of the vignette-based individual semi-structured interviews were read several times, examined in detail, and evaluated according to the rubric prepared for the pPCK in order to analyze the data obtained as a result of the study. Likewise, the qualitative data obtained from field observations and teaching video recordings during the PSTs' teaching practices in the classroom environment were analyzed in depth and evaluated according to the rubric prepared for ePCK. Furthermore, a science educator re-analyzed the data obtained from the data sources of the three PSTs participating in the study using both rubrics to ensure the reliability of the data obtained (Miles & Huberman, 1994). For pPCK and ePCK, the average agreement between the author and expert analyses was 86%.

Ethical Procedures

Ethical approval and written permission were obtained from the Munzur University Non-Interventional Research Ethics Committee with the decision dated 30.03.2023 and numbered 2023/05-09.

Results

PSTs' Topic-Specific pPCK

The pPCKs of the PSTs participating in this study were presented under separate subheadings specifically within the context of PCK components. PSTs' pPCKs (i.e., declarative PCK) about seasons are given in Table 1.

Table 1

PSTs' Topic-Specific pPCK about Seasons

	pPCK	Limited	Basic	Developing	Exemplary
Science curriculum	Concepts and achievements in the science curriculum	11	4	3	-
Students' understanding	Students' prior knowledge	10	4	4	-
	Students' learning difficulties (misconceptions) and their reasons	5	6	7	-
Instructional strategy and method	Instructional strategy and method	12	5	1	-
	Representations	6	10	2	-
Assessment	Assessment approaches and methods	14	4	-	-
	Assessment tools and their use	12	6	-	-

Science curriculum knowledge of PSTs

When the curriculum knowledge about the concepts and achievements of the seasons topic in the science curriculum was examined, it was found that most pre-service teachers did not know the program content. Regarding the concepts and achievements related to this science topic, 11 PSTs made limited explanations, such as students knowing the four seasons (spring, summer, fall, and winter), the Earth, and the Sun. Four PSTs explained these concepts at the basic level by giving an example from the objectives of the science program in addition to these concepts. On the other hand, three PSTs mentioned the concepts and achievements related to the formation of seasons, such as the Earth's motions, the Earth's axis of rotation, axis tilt, and the Earth's orbital motion around the Sun at the developing level.

Students' understanding knowledge of PSTs

In Table 1, when the findings declared by the PSTs in the interview regarding the students' understanding of the formation of seasons are analyzed, some of the PSTs either stated that they did not know the students' prior knowledge on the topic (n=4) or they gave limited answers with statements such as students know the names of the seasons and/or they know the order of the seasons (n=6). Furthermore, four PSTs declared that students have prior knowledge of the Earth's rotation and circulation, the Sun's motion, and the seasons' names at the basic level. According to the other four PSTs, the students had developed prior knowledge about the topic, such as the rotational motion of the Earth around its axis and the results of this motion, the motion of the Sun, and the direction and

motion of the Earth's orbit around the Sun. The knowledge of the PSTs on students' learning difficulties (misconceptions) and their causes regarding the formation of the seasons was attempted to be determined by open-ended questions posed to them during the interview using the vignette. Accordingly, seven PSTs defined two or three misconceptions of the students about this science topic, such as seasons are formed by the change in the distance between the Earth and the Sun or seasons are formed by the rotation of the Sun around the Earth and stated their reasons with developing explanations. While six PSTs were able to identify one or two misconceptions of the students in the vignette presented to them, they were not able to express fully their reasons. On the other hand, the other PSTs both stated that students would not have any difficulty with this science topic and that there would be no misconceptions, and they could not define the misconceptions in the vignette. Also, three of these PSTs were found to have misconceptions about the formation of seasons. Below, you may see some examples of interviews made with PSTs.

Researcher: (vignette in Figure 2) What do you think about the students' answers to teacher Sancar's question?

