Investigating Pre-Service Early Childhood Teachers’ cPCK and pPCK on the Knowledge Used in Scientific Process Through CoRe

Elif Buldu1 and Metehan Buldu2

Abstract
The study aimed to investigate pre-service early childhood teachers’ (PSTs) collective pedagogical content knowledge (cPCK) and personal pedagogical content knowledge (pPCK) on the knowledge used in scientific process (SP) through the content representation (CoRe) design, interview, and knowledge used in scientific process (KSP) forms. The data were collected from 36 sophomore PSTs’ with a case study design. At the beginning of the data collection process, the PSTs’ prior knowledge used in SP was determined individually through a pre-interview and the KSP form. At the conclusion of the 13-week science-focused course, post-interviews, the KSP form, and the CoRe form were applied again. The CoRe forms were filled collectively based on their science activities, which were designed at the end of the science course. The PCK developed by Magnusson et al. was used for data analysis and to decide on the main themes of the data. The study’s findings revealed that the PSTs initially had some misconceptions relating to knowledge of SP. While the participants were confused about the knowledge used in SP and made incorrect definitions prior to the science-focused course, nearly all of the PSTs’ conception were changed on all of the concepts used in SP and reflected the most confused skills (especially observing and measuring) to their teaching plans after the course. Therefore, their pPCK and cPCK development were supported by both the science-focused course and collaborative CoRe design. The findings of the study have important implications for government policies and teacher training programs.

Keywords
personal pedagogical content knowledge (pPCK), collective pedagogical content knowledge (cPCK), pre-service early childhood teachers (PST), science process skills (SPS), content representation (CoRe)

Introduction
The importance of teaching science to children through developmentally appropriate science experiences and supporting early childhood teachers’ professional development in teaching science is becoming increasingly recognized. The driving force behind it is that children have a great potential to learn science concepts during early childhood years. As it is understood how important it is to provide science education to children at younger ages, a number of studies have been conducted to understand children’s concept development. One argument also suggests that children’s early exposure to science knowledge can enhance the development of science concepts and scientific thinking later (Andersson & Gullberg, 2012). This notion is supported in Eshach and Fried (2005)’s study, which showed that children enjoy thinking, observing, and exploring the environment around them and reported that they develop a positive attitude toward science and can better understand scientific information in the future when they are exposed to science at an early age. Worth (2010) also states that presenting science concepts is crucial for the development of understanding the inquiry process and scientific reasoning in children. Supporting children’s science learning in early years with the guidance of skilled teachers can enhance their experiences and further learning (Worth, 2010). Research has shown that one of the factors that enable effective science learning is teachers possessing rich science knowledge and
understanding (Williams & Lockley, 2012). The National Science Teacher Association (NSTA, 2002), which is a path-finder in professional development in science education, suggests that supporting teachers’ subject-matter knowledge is an important factor in accomplishing standards because it is a determinant predictor of children’s science learning outcomes (Hong et al., 2013; Wilson et al., 2002). Many studies related to early childhood teachers’ confidence in teaching science revealed that staff often avoid teaching science due to lack of competence in teaching the subject matter (Coley & Padron, 1999; Smith & Neale, 1989; Torquati et al., 2013). Early childhood teachers’ self-perceived insufficiency leads to a lack of confidence, which in turn results in a lack of pedagogical content knowledge (PCK) in teaching science. This process shows a reciprocal relationship between self-efficacy and PCK in teaching science. Thomson et al. (2017) found that there is a significant correlation between teachers’ lack of self-efficacy and their lack of PCK in science and mathematics teaching. In the process of teaching science, the subject matter is an important component of teacher knowledge and understanding. According to Fleer and Hardy (2007), teachers are expected to focus on teaching the process of scientific inquiry and learning by discovery, as well as teaching content knowledge, because researchers believe that science learning is possible through supporting the discovery process. As for early childhood teachers, there is a growing demand on developing their science knowledge and integrating it to their daily routines (Nilsson & Elm, 2017). In this regard, several studies have been conducted to investigate the link between effective teaching of science and children’s learning of science through the use of science process skills (SPS; Jirout & Zimmerman, 2015; Meador, 2003; Minnaar & Naude, 2018; Rahman et al., 2018). Some of the findings showed that planning science activities based on SPS helps children to develop sophisticated process in their later scientific thinking and also mastering in science concepts.

Briefly, one of the main components of professional knowledge in science teaching is enhancing teachers’ PCK (Van Driel & Berry, 2012) because it is believed that PCK is a topic-specific construct. However, little is known about how teachers develop PCK for different science topics such as knowledge used in scientific process (SP). For this very reason, more research studies are needed on PCK development in different science topics. To respond to the needs on developing early childhood teachers’ science content knowledge used in SP and how this knowledge is represented in their teaching plans, this study aims to provide valuable information on PSTs’ development of PCK on the knowledge used in SP.

As stated by Veal and MaKinster (1999), each science topic has its own understanding, teaching instruction, approach, and assessment in the development of PCK. Therefore, topic-specific PCK was selected as the theoretical framework of this study to understand how PSTs’ PCK on the knowledge used in SP develop. As Magnusson et al. (1999) stated, the transformation of different types of knowledge for teaching process can be identified and investigated explicitly through this model because of providing information about novice teachers’ conceptual change. Therefore, this is one of the main reasons why this model was chosen in this study. The PCK model of Magnusson et al. (1999) provides useful information about science content knowledge of teachers. The five components incorporated in this model are as follows: (a) orientation toward science, (b) knowledge of curricula, (c) knowledge of students’ understanding (KUS) of science, (d) knowledge of instructional strategies (KIS), and (e) knowledge of assessment (KA). All these components interact with each other (Magnusson et al., 1999). In this study, this model was adapted by using three of them (KUS of science, KIS, and KA). As illustrated in Figure 1, the framework of this study was developed by selecting three observable components from Magnusson et al.’s (1999) model of PCK.

First, knowledge of student understanding element is adapted to reveal PSTs’ difficulties and misconceptions on knowledge used in SP. Also, KIS in teaching of SP was selected as one of the elements of this study because of observing PSTs’ knowledge of representation for teaching SP. Finally, KA on SP was also used in this adapted model because of observing how participants assess children’s SPS. Because the main focus of this study was not PSTs’ beliefs about goals of teaching and as PSTs did not experience their teaching plan in the real classroom, orientation to science teaching and knowledge of curricula were not properly represented in the collected data. Therefore, three outstanding components were included in the adapted model.

The Conceptualization of PCK

Teachers’ PCK is considered a crucial factor for teachers’ classroom practices and it is viewed as the heart of professional development (Barendsen & Henze, 2019; Kind, 2009; Verloop, 1992). Shulman (1986) asserted that PCK is a particular form of content knowledge that goes beyond subject-matter knowledge. From this perspective, Shulman (1987) stated that content and pedagogy should be blended into a teacher’s understanding of how topics, problems, and issues are organized. Thus, teachers can adapt this understanding to the learners’ interest and abilities through appropriate instructions. The explanation of PCK shows that the relationship between teachers’ understanding and their practice reciprocally affect each other. Shulman (1986) also states that there are two main components of PCK, namely, knowledge of representations of subject matter and understanding of specific learning difficulties. In subsequent years, Magnusson et al. (1999), also added four additional elements to Shulman’s existing definition of PCK: (a) goals and objectives for teaching a specific topic in the curriculum, (b) PSTs’ understanding of this topic, (c) instructional...
strategies concerning this topic, and (d) ways to assess students’ understanding of this topic (Barendsen & Henze, 2019). Gess-Newsome (2015) also defines PCK as “the knowledge that teachers bring forward to design and reflect on instruction” (p. 36). Several studies have been conducted to capture the development of PCK for both in-service and PSTs (Abell, 2008; Aydeniz & Kirbulut, 2014; Friedrichsen et al., 2009, 2011; Gess-Newsome, 2015; Padilla & Van Driel, 2011).

