DEVELOPMENT OF PRESERVICE SCIENCE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE FOR SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS IN THE CONTEXT OF LESSON STUDY

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ABSTRACT

DEVELOPMENT OF PRESERVICE SCIENCE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE FOR SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS IN THE CONTEXT OF LESSON STUDY

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The purpose of the present study was to investigate the development of preservice science teachers' pedagogical content knowledge for science, technology, engineering, and mathematics (STEM) education in the context of lesson study. The lesson study was integrated into the Practice Teaching in Science course, and there were four lesson study cycles throughout the study. Each lesson study cycle consisted of planning, teaching, reflecting, re-teaching, and re-reflecting phases. The design of the study was a multiple case study, and the participants of the study were four preservice science teachers who were in their final year in the science teacher education program. The data were collected through interviews, content representation, observation protocol, and video-recorded meetings. Inductive and deductive data analysis were used, and three PCK categories (topic-specific PCK, transitional PCK, and PCK for STEM) emerged to track participants' PCK for STEM development levels. The main findings of the study revealed that participants were not able to integrate the elements of STEM education into their content representation, and their PCK was topic-specific (PCK-A) at the beginning of the study. However, all participants showed improvement in the level of their PCK for STEM at the end of the study. Participants in the transitional PCK category (PCK-B) focused more on science or engineering disciplines while integrating STEM education. On the other hand, participants in PCK for STEM category (PCK-C) integrated STEM disciplines in a more balanced way. Moreover, the elements of lesson study were found to be influential in assisting preservice science teachers' improvement of PCK for STEM.

Keywords: STEM Education, Pedagogical Content Knowledge, Lesson Study, Science Teacher Education

ÖZ

FEN BİLGİSİ ÖĞRETMEN ADAYLARININ FEN, TEKNOLOJİ, MÜHENDİSLİK ve MATEMATİK (STEM) EĞİTİMİNE İLİŞKİN PEDAGOJİK ALAN BİLGİLERİNİN GELİŞİMİNİN DERS İMECESİ KAPSAMINDA İNCELENMESİ

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Bu çalışmanın amacı fen bilgisi öğretmen adaylarının fen, teknoloji, mühendislik ve matematik (STEM) eğitimine ilişkin pedagojik alan bilgilerinin (PAB) ders imecesi kapsamında gelişiminin incelenmesidir. Ders imecesi, Öğretmenlik Uygulaması dersi içerisine entegre edilmiş ve çalışma boyunca dört ders imecesi döngüsü tamamlanmıştır. Her ders imece döngüsü planlama, öğretim, yansıtma, tekrar öğretim ve tekrar yansıtma aşamalarından oluşmaktadır. Çalışmada çoklu durum deseni kullanılmış ve veriler görüşme, içerik gösterimi, gözlem formu ve video kayıtlarından elde edilmiştir. Çalışmaya son sınıfta öğrenimlerine devam eden dört fen bilgisi öğretmen adayı katılmıştır. Katılımcıların STEM eğitimine ilişkin PAB gelişimlerini incelerken üç kategori (fen alanına özgü PAB, geçiş PAB'ı, STEM'e ilişkin PAB) ortaya çıkmıştır. Çalışmada elde edilen temel bulgulara göre, katılımcılar çalışmanın başında fene özgü PAB'a sahiptir (PAB-A) ve hazırladıkları içerik gösterimleri STEM eğitiminin temel özelliklerini içermemektedir. Çalışmanın sonunda, bütün katılımcıların STEM eğitimine ilişkin PAB'ları gelişim göstermiştir. Geçiş PAB'ı (PAB-B) kategorisinde gelişim gösteren katılımcıların entegrasyon yaparken fen ya da mühendislik disiplinlerinden birine daha çok odaklandıkları görülmüştür. Diğer yandan, STEM’e ilişkin PAB (PAB-C) kategorisinde bulunan katılımcıların ise STEM disiplinlerini daha dengeli bir şekilde entegre ettikleri bulunmuştur. Katılımcıların STEM’e ilişkin PAB’larında ortak noktalar bulunmasına rağmen, gelişim örüntülerinde farklılıklar bulunmaktadır. Bununla birlikte bulgular, ders imecesi aşamalarının fen bilgisi öğretmen adaylarının PAB gelişimini desteklediğini ortaya koymaktadır.