PST-8: ...before studying this topic, students should be familiar with the movements of the Sun and the movements of the Earth... They also need to know what happens as a result of these because if students do not learn them well, they will have difficulty learning the next topics, and misconceptions will occur... For example, here, Student A says that the seasons are formed by the Sun revolving around the Earth, which is sad because the child does not know that the Earth revolves around the Sun... This child is in misconception... Student C also said that seasons occur when the Earth rotates both around the Sun and around its axis, which is wrong because seasons occur when the Earth rotates around the Sun... Student B thinks as I say, so this student is right... The other student (Student D) says that the seasons are formed not by the tilt of the Earth's axis but by the proximity or distance of the Earth to the Sun, which is wrong... So, Student D has incomplete knowledge, and I think she/he does not know the movements of the Earth and the Sun... Student F is also wrong... Only Student E is exactly right because he knows that the seasons are formed by the tilt of the Earth's axis... Other students already have learning difficulties because they do not have this information...

PST-1: Student A thinks that the Earth does not revolve around the Sun, but the Sun revolves around the Earth, this student has the misconception... That is, he did not say that seasons are formed by revolving the Earth around the Sun... Student C has incomplete knowledge, I think this student confused the formation of day and night with the formation of seasons... Student D knows something because he said that the Sun plays a role in the formation of the seasons, but the Sun is not the only factor in the formation of the seasons... Here, the student did not know about the tilt of the axis, and he fell into a misconception... Here, she/he made a mistake in the proximity and distance of the Earth to the Sun, that is, she/he thought that summer occurs when the Earth is close, and winter occurs when the Earth is far away... Student E said exactly the right thing, that is, this student does not have a misconception... She/He said that seasons are formed due to the tilt of the Earth's axis... I believe she/he has the right prior knowledge... Student F is also in misconception...

Instructional strategy and method knowledge of PSTs

When the findings in Table 1 regarding the teaching strategies and methods declared by the PSTs in the interview were examined, it was observed that 12 PSTs would use teacher-centered teaching strategies in teaching the topic of seasons either by making plain explanations on the topic or by using only the question-answer technique. Furthermore, these PSTs stated that they did not know how to plan and teach their lesson or how to create an activity because their knowledge of the content of this science topic was insufficient. However, five PSTs stated their explanations on how to create learning activities, such as showing the Earth's orbit around the Sun with a model for the formation

of seasons, etc., by using hands-on materials (e.g., globes) in a way that students would be active at the basic level. Only one PST gave developing explanations on how to create student-centered learning environments based on the constructivist learning approach and making students active in the process of teaching this topic. It was observed that six of the PSTs who participated in the study were at the limited level because they either stated that they would not use any representation while teaching the topic of the seasons or that they would use a representation to inform students about this topic (i.e., in a teacher-centered way). Furthermore, 10 PSTs gave basic explanations on how they would use representations such as illustrations, videos, simulations, hands-on materials, models, etc. either to summarize the lesson or to reinforce students' knowledge on this topic. Two PSTs stated that they would use representations to concretize/visualize this scientific phenomenon or eliminate students' misconceptions about it with developing-level explanations. They also said that they would use these representations to motivate, encourage, and engage students in science lessons.

Assessment knowledge of PSTs

When the findings reported by the PSTs in the interview regarding the assessment component are analyzed in Table 1, 14 PSTs made limited explanations by stating that they would evaluate students' understanding of the seasons at the end of the lesson (i.e., the traditional assessment approach). Other PSTs provided basic-level explanations. Regarding assessment tools and their use, 12 PSTs stated that they would assess students' learning on this topic at the end of the lesson through question-answer (oral roll call), true-false or multiple-choice tests, or homework. Furthermore, six PSTs stated that they would assess students' understanding of how the seasons are formed at the basic level by making drawings, assigning project homework, or evaluating students' understanding through student work.

PSTs' Topic-Specific ePCK

The ePCKs of the PSTs participating in the study were presented under separate subheadings specifically within the context of PCK components. PSTs' ePCKs (i.e., dynamic PCK) about seasons are given in Table 2.