Park and Oliver (2008) revealed that PCK development has two important dimensions: reflection in action and reflection on action. However, their PCK model was revised to redevelop a new model, namely, the refined consensus model (RCM; Carlson & Daehler, 2019). This new model is centered around the practice of science teaching and indicates three distinct realms of PCK, which are collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK). All of the realms of PCK are key features to shape and inform teachers on their professional development (Carlson & Daehler, 2019).

In this study, the RCM’s personal PCK and collective PCK were utilized as one of the frameworks of this study. Personal PCK represents teachers’ beliefs and attitudes of individual teacher to reflect their own teaching and learning experiences (Carlson & Daehler, 2019). In this study, PSTs’ personal PCK were investigated through interviews and knowledge used in scientific process (KSP) form at the science-focused course. Furthermore, collective PCK means that a group of teachers can contribute to their knowledge through conversation and sharing ideas with their colleagues. In other words, collective PCK encompasses the science knowledge that more than one person possesses (Carlson & Daehler, 2019). In this study, using collective PCK is found useful while collecting data through content representation (CoRe) that are filled from a group of teachers collaboratively (Carpendale & Hume, 2019).

The Effect of CoRe as a Pedagogical Tool for Developing PCK

The CoRe is a pedagogical tool for teacher educators to investigate teachers or PSTs’ knowledge, misconceptions, learning difficulties, and instructional and assessment strategies (Carpendale & Hume, 2019). With this aim, a number of studies have been conducted to investigate the development of PCK through CoRe design. According to Bertram and Loughran (2005), CoRes provide sophisticated information to investigate science teachers’ knowledge in specific contexts. In parallel with this, Nugraha (2017) conducted a study that involved 20 PSTs on the topic of the digestive system, and the data were mainly recorded through CoRes, PSTs’ reflective journals, filed notes, and interviews. The findings of the study were promising, indicating that the use of CoRe facilitated the development of PSTs’ PCK. Nilsson and Karlsson (2019) also used CoRes and video recordings for assessing the PCK of 24 secondary school science PSTs. The findings of the study suggested that the CoRe is a very effective tool for structuring PSTs’ reflection on action. In addition to that, Nurmatin and Purwianingsih (2017) conducted studies with teachers by using a variety of data sources to depict the development of PCK through CoRe. The studies’ findings showed that PSTs do not show integration between

Figure 1. The adapted model of Magnusson et al.’s PCK framework for this study.

Note. PCK = pedagogical content knowledge; SPS = science process skills.
content capability and pedagogical capability. What these studies have in common is that all of them used CoRe to represent teachers’ PCK. The findings confirm that CoRe are an important tool for both assessing teachers’ understanding of content and conveying the knowledge (Loughran et al., 2006). In addition, these studies pointed out that the use of CoRe provides an opportunity to develop PCK in their professional practice (Hume & Berry, 2011).

Enhancing the Knowledge Used in Science Process and SPS
According to Lind (2005), children begin to develop an understanding of science and mathematics concepts and construct their foundational knowledge during early childhood years. Children, from birth, start to construct basic concepts by using their sense of taste, smell, sight, and hearing. During preprimary school years, they start to observe, count, and mentally organize data to find answers to their questions, similar to scientists (Lind, 2005). Their activities and explorations help them develop scientific thinking skills and these skills continue to develop provided they are exposed to appropriate science education (Elkeey, 2017). According to Gelman et al. (2010), children develop scientific thinking skills best when they are given multiple opportunities to experience through inquiry. In addition, working on the same science concepts over weeks, months, and even a year is important to effectively build scientific understandings (National Research Council [NRC], 2007). Therefore, it is vital to plan and implement effective science teaching in early childhood, which is important for science education and enhancing children’s SPS (Carey, 2009).

In addition, Choirunnisa et al. (2018) conducted an experimental study with primary school students to describe the effectiveness of 5E model–based learning instructions to improve students’ SPS. The result of the study showed that the percentage of students’ SPS test results increased after the 5E model–based instructions. Moreover, Chabalengula et al. (2012) investigated PSTs’ understanding of SP concepts and they found that the participants’ perception of SP changed significantly after they completed a series of science education courses. To nurture children’s science knowledge, teachers should recognize the importance of the connection between science content and children’s practical experience to develop an understanding of how children’s discoveries relate to science content (NGSS Lead States, 2013). When engaging children in science-related experiences, providing the children with SP can help teachers teach science appropriately and knowledgeably (NRC, 2012).

From a constructivist perspective, children continuously construct their cognitive representations and schemas through their interactions and experiences by testing theories in their minds (Piaget, 1977). During the testing process, children actively compare their past knowledge with the new to determine which one is consistent with their previous concepts. However, they frequently need adult guidance and varied opportunities to test and build upon this knowledge (Vygotsky, 1978). This scaffolding process is an important point for deciding the role of teachers in teaching science. From a social constructivist perspective, teachers enhance children’s knowledge through scaffolding by helping them create a link between previous experiences and existing knowledge (Hong et al., 2013). Based on these theories, the role of early childhood teachers in teaching science generates new questions such as “Do teachers have sufficient knowledge used in science process to help children?” This means that it is very important to know the extent of early childhood teachers’ knowledge used in SP. In the related literature, it is pointed out that it is important to consider early childhood teachers’ knowledge of teaching science and SPS (Trundle, 2010) and to provide appropriate support for their PCK in science teaching (Alisianoğlu et al., 2012; Chabalengula et al., 2012; Oppermann et al., 2021; Shahali et al., 2017).

In line with the findings of earlier studies, ensuring that teachers receive continual training in specific science concepts and providing mentoring help them understand how children learn and how to teach science appropriately (NSTA, 2009; Sorque et al., 2013). As Barendsen and Henze (2019) stated, there is a lack of research findings on teacher knowledge and teachers’ classroom practices because of the inherent complexity of the relationship between them. In addition, Aydeniz and Kurbulut (2014) state that measuring pre-service science teachers’ PCK is a challenging task for science teacher educators. This study, therefore, aimed to conduct in-depth research on pre-service early childhood teachers’ (PSTs) knowledge used in SP by connecting their science activity plans to the CoRe and other data collection tools.

In this study, multiple data sources were used to put forward a useful model in science teaching by focusing on practice. Therefore, individuals’ personal PCK and collective PCK in different components will help us understand their knowledge used in SP. Moreover, this study is the first that uses CoRe design to explain PSTs’ knowledge used in SP. In light of this information, this study will address the following research question:

Research Question 1 (RQ1): How did PSTs’ PCK on the knowledge used in SP develop throughout the science education-focused course?