Anahtar Kelimeler: STEM Eğitimi, Pedagojik Alan Bilgisi, Ders İmecesi, Fen Bilgisi Öğretmen Eğitimi

To Cengiz Nalbantoğlu

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LIST OF ABBREVIATIONS

STEM	Science, Technology, Engineering and Mathematics
PCK	Pedagogical Content Knowledge
SMK	Subject Matter Knowledge
MoNe	Ministry of National Education

CHAPTER 1

INTRODUCTION

1.1. Background to the Study

The shift from a single-discipline perspective to a multi-disciplinary perspective in science education has become apparent in recent years (Johnson et al., 2016). Koehler et al. (2016) assert that “traditional classroom lecture methods are not preparing our youth for the challenge of the coming global change” (p. 13). Accordingly, there is a strong emphasis on integrating Science, Technology, Engineering, and Mathematics (STEM) disciplines into lessons explicitly in the published reports and studies in Turkey and international context (Akgunduz et al., 2015; Aydin-Gunbatar & Tabar, 2019; Moore et al., 2020; National Research Council, 2012; 2014; Rinke et al., 2016; Thibaut et al., 2019). In the simplest term, STEM education is an interdisciplinary approach that integrates isolated subject areas instead of separating them (Sanders, 2012; Vasquez et al., 2013). With the increased attention toward STEM education, some major goals are defined (National Research Council [NRC], 2012). Firstly, STEM education aims to increase the number of students who choose STEM-related careers and enhance the participation of women and minorities in STEM fields. Research suggests that the number of students pursuing a STEM-related career has been decreasing (Ball et al., 2017; Wang & Degol, 2013). There is a similar situation in Turkey, and it is underlined that there is a rising need for STEM careers in Turkey (STEMTUSIAD, 2015). Allen-Ramdial and Campbell (2014) used the "STEM pipeline leak" metaphor to explain this issue. They indicate that students enter the STEM pipeline, which leaks at some points (such as high school graduation or college entrance), and students tend to choose non-STEM fields at these points (p. 613). They suggested the careful examination of various points of leaky STEM pipeline to make students stay in the pipeline and involve them in STEM-related careers. Moreover, it is reported in the literature that girls' interest in pursuing a career in math, computer, etc., is lower than boys (Fouad et al., 2010). The decrease in women's participation in STEM fields is higher than men's (Boucher et al., 2017) and as girls grow up, their participation in STEM majors is decreased (National Science Foundation, 2009). Engaging students with STEM subjects as early as possible is crucial for their future academic performance and education-related choices (Hernandez et al., 2014), developing their perceptions regarding STEM careers (Atkinson & Mayo, 2010; DeJarnette, 2012), providing opportunities for students to start to develop STEM content knowledge (Nadelson et al., 2013) and engineering experiences (English & King, 2015).

The other primary goal of STEM education is raising STEM literacy for all students, which is defined as "acquiring scientific, technological, engineering, and mathematical knowledge and using that knowledge to identify issues, acquire new knowledge, and apply the knowledge to STEM-related issues" (Bybee, 2010, p. 31). Additionally, STEM education is crucial for promoting 21st-century skills (Ring et al., 2017; NRC, 2012). It provides context for developing 21st-century skills such as collaboration, innovation, creativity, technology skills, problem-solving, etc. (Partnership for 21st Century Learning [P21], 2016). These skills are also included in the latest science curriculum in Turkey (Ministry of National Education [MoNE], 2018a). Considering these major issues, it could be stated that STEM education has been gaining vital importance at all levels of education.