Table 2
PSTs' Topic-Specific ePCK about Seasons

	ePCK	Limited	Basic	Developing	Exemplary
Science curriculum	Referring to the concepts and achievements in the science curriculum	9	6	3	-
Students' understanding	Questioning students' prior knowledge and learning difficulties (misconceptions)	11	5	2	-
	Recognizing and acknowledging students' prior knowledge and learning difficulties (misconceptions)	13	4	1	-
Instructional strategy and method	Use of instructional strategy and method	11	5	2	-
	Use of representations	10	6	2	-
Assessment	Assessment approaches and methods	14	4	-	-
	Use of assessment tools	14	4	-	-

Science curriculum knowledge of PSTs

When the science curriculum component was examined, it was observed that only three PSTs referred to concepts such as the position of the Earth, the motion of the Earth's orbit around the Sun and its consequences, and the tilt of the Earth's axis of rotation (axial tilt) about the seasons, and they taught their lessons by making logical connections between most of these concepts. Six PSTs were identified as being at the basic level because they focused on some of the concepts about this topic (such as the structure of the Sun, the sizes of the Earth and the Sun, and the rotational and orbital motions of the Earth) and only taught by establishing relationships between these concepts. Nine PSTs were found to be at a limited level because they did not teach most of the important concepts about how seasons come to be; they mostly focused on concepts that had nothing to do with each other, and they did not make connections between concepts related to this topic.

Students' understanding knowledge of PSTs

When the results of the ePCK of the PSTs on students' understanding are examined in Table 2, 11 PSTs were assessed to be at the limited level because they did not question students' possible prior knowledge and learning difficulties (misconceptions) about seasons, and five PSTs were assessed to be at the basic level because they partly questioned them by asking only a few. It was observed that the other PSTs identified students' prior knowledge and at least two misconceptions about the topic, such as the summer and winter seasons are formed by the side of the Earth facing the Sun. For example, these PSTs questioned students' prior knowledge and misconceptions by asking them some open-ended questions about the topic, by having a few students draw on the board how the seasons occur, or by asking questions based on pictures or a model of the Solar system. Hence, the competencies revealed by these PSTs during the lesson were scored as developing. During the lesson, 11 out of 13 PSTs did not question students' prior knowledge and learning difficulties regarding the seasons and, therefore, did not teach their

lessons by taking learners' thinking into account. The two PSTs partially questioned the students by asking a few questions, but it was observed that they did not take the students' answers into account and did not recognize their misconceptions. Therefore, the competencies enacted by these PSTs in a real classroom environment were scored as limited. Four PSTs questioned students' prior knowledge and learning difficulties but continued the lesson by partially taking into account the students' thoughts and, therefore, were scored as basic. The other PST was scored as developing because she/he recognized and acknowledged students' prior knowledge, such as that there are four seasons, that the Earth moves in a circle, and that the Sun is bigger than the Earth, and some of the students' misconceptions about the seasons during the lesson.

Instructional strategy and method knowledge of PSTs

During the classroom teaching practices, it was observed that 11 PSTs used the lecture method while teaching the topic of the seasons and did some of the teacher-centered activities in which students were passive. It was also observed that these PSTs were weak in classroom management. When the findings related to the use of instructional strategy and method in Table 2 are examined, it is observed that the competencies revealed by these PSTs during the lesson were scored as limited. The competencies of five PSTs during the lesson were scored as basic because they explained the topic by drawing shapes on the board or asking questions through some representations such as pictures, slides, videos, and models/mock-ups and then made explanations about the topic and were partially successful in classroom management. On the other hand, two PSTs used a model/mock-up of the Earth and a flashlight to have students explore the topic by asking questions, or they used a model/mock-up of the Solar system and asked questions related to the topic and created discussion environments primarily with dialogues between the teacher and the students, or they showed a video or simulation and asked various questions about the formation of the seasons and made explanations. In this regard, the competencies of these PSTs during the lesson were also scored as developing. 10 PSTs who participated in the study were scored as limited because they either did not use any representation about the topic or used representations such as illustrations and diagrams to make direct explanations about the seasons. The competencies of 6 PSTs were scored as basic during the lesson because they partially used representations such as illustrations and models/mock-ups to summarize the related topic at the end of the lesson or to question students' prior knowledge about the seasons, etc. The other PSTs were rated at the developing level for their competencies in the use of representations such as hands-on materials (e.g., globes, flashlights), models, videos, and simulations during classroom teaching practices.