Method
This study aimed to investigate the development of the PSTs’ pPCK and cPCK on the knowledge used in SP by using a qualitative approach, which is one of the most appropriate ways of finding out what individuals know and what they think (Fraenkel et al., 2012). With this primary aim, this study effectively examined 36 PSTs’ PCK on SP using the “single case” study approach by collecting various data sources. According to Merriam (1998), the case study
paradigm recognizes the subjective human creation of meaning. The bounded case system in this study was a group of PSTs who participated in a science education–focused course with the knowledge used in SP (observing, classifying, communicating, measuring, inferring, interpreting, and hypothesizing). The data were collected using the KSP form, interviews, and CoRe. The materials developed by the researcher are expected to contribute to the literature by way of supporting early childhood teachers’ professional development in science teaching and creating a model for understanding teachers’ knowledge used in SP.

The Context of Study and Participants

The Early Childhood Education (ECE) programs in Turkey provide 4 years of teacher training for early childhood teachers of children aged 0 to 6 years. This program is a higher education program that is centralized to provide similar training in courses through the governing Council of Higher Education (CHE). “Science in Early Childhood Education” is a compulsory subject in ECE programs and it is usually suggested to include “methods of teaching science, concept development in science, SPS, science learning environment . . . etc.” This study was conducted in a state university located in the central region of Turkey.

The participants of this study are 36 PSTs (seven male, 29 female), who are second grade (sophomores), enrolled in the science-focused course. To select the participants, the purposive sampling procedure was utilized. Throughout the 2018–2019 academic year, all the PSTs enrolled in the science-focused course, voluntarily participated in the study for 13 weeks, and completed all the classroom tasks related to subject science in ECE. The researcher closely worked with these 36 PST participants who were selected for this study and hence had developed a close relationship with them.

Participant PTSS have some important characteristics related to their profiles. All the PSTs’ ages varied slightly between 19 and 21 years and came from different parts of Turkey for receiving teacher education. To receive acceptance to the program, they had to get a certain score from a placement exam that was conducted nationally. Therefore, all of them have similar educational backgrounds and similar academic achievement. The most important characteristic of participants, for this study, is that they most recently took a science-related course in their high school years. In addition, the PSTs did not have any teaching practices in a real classroom environment until now.

Data Collection Tools

PSTs’ PCK on the knowledge used in SP was investigated using data obtained from “the KSP form, interviews, and the CoRe form.” An important aspect of this study is that it did not utilize either restricted observation forms or surveys to capture all the details about their practices. Instead of this, a data collection process based on open-ended forms was utilized in the course of research. Both the interview questions and the KSP form were developed by the researcher in parallel with the purpose of CoRes to understand the PSTs’ knowledge used in SP.

The KSP form. Early childhood science education often focuses on simple SPS concepts such as observing, comparing, classifying, communicating, and describing (NSTA, 2007). Therefore, as indicated in National Association for the Education of Young Children (2018), observing, measuring, classifying, communicating, inferring, and interpreting concepts were initially included in the KSP form. To capture PSTs’ conceptual change on knowledge used in SP, the KSP form—parallel to the Magnusson’s three PCK elements—was developed by the researchers. In this form, PSTs were asked reflective questions such as “the definitions of SPS concepts,” by referring to KSU; “how to teach SPS in early childhood education,” by referring to KIS; and “how they assess children’s SPS,” by referring to KA. These questions were developed based on the items on the CoRe, the relevant literature (Sâckes et al., 2013; Trundle, 2010), and the course content. After the first drafts of the knowledge of SP forms were developed, two experts, who are in the fields of science education and ECE, reviewed and just changed the wording of questions. As can be seen in Table 1, for knowledge of SP,
the PSTs answered the questions, “What is it?” “How do you teach it?” and “What are the benefits of teaching this skill to children?” As the participants had not enrolled on the assessment and evaluation course yet, the third question was asked indirectly to put forward an idea about assessing children’s learning. This form is a short but useful tool for collecting the participants’ understanding of knowledge of SP as a concept.

The interview form. The interview form, comprising six open-ended questions, was developed by the researchers for investigating participants’ knowledge used in SP. The questions mainly focused on their knowledge used in SP. All of the questions were developed based on the relevant literature on teaching science and teaching SPS to children. To create integrity on data, the questions were designed parallel to the items of CoRe. For example, “What does science process skills mean to you?” and “How to use these skills in your teaching science?” are some of the questions that were asked. The two early childhood experts reviewed the questions twice, in terms of meaning and wording, and some minor changes were made. Before asking the final version of the questions to the participants, the pilot study was conducted with four third-grade (junior) PSTs in the ECE Department, who enrolled in the science-focused subject the previous year. The questions were clearly understood by them and no changes were made.

CoRe. The CoRe form is a kind of data collection tool that includes big science ideas or concepts in its horizontal axis and factors that influence teachers’ decisions in the vertical axis (see Table 2). Big ideas could be basic concepts that are necessary to understand a particular topic (Loughran et al., 2004). Loughran and his colleagues (2004) viewed CoRe as an instrument for demonstrating teachers’ knowledge on what they see as valuable to frame the topic as a whole. In this study, knowledge used in SP has been considered as a big science concept under this form, and how participants reflected each knowledge to CoRe based on their science activity plans. Preparing science activity is one of the course assignments for the science-focused course. Initially, all of the participants created science activity plans and then reflected those to CoRe and revised their activity plans based on questions on CoRe. To this end, the CoRe form was integrated with knowledge used in SP.

Expert opinion for the adapted CoRe form was taken by two researchers. One of the experts was selected from the field of ECE and the other from the department of science education. The experts reviewed all the items and discussed each item to reach a consensus. After the changes were completed, the pilot application of the CoRe form was conducted and no changes were made. In addition, the pilot study participants stated that all the items were clear and understandable. For all of the data collection tools, pilot studies help to increase validity and reliability and the alignment of the data collection process (Creswell, 2012; Stake, 2006).

Data Collection Process and Intervention

According to Creswell (2007), qualitative sample sizes should be large enough to gather sufficient information to address and explain the research questions. In this regard, 36 PSTs were estimated as an adequate sample size for this study related to the concept of saturation, the numbers of data collection methods, and the duration of data collection process. The timeline for the data collection process is presented in Figure 2, and each of the data collection part is explained as follows.

Step 1. For the initial investigation, both pre-interview and the KSP form were used prior to the early childhood PSTs commencing the science education–focused course. The pre-interview and the KSP form were filled in by the participants, taking approximately 75 to 80 min.

Step 2 (teaching science in early childhood course). Throughout the 13-week science education–focused course, the PSTs learned various topics related to teaching science to children. Through this course, basic terminologies for science topics and phenomena were presented by focusing on formal and
informal learning environments. Instruction was given in the form of lectures and hands-on activities. Although this course did not have any prerequisites, all participants took a course known as basic science in the previous semester. This course aims to teach basic science concepts in the fields of physics, chemistry, and biology. Throughout this course, which lasts 4 hr a week, the aim was to develop participants’ knowledge of SP. To this end, the first 2 hr of the course had been redesigned for lectures and the last 2 hr for practice using different activities. One of the main outcomes of this science course was enhanced PST knowledge used in SP. To do this, all the course requirements and tasks were planned based on knowledge used in SP and SPS. At the end of the course, the participants were expected to design a science activity plan and implement it in the classroom. Before developing and implementing this activity plan in the classroom, they were asked to select a concept by using the knowledge of SP. The topics of science activities were chosen from problems relating to environmental issues and three major environmental topics were selected: deforestation, sea pollution, and water cycle.

**Step 3.** At the end of the course, post-interviews and the KSP forms were conducted again with the participants as a group, which lasted approximately 90 min. The CoRes were also completed by seven groups of PSTs, each comprising five or six individuals. The CoRes were originally developed to represent a group of individuals’ PCK (Lehane & Bertram, 2013); therefore, it was used in this study to codify the groups’ PCK on the knowledge used in SP, thus the PSTs worked in groups.

**CoRe design within the course.** PSTs filled out the CoRe at the end of the science course based on their science activities (deforestation, sea pollution, and water cycle). The activities, which were designed by the participants, were created based on SPS by integrating each of the skills into their teaching process. After science activity plans were designed, they were requested to link these teaching plans to the CoRe. In this way, the participants developed their own representations of teaching knowledge of SP and the CoRe forms also helped the participants through pedagogical prompts. For instance, one of the questions in the CoRe form, “What kind of instructional methods or strategies would you use to teach this concept?” helped PSTs select both skills and the teaching method for an activity. Thus, they created the activity on the topic of deforestation or water pollution by using their knowledge of SP and creative drama method. Therefore, the CoRe forms offered the PSTs a way to consider the activity plan preparation process carefully.

To overcome researcher bias because of the researcher–teacher paradigm, the PSTs’ practices were observed across different and diverse courses and teaching activities over a long time. On that course, the researchers collected data over the long term, using different data collection tools (interviews, KSP forms, and CoRe forms).

In addition, because the whole data collection process was embedded in the science-focused course, and some data collection tools such as designing science activities and reflecting on CoRe forms were considered as part of the course work, all participant PSTs received regular feedbacks about the tasks they did in the process of study. Moreover, ensuring a member check to provide accuracy and consistency between their statements and views (Creswell, 2007), the transcribed interviews were given to the participants for checking their responses.

**Data Analysis**

The analysis was completed in two stages. In the first stage, PSTs’ responses to interview questions, the KSP form, and CoRes were analyzed using the pedagogical framework developed by Magnusson et al. (1999). Magnusson et al. (1999) proposed five main knowledge components in
As this PCK model is one of the most useful frameworks for analyzing novice science teachers’ PCK development, three out of five knowledge components in this PCK model were selected for the analysis procedure. Two other elements, namely, orientation toward science and knowledge of curriculum, were not used in this study because the main focus of this study is not investigating participants’ beliefs about goals of teaching and knowledge of using curriculum. Furthermore, as PSTs did not experience their teaching plan in the real classroom, these two elements were not properly represented in the collected data.

As presented in Figure 3, the selected knowledge components for this study are “knowledge of students’ understanding (KSU),” “knowledge of instructional strategies (KIS),” and “knowledge of assessment (KA).”

In the second stage, constant-comparative data analysis method was used to determine categories and codes after major themes (KSU, KIS, and KA) were determined (Table 3). The researcher and a second coder compared their codes and any disagreements were discussed until a consensus was reached.

Table 3. Analyzing the CoRes Through Corresponding Themes.

| CoRe’ items and corresponding PCK elements | Knowledge of instructional strategies | Knowledge of students understanding |
|-------------------------------------------|-------------------------------------|-----------------------------------|
| 1. What do you intend the students to learn about this concept/idea? | Knowledge of instructional strategies | Knowledge of students understanding |
| 2. Why do students need to know this? | Knowledge of instructional strategies | Knowledge of students understanding |
| 3. What else might you know about this idea (that you don’t want the students to know yet) | Knowledge of instructional strategies | Knowledge of instructional strategies |
| 4. Difficulties/limitations connected with teaching this idea | Knowledge of instructional strategies | Knowledge of instructional strategies |
| 5. Knowledge about students’ thinking that influences your teaching of this idea | Knowledge of instructional strategies | Knowledge of instructional strategies |
| 6. Other factors that influence your teaching of this idea | Knowledge of instructional strategies | Knowledge of instructional strategies |
| 7. Teaching procedures (and particular reasons for using these to engage with this idea) | Knowledge of instructional strategies | Knowledge of instructional strategies |
| 8. Specific ways you will use to ascertain students’ understanding or confusion around the idea | Knowledge of assessment children | Knowledge of assessing children |

Note: CoRe’ = content representation; PCK = pedagogical content knowledge.

The Role of Researchers

According to Patton (2015), the researcher should be aware of their role and viewpoint before collecting and interpreting the data during the study. In this regard, it is important to explain the researchers’ positionality in the study. The positionality can be described as the adopted tasks throughout the study (Foote & Bartell, 2011). In line with this information, both researchers have been involved in early childhood teacher education for many years and have conducted many studies in this field. For this study, after the researchers decided on the research topic, they designed the course process for teaching science, such as the contents of course...
sources and presentations, assignments, and data collection tools specific to the nature of this course. Although the science teaching course was carried out under the responsibility of the second author, both researchers equally took part in the data collection and analysis processes to overcome researchers' personal bias and make cross-checking. To increase the trustworthiness of the data analysis, another field expert not involved in this study was determined as a second coder.

Because the researchers spent a lot of time and effort on conducting this study, there were some possible biases while interpreting the information collected from the participants. However, the researchers were aware of all these biases at every step of the study. To overcome these biases, several different data collection tools were included, such as interviews, KSP, and the CoRe forms. For each of the data collection tools, the experts reviewed the tool and gave suggestions. Moreover, the researchers took some field notes at the end of each course, not with the purpose of collecting data, but only to increase trustworthiness.

**Findings**

To find an answer to the research question, “How did PSTs’ PCK on the knowledge used in SP develop throughout the science education-focused course?” a variety of data collection tools were utilized. Each of the items in these data collection tools covers three PCK elements and were analyzed based on the pedagogical framework in the PCK of Magnusson et al. (1999) under the three themes of KSU, KIS, and KA. The pre- and post-data were blended under the three selected themes because in-depth and cohesive information derived from different data sources was being presented.

**Knowledge of PSTs’ Understanding About Science Process**

Throughout the study, which lasted 13 weeks, a variety of PST responses were collected through interviews, the KSP form, and the CoRes form. Prior to teaching the science course to PSTs, pre-interviews were conducted and the KSP forms were filled in by the participants. The pre-data, analyzed under the “knowledge of students’ understanding (KSU)” theme, mainly showed that there was a marked difference in the concept knowledge used in SP (observing, communicating, measuring, and inferring) before and after the science course (Table 4). Interestingly, the PSTs’ prior understanding on the knowledge of SP showed that their misconceptions were mostly associated with assessment-related activities.