Assessment knowledge of PSTs

Fourteen of the PSTs participating in the study either did not assess students' understanding of the seasons or tried to assess it by asking questions to a few students at the end of the lesson and did not use any assessment tool. Therefore, the competencies of these PSTs regarding assessment approaches and methods and the use of assessment tools during the lesson were scored as limited (Table 2). The four PSTs tried to partially evaluate the students' understanding of the topic from the beginning to the end of the lesson and had them draw and explain how the seasons are formed on a piece of paper and then collected

the papers. The competencies that these PSTs demonstrated in a real classroom environment were scored as basic. None of the PSTs' competencies in assessment approaches and methods and use of assessment tools demonstrated during the lesson were rated as developing or exemplary.

Discussion and Conclusion

This study examined the pPCK (i.e., declarative PCK) and ePCK (i.e., dynamic PCK) of the PSTs on the topic of seasons. According to the data obtained from the vignette-based individual semi-structured interviews held with the PSTs who participated in the research, the pre-service teachers had a limited level of pPCK on the topic of seasons. According to the data obtained as a result of the examinations made during the lectures of the PSTs in the real classroom environment, the pre-service teachers had a limited level of ePCK related to the topic of seasons. The PSTs' knowledge of all components of topic-specific pPCK and the PSTs' competencies regarding all components of topic-specific ePCK during the teaching practice were mostly limited. Regarding the other components of the topic-specific pPCK, the majority of the PSTs' knowledge of students' understanding was the best, and their knowledge of assessment was the worst. Regarding the other components of the topic-specific ePCK, the knowledge of the science curriculum was the best, and the knowledge of assessment was the worst. Likewise, in previous studies, it has been indicated that the knowledge and competencies of teachers and/or pre-service teachers on the components of PCK would not develop at the same level (Aydın, 2012; Barendsen & Henze, 2019). In studies, it has also been observed that the PSTs' knowledge of assessment and their competencies regarding assessment revealed during the lecture were quite weak (Aydın, 2012; Sağbilge, 2022). The general reasons for this situation may include the fact that pre-service science teachers do not take applied courses on assessment approaches and methods and assessment tools during their university education, that they do not attach importance to the process of evaluating what students have learned during their lesson planning and teaching practices as well as students' learning experience, etc. Furthermore, in the present study, none of the pre-service teachers' explanations regarding the components of pPCK and the competencies regarding the components of ePCK during the lecture were at an exemplary level. Similarly, in the literature, it has been stated that teachers' and/or pre-service teachers' knowledge of topic-specific pPCK in various science topics and their competencies regarding topic-specific ePCK were weak (e.g., Barendsen & Henze, 2019; Mavhunga, 2014). The reasons for this may be, in particular, pre-service teachers' lack of content knowledge and teaching experience (Barendsen & Henze, 2019; Kim, 2020; Kind, 2009; Mazibe, 2020; Rollnick et al., 2008). Many PSTs who participated in the current study also admitted during the interviews that they lacked content knowledge on the relevant science topic. In the literature, it has been emphasized that teachers' content knowledge is a prerequisite for PCK (Kim, 2020; Mazibe, 2020). However, in some studies, it has been indicated that a good level of content knowledge alone is not sufficient for teachers or pre-service teachers to have a strong PCK (Davidowitz & Potgieter, 2016; Rollnick & Mavhunga, 2014; van Driel et al., 1998). In this context, it has been stated that in addition to content knowledge, teachers and/or pre-service teachers need to gain experience in classroom teaching practices, attend education-related seminars, and exchange opinions with more experienced teachers to develop their topic-specific PCK (Aydın, 2012; Henze et al., 2008; van Driel et al., 1998). In short, it is suggested that PSTs should first develop

their cPCK regarding their knowledge and competencies in the teaching profession during their undergraduate education. cPCK, which is defined as an expert knowledge base for science teaching in RCM (Carlson & Daehler 2019), also includes teachers' pPCK and ePCK. According to this model, to what extent this form of PCK is amplified and/or filtered by each teacher or pre-service teacher, they can develop their pPCK and ePCK proportionally (Carlson & Daehler 2019; Mazibe, 2020). In this respect, it is suggested that educational activities should be carried out through in-service training for teachers or teacher education programs for pre-service teachers to share, learn, and gain knowledge and skills about cPCK.