The answers to the question on PSTs’ knowledge used in SP showed that the participants’ knowledge used in SP in their teaching process seems somewhat problematic. Three of the participants answered the question about knowledge used in SP as follows:

- “SPS teach children to follow a predetermined programme,”
- “SPS means accelerating the teaching and learning process,”
- “SPS help children to understand more easily.” (September 15, 2018, pre-interview)

At the end of the science course, the participants’ responses were getting closer to the meaning and they answered the question as follows:

- “SPS allow the child to stay in the learning process through active participation,”
- “Children learn the concept from every angle and in-depth.” (December 24, 2018, post-interview)

More than half of the PSTs described “observing” as monitoring children to make an assessment. One participant explained why observing is used in science teaching:

- Teachers play an active role during children’s learning process and make observations by monitoring children. (September 15, 2018 pre-KSP form)

The same PST explained the observing of skill at the end of the course as

- Starting to examine an event or situation by using children’s senses. (December 24, 2018, post-KSP form)
For the knowledge of “classifying,” almost all the PSTs’ explanations matched the actual definition in the literature. Nearly all the participants defined “classifying” as categorizing the object based on one feature. For instance, one of them defined it as follows:

Grouping objects, situations, and cases based on one or more features. (September 15, 2018, pre-interview)

Furthermore, the knowledge of “measuring” is mostly explained as the process of assessing children’s learning. Some PSTs’ descriptions of measuring were worded as follows:

“Developing an assessment tool in accordance with our teaching activity plan and teachers use it at the end of the activity,” “Ask questions to the child,” “Measuring is done through exams, experiments, and questions.” (September 15, 2018, pre-interview)

Whereas some PSTs still explained the knowledge of measuring as a process of assessing the children after the course, a great majority of the participants explained it as measuring an object to determine its unknown features. One explanation was as follows:

Measuring is used to measure the properties of objects such as quantity, size, and width. (December 24, 2018, post-KSP form)

The knowledge of “inferring” is explained mostly as giving an opinion about unknown things. Some of the PSTs described it as follows:

“Helping children to put forward an idea using existing knowledge,” “Giving an opinion about unknown things,” “Thinking about the possibility of an unknown situation.” (September 15, 2018, pre-KSP form)

Furthermore, some participants explained the knowledge of inferring as making a guess based on observations. The examples are as follows:

“The teacher may ask children to predict what they will observe,” “Ask children to predict what will happen as a result of the activity.” (September 15, 2018, pre-KSP form)

Most of the participants’ explanations for the knowledge of “interpreting” are confused with the skill of inferring. They mostly explained interpreting as follows:

“Using verbal expressions to explain our opinion,” “Children explain their predictions to others,” “Ask children to complete a story by guessing.” (September 15, 2018, pre-KSP form)

Surprisingly, the knowledge of “hypothesizing” is the least confused concept among the SPS. Most of the PSTs gave accurate explanations, saying that hypothesizing is a process for making connections between information to create new ideas, in both pre- and post-data. For instance, one explanation from the pre- and post-knowledge of SP form was as follows:

Making a connection between known pieces of information to answer questions. (September 15, 2018, pre-KSP form)

When the CoRe forms were analyzed in terms of the knowledge of student teachers’ understanding, the analysis showed that there were some minor changes in participants’ understanding in SPS compared with other data collection tools such as interviews and the KSP form. The PST responses were used to illustrate the findings taken from the CoRe table. While the PSTs’ science activities as applied to the CoRe were investigated, it was seen that they made a clear distinction between the knowledge of observing and measuring when compared with analysis of the previous data sources:

Let the children go out of the classroom to observe the trees so I can make them realize that trees exist around them. In addition, I can bring a plant to the classroom and have them observe it in the classroom. (December 31, 2018, CoRe)

In a measuring process, I let the children use measurement tools and measure the properties of objects such as length, weight, and temperature. This way, we might have collected the necessary information to determine the tree that is suitable for the climatic conditions. (December 31, 2018, CoRe)

In particular, the analysis of the interviews and the KSP form showed that PSTs had some confusion about the knowledge of inferring and interpreting. However, nearly all the PSTs could reflect these concepts in their activity process successfully:

I ask children questions to infer the negative effects of water pollution on the lives of animals and plants. I think it is important in terms of environmental awareness. (December 31, 2018, CoRe)

All conversations and information collected so far are taken into account. We need to help children understand the effect of water pollution on living things and help them produce solutions. (December 31, 2018, CoRe)

By contrast, the understanding of the knowledge of hypothesizing and classifying did not change when compared with previous data collection tools because the participants had no problem with their meaning.
When the early childhood PSTs’ responses were analyzed under the theme of “knowledge of instructional strategies,” it was found that providing children with opportunities to express their ideas and supporting them in the learning process is the instructional method mentioned the most in both pre- and post-data. For instance, helping children to use their senses, comparing and contrasting objects, providing children with an opportunity to express themselves, and helping to see a cause and effect relationship are mentioned as teaching instructional strategies to support their knowledge used in SP.

For this theme, the most challenging point is to analyze the first question of the CoRe form. Although the question seems to be more appropriate for analyzing it under the PCK element of orientation toward science, nearly all of the PSTs’ responses to this question referred to strategies used in their teaching process. Therefore, both the researchers and the coders decided to analyze the responses to this question under the KIS element.

As can be seen in Table 5, the participant responses were not differentiated before and after the science-focused course. Most of them stated similar instructional methods in both the pre- and post-interviews and KSP forms. One notable difference between the chosen instructional methods was seen in the skill of “measuring.” Whereas almost all the PSTs stated that they would use the assessment tools for assessing children in the process of measuring in pre-interview and KSP form, their explanations had changed by the end of the course. They explained the skill of measuring as using measurement tools for measuring features of objects. Some of the statements were as follows:

Measuring enables teachers to conduct assessment appropriately to make the next activity effective and meaningful for the child. (September 15, 2018, pre-KSP form)

Children use measuring tools to measure the features of objects and conditions that they are curious about. (December 24, 2018, post-KSP form)

When the PSTs’ responses were analyzed according to pre- and post-interview questions, more in-depth information was obtained for their preferred instructional methods in teaching SPS. “Doing experiments” and “questioning” are instructional methods mentioned the most by the PSTs with the intent of providing children’s active participation. One statement was as follows:

Experiment and children’s active participation. I will choose this because it will help children to learn permanently and easily. (September 15, 2018, pre-interview)

Another PST provided the following explanation:

I can teach SPS using experiments. I think that it will help children participate actively in their learning process through observation, classification, and measurement. (September 15, 2018, pre-interview)

After the science-focused course, the participants described instructional methods in similar terms by explaining instructional methods as doing experiments and questioning. Some examples from the participants’ statements are as follows:

I can make the child predict what might happen at the end of the experiment without seeing the result of it by asking open-ended questions. (December 24, 2018, post-interview)

The application of CoRe showed that the teaching methods, especially questioning, mentioned by the PSTs underwent the most changes under the SPS concept of measuring. The CoRe helps the PSTs understand the relationship between SPS concepts and different teaching strategies. The participants use “experiments, creative drama, questioning, investigation through observing” as teaching strategies in the CoRe table to teach science through SPS:

I can bring different measuring tools such as rulers, balancing scales, and magnifying glasses to use all their senses while investigating the features of different soils. (December 31, 2018, CoRe)
Conversely, the teaching methods they mentioned remained unchanged for the other SPS concepts:

I think that open-ended questions should be asked to make the child reasonably estimate the characteristics such as soil, flowerpot, and light needed for planting the seed or sapling. (December 31, 2018, CoRe)

Since children do not enter the formal operational period, they may have difficulty comparing abstract concepts. So, I need to tell them using concrete objects and examples as much as possible. (December 31, 2018, CoRe)

However, a deeper analysis of the participants’ explanations about their teaching process and mentioned teaching strategies showed that a few of them had some confusion about the appropriate usage of strategies. This means that they planned a teaching process in which children were not able to observe, measure, or classify the process that they used as a teaching instruction in their activity plans:

Children should observe the dust of factories to understand how it affects the water cycle and all living creatures. (December 31, 2018, CoRe)

I ask children questions such as how we can measure dirty and clean water. In this way, we can provide children with an opportunity to measure their differences. (December 31, 2018, CoRe)

The theme of “knowledge of assessment on SP” was determined as one of the main themes during preliminary analysis because in-depth analysis showed that the PSTs frequently mentioned assessment tools and assessment strategies while explaining their knowledge of SP. When the PSTs’ responses were analyzed under the theme of “knowledge of assessment,” there was some confusion between concepts concerning the methods for assessing SPS. As almost all the PSTs perceived the skill of measuring to mean making an initial assessment of the children, they frequently mentioned such assessment methods as making observations, asking questions, using questionnaires and checklists, and so on. For instance, for the observation concept of SPS, one of the PSTs stated,

Making observations and asking questions help us learn children’s understanding of the concepts. (September 15, 2018, pre-KSP form)

As can be seen in Table 6, the PSTs mentioned more assessment methods prior to enrolling on the science-focused course to assess children’ SPS. However, in-depth analysis showed that the participants did not use these assessment methods to make assessments because they understood it to mean assessing children.

After the science-focused course, the PSTs’ statements about “knowledge of assessment” changed and they made more appropriate explanations. Asking open-ended questions and observation are the most frequently mentioned assessment methods among the PSTs to assess SPS. One of the PSTs stated,

To assess the skill of prediction, the teacher should ask such questions as I think about this, so what do you think about this topic? (December 24, 2018, post-KSP form)

One other PST said,

By being asked open-ended questions, the children are prompted to put forward their ideas about the situations so that we can find out what they have learned. (December 24, 2018, post-interview)

The analysis of the CoRe showed that PSTs became more aware of the purpose of assessment in teaching SPS. However, they did not mention specific assessment tools or which assessment tools could be used for assessing children’s learning through SPS. Nearly all the PSTs tend to use questioning and observation to assess children in their activity plans:

I can ask questions related to my observations of the children. As a result of these questions, I can determine whether children can understand some adjectives for objects such as small, big, heavy, or light. (December 31, 2018, CoRe)
During the experimental phase, I elicit questions to assess children’s understanding of what the differences are between irrigated and non-irrigated plants. (December 31, 2018, CoRe)

Discussion

The findings of the study confirmed that the PSTs were able to change the knowledge of SP after the science-focused course to some degree. To begin with, the findings showed that creating science activity plans together with CoRe design is very beneficial for enhancing participants’ both pPCK and cPCK on the knowledge used in SP. Similar findings were also reported by Hume and Berry (2011), Carpendale and Hume (2019), and Nilsson and Karlsson (2019) saying that these studies showed that CoRes help participants to scaffold their knowledge of different science topics.

The findings of the study are in line with studies that worked with CoRes in both in-service and PSTs’ PCK (Barendsen & Henze, 2019; Carpendale & Hume, 2019; Elkeey, 2017; Hong et al., 2013; Minnaar & Naude, 2018; Nilsson & Karlsson, 2019; Nugraha, 2017; Nurmatin & Purwianingsih, 2017). Their completed CoRe forms demonstrated significantly that the development of the knowledge of SP was enhanced in terms of “knowledge of students understanding knowledge,” “knowledge of instructional strategies,” and “knowledge of assessment.”

The analysis showed that the majority of the PSTs were confused about the knowledge used in SP and made incorrect definitions prior to the science-focused course. In particular, the PSTs had difficulty in defining the knowledge of observing and measuring skills in scientific context, but not in educational context. Similar findings were reported by Sandra and Deborah (1994). The researchers investigated students’ definition of science based on Bloom’s classification theme by searching similarities and discrepancies. They found that students frequently failed to distinguish between science and science education. Therefore, they created a new category in addition to Bloom’s, which is education. Chabalengula et al. (2012) and Shahali et al. (2017) also found that PSTs have a poor conceptual understanding on the knowledge of SP concepts and therefore made incorrect definitions. Furthermore, the findings were similar to those in the study by Rollnick et al. (2002). They also found that teachers had difficulty in defining the measuring skill during experiments. As the PSTs lacked knowledge and training in assessment and SPS initially, they were confused while explaining observation and measuring skills. One of the possible reasons for this finding may be that the PSTs had taken a science-related course a long time ago in their high school years. However, after the course, nearly all the PSTs defined and integrated both of these skills into their teaching process correctly.

In addition, the participants initially had some misconceptions about the meaning of communicating, which they defined with examples such as giving a lecture and conversation between children. At the end of the course, they had obtained a clearer definition of the meaning of communicating. Similar results were also reported by Choirunnisa et al. (2018), who found that PSTs’ conception of SP increased significantly, especially for the communicating skill, after training.

Moreover, in-depth analysis of the CoRe indicated that the PSTs tend to use child-centered teaching methods while teaching science topics through SPS, such as conducting experiments, usage of drama, questioning, investigation though observing, and so on. From this preference, it could be surmised that PSTs became familiar with the knowledge used in SP during the science-focused course. In addition, Hume and Berry (2011) indicated that completing the CoRe enabled them to re-familiarize their knowledge in SP. On the contrary, while the responses given by the PSTs before and after the course were compared, it was found that there was little change in their instructional methods and they could not diversify them too much. The main reason could be that the PSTs are lacking classroom experience in terms of teaching science to children. As mentioned by Hume and Berry (2011), lack of experience is a limiting factor in their PCK development at this stage of their professional development. The science-focused course most probably enhanced their knowledge used in SP but the lack of classroom experience impedes their implementation of instructional methods.

An interesting finding in this study is that the PSTs made consistent and correct definitions before and after the science-focused course on the following skills: classifying, interpreting, and hypothesizing. Although these skills are high-level skills compared with others, the participants’ conceptual understanding is correct. The findings are consistent with the study conducted by Chabalengula et al. (2012). They also found that the participants have a correct conceptual understanding of the classification and interpretation skills. One of the possible reasons for this finding is that the concept of classifying and interpreting can also be used by people in their everyday life. To explain what classification is, there is no need for high-level academic knowledge. This assumption is supported by Chabalengula et al. (2012), who believe that students sort things out in everyday life chores. Moreover, they may have some preconception about the skill of hypothesizing that they learned from their own school experiences. Similarly, Lortie (1975) also believes that professional development begins to develop before PSTs enter the teacher training programs and that their knowledge is shaped by their own school experiences.

Furthermore, one of the interesting findings was related to the KA theme. The findings of the study showed that, while PSTs assessed children’s SPS by using assessment techniques compatible with the learning process at their teaching plan, they reported less assessment techniques compared with initial answers. The main reason could be that PSTs designed the assessment part in their teaching plans in accordance with National Early Childhood Curriculum that
suggests using “a child observation form” at the end of each semester. Therefore, participants may prefer to use observing and questioning assessment techniques in their CoRe forms. This finding is consistent with Aydn’s (2012) study, which revealed that participants preferred summative assessment techniques at the end while they preferred to use informal assessment during teaching. Moreover, Fraser (2016) indicated that the participants did not give deserving attention to the assessment part in their teaching plans and they just approach assessment as a simultaneous talk.

**Educational Implications**

In science education, knowledge used in SP is a very important acquisition but there is still a serious gap in putting these skills into practice and representing correct understanding (Jack, 2013). The findings of this study give more insight into enhancing the development of PCK during teacher training years. The findings of the study confirm that PSTs have some misconceptions about the knowledge used in SP. To reveal their misconceptions and raise their pPCK and ePCK, the CoRe is a very useful tool for the development of PCK. Lack of experience during teacher training years and the need to deal with incorrect knowledge on SP make it necessary to integrate CoRe into the activity planning process in science education for PSTs. This is also suggested by Hume and Berry (2011), who claimed that adding the CoRe form to the teaching process can help to raise feelings of confidence and competence when the science concepts are organized for the first time.

Moreover, in-depth analysis made it possible to understand the gradual development of PSTs’ knowledge used in SP throughout the science-focused course. The overall findings suggest that there is an increasing need to improve PSTs’ poor conceptual knowledge of SP and their PCK in it. As Kleickmann et al. (2013) stated, teacher education programs may affect the development of PCK. Similarly, Sandra and Deborah (1994) suggest that students’ naive views of science have been constructed over the years and it is sometimes difficult to influence. Therefore, students must be provided opportunity to reflect their existing conception to become aware of their ideas. Hence, to help PSTs’ acquisition of knowledge used in SP, the science teaching courses in teacher training programs can be designed in two parts, namely, theory and practice. In this regard, hands-on activities can be designed to use each skill so they can understand what the knowledge of SP really means. In addition, an explicit intervention can be recommended on teaching SP and provide more classroom practices for teaching science for early childhood teacher education programs. Otherwise, the elements of PCK, such as knowledge of PSTs’ understanding, KJS, and KA are not sufficiently supported by their teacher training program. In addition, it can be suggested that the teacher training programs can be accredited to offer basic standards on teaching science in the early years so that PSTs can start their professional career by learning basic SPS. For further assistance, SPS workshops can be offered to both pre-service and in-service early childhood teachers to support their professional development on teaching through SPS.

This study tried to minimize limitations by using multiple sources of data. However, observing participants while implementing their activities could be very useful for the findings of the study. Furthermore, only the model developed by Magnusson et al. (1999) was utilized in this study. To compensate for this limitation, the researchers’ experience in qualitative study was important to interpret the findings. Finally, as the study was conducted with PSTs, selecting participants from in-service teachers could be beneficial in explaining development of PCK on the knowledge used in SP.

**Acknowledgments**

This research was not supported by any institution. The authors thank a colleague, Dr. Metehan Buldu from Kirikkale University, who provided insight and expertise that greatly assisted the research. The authors thank the “anonymous” reviewers for their insights. The authors are also immensely grateful to participant pre-service teachers who are sophomore students in the Department of Early Childhood Education for their participation through one semester. The authors are thankful for consideration of this article.

**Ethical and Informed Consent Forms Permissions**

The data for this study were obtained as part of a larger project. Ethical permission was obtained on behalf of the principal investigator of the project. Written informed consent forms were obtained from participant pre-service teachers before the study. All participants reported that they voluntarily participated in the study.

**Declaration of Conflicting Interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) received no financial support for the research, authorship, and/or publication of this article.

**ORCID iDs**

Elif Buldu [https://orcid.org/0000-0003-0585-0138]

Metehan Buldu [https://orcid.org/0000-0001-5820-7299](https://orcid.org/0000-0001-5820-7299)

**References**

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education, 30*(10), 1405–1416.

Alisinanoglu, F., Inan, H. Z., Ozbey, S., & Usak, M. (2012). Early childhood teacher candidates’ qualifications in science teaching. *Energy Education Science and Technology Part B: Social and Educational Studies, 4*(1), 373–390.
Andersson, K., & Gullberg, A. (2012). What is science in preschool and what do teachers have to know to empower children. *Cultural Studies of Science Education, 9*(2), 275–296.

Aydiniz, M., & Kirbulut, Z. D. (2014). Exploring challenges of assessing pre-service science teachers’ pedagogical content knowledge (PCK). *Asia-Pacific Journal of Teacher Education, 42*(2), 147–166.

Aydin, S. (2012). *Examination of chemistry teachers’ topic-specific nature of pedagogical content knowledge in electrochemistry and radioactivity* [Unpublished doctoral dissertation]. Middle East Technical University.

Barendsen, E., & Henze, I. (2019). Relating teacher PCK and teacher practice using classroom observation. *Research in Science Education, 49*, 1141–1175.

Bertram, A., & Loughran, J. (2005). Science teachers’ views on CoRes and PaP-eRs as a framework for articulating and developing pedagogical content knowledge. *Research in Science Education, 42*(6), 1027–1047.

Carey, S. (2009). *The origin of concepts*. Oxford University Press.

Carlson, J., & Daehler, K. R. (2019). The refined consensus model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers’ knowledge for teaching science* (pp. 77–92). Springer.

Carpendale, J., & Hume, A. (2019). Investigating practising science teachers’ pPCK and ePCK development as a result of collaborative CoRe design. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers’ knowledge for teaching science* (pp. 225–252). Springer.

Chabalengula, V. M., Mumba, F., & Mbewe, S. (2012). How PSTs’ understand and perform SPS. *Eurasia Journal of Mathematics, Science & Technology Education, 8*(3), 167–176.

Choirunnisa, N. L., Prabowo, P., & Suryanti, S. (2018). Improving SPS for primary school students through 5e instructional model-based learning. *Journal of Physics Conference Series, 947*(1), Article 012021.

Copley, J. V., & Padron, Y. (1999). Preparing teachers of young learners: Professional development of early childhood teachers in mathematics and science. In G. D. Nelson (Ed.), *Dialogue on early childhood science, mathematics, and technology education* (pp. 117–129). American Association for the Advancement of Science.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches*. Sage.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Pearson.

Elkeey, S. S. (2017). Developing SPS and some accompanying skills through observation of life cycle of silkworm by kindergarten child. *The Online Journal of New Horizons in Education, 7*(1), 53–63.

Eshach, H., & Fried, N. (2005). Should science be taught in early childhood. *Journal of Science and Technology, 14*(3), 315–336.

Foote, M. Q., & Bartell, T. G. (2011). Pathways to equity in mathematics education: How life experiences impact researcher positionality. *Educational Studies in Mathematics, 78*, 45–68.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education* (8th ed.). McGraw-Hill.

Fraser, S. P. (2016). Pedagogical content knowledge (PCK): Exploring its usefulness for science lecturers in higher education. *Research in Science Education, 46*(1), 141–161.

Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkman, M. J. (2009). Does teaching experience matter? Examining biology teachers’ prior knowledge for teaching in an alternative certification programme. *Journal Research in Science Teaching, 46*(4), 357–383.

Friedrichsen, P. J., Driel, J. H. V., & Abell, S. K. (2011). Taking a closer look at science teaching orientations. *Science Education, 95*(2), 358–376.

Gelman, R., Brenneman, K., Macdonald, G., & Roman, M. (2010). *Preschool pathways to science: Ways of doing, thinking, communicating, and knowing about science*. Brookes.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK Summit. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Reexamining pedagogical content knowledge in science education* (pp. 28–42). Routledge.

Hong, S. Y., Torquati, J. C., & Molfese, V. J. (2013). Theory guided professional development in early childhood science education. In L. E. Cohen & S. Waite-Stupiansky (Eds.), *Advances in early education and day care. Vol. 17: Learning across the early childhood curriculum* (pp. 1–32). Emerald Group.