According to the qualitative findings obtained in this study, the PSTs' pPCK on the topic of seasons that they articulated in the interviews and their competencies regarding ePCK that they revealed in the classroom environment mostly differed. However, it can also be said that pre-service teachers' competencies they enacted during the teaching practices (ePCK) were heavily dependent on the available knowledge (pPCK) they articulated in vignette-based interviews, but their pPCK did not fully reflect their ePCK captured in the real classroom environment. This may be explained by the fact that the competencies revealed by the PSTs in their use of topic-related representations during the teaching practice (ePCK) relied on their knowledge of instructional strategies and methods or representations that PSTs declared in the interviews; however, PSTs did not apply their knowledge of representations in the classroom environment. This result is consistent with RCM, which positions ePCK as a subset of pPCK (Carlson & Daehler 2019) (Figure 1). In addition, PSTs' components of topic-specific pPCK and ePCK were mostly determined to differ. For example, when the data on the students' understanding component of PCK was examined, it was seen that the PSTs did not recognize and acknowledge the students' misconceptions on this topic in teaching practices or did not teach the topic by considering students' thoughts, although some of them articulated the students' explanations of learning difficulties (misconceptions) and the causes of these difficulties regarding the formation of seasons at a developing level in the interview (see Tables 1 and 2). The findings of this research support the relationships between pPCK and ePCK specified in the RCM (Carlson & Daehler, 2019). According to this model, PSTs' pPCK forms the basis for the ePCK they reveal during classroom teaching practices and serves as an existing knowledge and skill repository from which they can benefit (Alonzo et al., 2019). At the same time, according to RCM, PSTs' pPCK and their ePCK are not expected to be compatible since ePCK is flexible and changes for a particular learning environment, a particular student group, a particular science topic, or is formed and used at that moment in the classroom setting (Alonzo et al., 2019). The results of some studies (Kim, 2020; Mazibe, 2020; Mazlum Güven & Yiğit, 2020) on different science topics in the literature are consistent with the results of this research.

Considering the study's overall findings, it was seen that most of the PSTs' topic-specific pPCK was partially of better quality than their topic-specific ePCK. For instance, some pre-service teachers partially declared their knowledge and skills about the students' prior knowledge of seasons and how to determine them in a theoretical way, but they were weak in applying their knowledge and skills while teaching the lessons on the relevant topic in a real classroom environment. It can be suggested that the general reasons for this are that the general or topic-specific pedagogical knowledge and competencies of PSTs were weak, that very few lessons are directly related to discipline-specific (science-

specific) pedagogical knowledge and skills in the science teacher education program, and that most importantly, very few opportunities regarding teaching practices are provided to PSTs in a real classroom environment during undergraduate education (Alonzo & Kim, 2016; Mazibe et al., 2020). From these perspectives, it was concluded that pre-service teachers need to carry out more instructional practices in order to transfer the PCKs (pPCK) they have or acquired to their lessons in the real classroom environment. Moreover, it is suggested that pre-service teachers should constantly reflect on the experiences they acquired during these teaching practices or different/initial experiences of themselves (reflective practice) (Park & Oliver, 2008). When the findings regarding the topic-specific pPCK and ePCK components of PSTs were examined, it was seen that the PSTs' pPCK was of slightly better quality than their ePCK in all components except the science curriculum component. This may be explained by the fact that even though pre-service teachers consider the students' misconceptions on the relevant topic and effectively plan the instructional activities and the assessment process, they may be weak while practicing the designed lesson plan in the real classroom environment. Compared to the other components, the general reason why the PSTs' competencies of the topic-specific science curriculum component in the classroom environment (ePCKs) were of slightly better quality than their knowledge of this component (pPCKs) might be that pre-service teachers repeat their content knowledge on the relevant topic during the planning of the lesson and review the concepts, achievements, etc. in the science program before teaching the lesson. Likewise, in previous studies, it has been stated that the declarative knowledge and teaching practices of teachers and/or pre-service teachers would develop differently (Alonzo & Kim, 2016; Mazibe, 2017; 2020; Mazlum Güven & Yiğit, 2020). In this respect, the results of this study are thought to be important in terms of presenting empirical evidence while explaining the relationships between teachers' knowledge and their classroom teaching practices.