Hume, A., & Berry, A. (2011). Constructing CoRes: A strategy for building PCK in pre-service science teacher education. *Research in Science Education, 41*, 341–355.

Jack, G. U. (2013). The influence of identified student and school variables on students’ SPS acquisition. *Journal of Education and Practice, 4*(5), 16–23.

Jirout, J., & Zimmerman, C. (2015). Development of science process skills in the early childhood years. In K. Cabe Trundle & M. Saçkes (Eds.), *Research in early childhood science education* (pp. 143–165). Springer.

Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education, 45*(2), 169–204.

Kleckmann, T., Richter, D., Kunter, M., Elsner, J., Besser, M., Krauss, S., & Baumert, J. (2013). Teachers’ content knowledge and pedagogical content knowledge: The role of structural differences in teacher education. *Journal of Teacher Education, 64*, 90–106.

Lehane, L., & Bertram, A. (2013, September 2–7). *Insight into the inquiry orientations of a cohort of Irish and Australian pre-service science teachers using a pedagogical content knowledge lens* [Paper presentation]. The bi-annual European Science Education Research Association, Nicosia, Cyprus.

Lind, K. K. (2005). *Exploring science in early childhood education: A developmental approach* (4th ed.). Thomson Delmar Learning.

Lortie, D. (1975). *Schoolteacher: A sociological study*. University of Chicago Press.

Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers’ pedagogical content knowledge*. Sense.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*, 370–391.

Magnusson, S., Krajcik, J. S., & Borko, H. (1999). Secondary teachers’ knowledge and beliefs about subject matter and their
impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), Examining pedagogical content knowledge (pp. 95–132). Kluwer.

Meador, K. S. (2003). Thinking creatively about science suggestions for primary teachers. Gifted Child Today, 26(1), 25–29.

Merriam, S. B. (1998). Qualitative research and case study applications in education. Jossey-Bass.

Minnaar, R., & Naude, F. (2018). Grade R teachers’ awareness of development of science process skills in children. Unisa Press.

National Association for the Education of Young Children. (2018). Engaging teachers and toddlers in science (Voice). https://www.naeyc.org/resources/pubs/yc/sep2018/engaging-teachers-toddlers-science

National Research Council. (2007). Taking science to school: Learning and teaching science in grades K-8. Committee on science learning, kindergarten through eighth grade. National Academies Press.

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. National Academies Press.

National Science Teachers Association. (2002). NSTA position statement: Elementary school science.

National Science Teachers Association. (2007). NSTA position statement: The integral role of laboratory investigations in science instruction.

National Science Teachers Association. (2009). NSTA position statement: Parent involvement in science learning.

NGSS Lead States. (2013). Next generation science standards: For states, by states. National Academies Press.

Nilsson, P., & Eln, A. (2017). Capturing and developing early childhood teachers’ science pedagogical content knowledge through CoRes. Journal of Science Teacher Education, 28(5), 406–424.

Nilsson, P., & Karlsson, G. (2019). Capturing student teachers’ pedagogical content knowledge (PCK) using CoRes and digital technology. International Journal of Science Education, 41(4), 419–447.

Nugraha, I. (2017). CoRes utilization for building PCK in preservice teacher education on the digestive system topic. https://aip.scitation.org/doi/pdf/10.1063/1.4983930

Nurmatin, S., & Purwianingsih, W. (2017). Capturing the PCK ability of prospective science teachers using core and PaP-Er. Jurnal Pendidikan IPA Indonesia, 6(2), 271–276.

Oppermann, E., Hummel, T., & Anders, Y. (2021). Preschool teachers’ science practices: Associations with teachers’ qualifications and their self-efficacy beliefs in science. Early Child Development and Care, 191, 800–814.

Padilla, K., & Van Driel, J. (2011). The relationships between PCK components: The case of quantum chemistry professors. Chemistry Education Research and Practice, 12, 367–378.

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. Research in Science Education, 38(3), 261–284.

Patton, M. Q. (2015). Qualitative evaluation and research methods. SAGE.

Piaget, J. (1977). The development of thought. Equilibration of cognitive structures. Basil Blackwell.

Rahman, N. A., Yusop, N. A. M., & Yassin, S. M. (2018). Science process skills in pre-schoolers through project approach. International Journal for Studies on Children, Women, Elderly and Disabled, 5, 104–114.

Rollnick, M., Lubben, F., Lotz, S., & Dlamini, B. (2002). What do underprepared students learn about measurement from introductory laboratory work. Research in Science Education, 32, 1–18.

Sačkes, M., Trundle, K. C., & Bell, R. L. (2013). Science learning experiences in kindergarten and children’s growth in science performance in elementary grades. Education and Science, 38(167), 114–127.

Sandra, K. A., & Deborah, C. S. (1994). What is science? Preservice elementary teachers’ conceptions of the nature of science. International Journal of Science Education, 16(4), 475–487.

Shahali, E. H. M., Halim, L., Rasul, M. S., Osman, K., & Zulkifeli, M. A. (2017). STEM learning through engineering design: Impact on middle secondary students’ interest towards STEM. EURASIA Journal of Mathematics, Science and Technology Education, 13(5), 1189–1211.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4–31.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. Harvard Educational Review, 57(1), 1–22.

Smith, D. C., & Neale, D. C. (1989). The construction of subject matter knowledge in primary science teaching. Teaching and Teacher Education, 5, 1–20.

Stake, R. E. (2006). Multiple case study analysis. Guilford Press.

Thomson, M. M., DiFrancesca, D., Carrier, S., & Lee, C. (2017). Teaching efficacy: Exploring relationships between mathematics and science self-efficacy beliefs, PCK and domain knowledge among preservice teachers from the United States. Teacher Development, 21(1), 1–20.

Torquati, J., Cutler, K., Gilkerson, D., & Sarver, S. (2013). Early childhood educators’ perceptions of nature, science, and environmental education. Early Education & Development, 24(5), 721–743.

Trundle, K. C. (2010). Teaching science during the early childhood years. In best practices and research base. National Geographic. https://ngl.cengage.com/assets/downloads/ngsci_pro0000000028/am_trundle_teach_science_early_child_sc12-0429a.pdf

Van Driel, J. H., & Berry, A. (2012). Teacher professional development focusing on pedagogical content knowledge. Educational Researcher, 41(1), 26–28.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. Electronic Journal of Science Education, 3(4). https://eric.ed.gov/?id=E651188

Verloop, N. (1992). Praktijkkennis van docenten: een blinde vlek van de onderwijskunde [Craft knowledge of teachers: A blind spot in educational research]. Pedagogische Studiën, 69, 410–423.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

Williams, P. J., & Lockley, J. E. (2012, June 26–30). An analysis of PCK to elaborate the difference between scientific and technological knowledge. Paper presented at the PATT 26 Conference. Stockholm, Sweden: PATT.

Wilson, S. M., Floden, R. E., & Ferrini-Mundy, J. (2002). Teacher preparation research: An insider’s view from the outside. Journal of Teacher Education, 53(3), 190–204.

Worth, K. (2010). Science in early childhood classrooms: Content and process. In Collected Papers from the STEM in Early Education and Development Conference. University of Northern Iowa, Cedar Falls, Iowa, USA. https://ecrp.illinois.edu/beyond/seed/worth.html