Previous studies in the literature have determined that the quality of topic-specific PCK of teachers/pre-service teachers differs based on the topic. For example, Aydın (2012) has examined the PCKs of two chemistry teachers on electrochemistry and radioactivity and has stated that there are two different types of PCK for two different science topics: PCK A for teaching electrochemistry and PCK B for teaching radioactivity. Therefore, as in the current study, it was concluded that it would be more appropriate to research PCK in its topic-specific dimension since the quality of pre-service teachers' pPCK and ePCK may vary within the scope of different science topics (Mazibe, 2020; Rollnick & Mavhunga, 2014). Accordingly, it can be recommended to conduct studies examining PCK and classroom teaching practices of science teachers/pre-service teachers regarding different science topics that students have difficulty learning in order to provide concrete evidence to researchers on teacher education. In addition, in this study, the vignette was used to examine the topic-specific pPCK of the PSTs, and vignette-based individual semi-structured interviews within the scope of the related science topic were held with the PSTs. Based on the current research findings, it is thought that the vignettes used during the interviews in the study have a significant potential to provide valid and reliable information about the quality of topic-specific pPCK of pre-service teachers. It can be recommended the vignette be used in PCK studies to be carried out in the field of teacher education. It is suggested that presenting concrete situations to participants through written short stories or short videos is more effective in terms of assessing these concrete cases and

expressing views. Therefore, it is thought that it is important for researchers to explore or question the knowledge and skills of participants in different dimensions.

Conflicts of Interest

The author declares that there is no conflict of interest.

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Appendices

Appendix 1

A Sample Extract of the pPCK Rubric

pPCK	Limited	Basic	Developing	Exemplary
Students' prior knowledge	-No prior knowledge of the science topic was mentioned. -Several major concepts were not mentioned as prior knowledge about the science topic.	-A few major concepts were mentioned as prior knowledge about the science topic.	-Some major concepts related to the science topic were mentioned sufficiently as prior knowledge.	-As prior knowledge about the science topic, many major concepts were mentioned extensively.
Students' understanding	-No learning difficulties were mentioned about the science topic. -No misconceptions related to the science topic were identified.	-One or two misconceptions related to the science topic were identified. -The reasons for these misconceptions were not fully explained or partially explained.	-Two or three misconceptions related to the science topic were identified. -The reasons for these identified misconceptions were explained sufficiently.	-All misconceptions related to the science topic were identified. -The reasons for these misconceptions were explained extensively.

Appendix 2

A Sample Extract of the ePCK Rubric

ePCK	Limited	Basic	Developing	Exemplary
Questioning students' prior knowledge and learning difficulties (misconceptions)	-During the lesson, students' possible preliminary knowledge and misconceptions about the science topic were not questioned.	-During the lesson, students' possible preliminary knowledge and misconceptions about the science topic were partially questioned.	-During the lesson, students' possible preliminary knowledge and misconceptions about the science topic were questioned in an acceptable way.	-During the lesson, students' possible preliminary knowledge and misconceptions about the science topic were adequately questioned.
Students' understanding	-During the lessons, students' misconceptions related to the science topic were not recognized. -During the lessons, the preliminary knowledge and misconceptions of the students were not taken into consideration.	-During the lesson, a few of the students' misconceptions related to the science topic were recognized. -During the lessons, the preliminary knowledge and misconceptions of the students about the science topic were partially taken into consideration.	-During the lesson, some of the students' misconceptions related to the science topic were recognized. -During the lessons, students' preliminary knowledge and misconceptions related to the science topic were taken into account in an acceptable way.	-During the lesson, many of the students' misconceptions related to the science topic were recognized. -During the lessons, students' preliminary knowledge and misconceptions related to the science topic were adequately taken into consideration.



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