Furthermore, the integration of STEM education offers an environment for engaging students with everyday life issues and making learning more meaningful. Engineering practices such as defining a problem and designing a solution provide engaging and problem-solving contexts to apply science and mathematics concepts (Dare et al., 2018; English, 2017; Moore et al., 2015; Roehrig et al., 2012). Besides, Next Generation Science Standards (NGSS Lead States, 2013) concentrate on the explicit integration of science with engineering, and the NRC framework (2012) also emphasizes the "scientific and engineering practices and their integration with the core concepts" (p. 316). The engineering and engineering design process is at the centre of these standards and frameworks. Students are expected to develop engineering thinking to solve problems and use the engineering design process (English & King, 2015). The engineering design process is described as "an iterative process involving identifying an engineering problem, researching the problem, planning, designing a prototype, testing and evaluating the prototype, and redesigning" (Guzey et al., 2014, p. 144). Students learn from failure, consider multiple perspectives while solving a problem, and develop skills in terms of collaboration and communication with team members through the engineering design process. Coupled with scientific inquiry and mathematical thinking, the engineering and engineering design process constitutes essential parts of STEM education (English, 2016).

The Ministry of National Education (MoNE) of Turkey has revised the science curriculum, and one of the changes in the science curriculum is the inclusion of engineering and design practices (MONE, 2018a). Engineering in the science curriculum is described as "practices to design objects, processes, and systems to meet human needs and desires" (MoNE, 2018a, p. 10). However, there is no clear emphasis on the engineering design process in the currently implemented curriculum. The limited definitions of engineering practices in the Turkish science curriculum make it challenging to develop a holistic understanding regarding STEM education and translating these changes into practice might become challenging for teachers.

Teachers play a key role in integrating STEM into their practices in their classrooms at this point; therefore, teacher quality becomes a major issue (Margot & Kettler, 2019; Sullivan & Bers, 2018). Teachers are expected to have strong STEM content knowledge and know how to implement STEM in the classroom (Johnson et al., 2016). Since STEM education is considered a messy construct, it is unclear how to support and educate preservice teachers to use it effectively in classrooms (Rinke et al., 2016). Pedagogical content knowledge (PCK), as one type of teacher knowledge, is needed to integrate STEM education (Honey et al., 2014; Saxton et al., 2014). When Shulman (1986) initially introduced PCK, he defined it as "the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). Put it differently, it is the knowledge teachers possess to teach a subject that differentiates teachers from subject specialists. As Daehler et al. (2015) indicated, "teachers use or enact this professional knowledge while actively engaged in content-specific teaching and while planning, analyzing student work, and reflecting on their instruction" (p. 45). PCK as a theoretical framework was used in the present study. Several PCK models have been proposed by different researchers in the literature (Carlson & Daehler, 2019: Cochran et al., 1991; Grossman, 1990; Park & Oliver, 2008). Among them, the PCK model developed by Magnusson et al.'s (1999) was used and adapted to examine preservice science teachers' PCK for STEM in this study. Details of the modified version of Magnusson et al.'s (1999) PCK for STEM are presented in the next chapter.

Additionally, it is reported that professional development programs are needed to increase teachers' PCK for STEM (Lau & Multani, 2018; Srikoom et al., 2018). The effect of traditional forms of professional development programs on teachers' practice is a controversial issue. The literature underlines that "make a shift from professional development as something that is done *to* teachers toward considerations of professional learning which entails work *with* and *by* teachers" (Nilsson, 2014, p. 1795). With this understanding, lesson study as a professional development program has gained importance in the last decades (Dudley, 2015). Lesson study has a cyclic procedure in which a group of teachers works together to design, implement and revise a lesson in their natural settings to enhance student learning. Lesson study allows teachers to plan a lesson plan as a team, observe the implementation of the shared lesson plan in the classroom, collect data, reflect upon it by considering what is learned during the process, and revise the lesson (Lewis, 2002). Participating in a lesson study provides opportunities to improve content knowledge (Lewis et al., 2006) and pedagogical content knowledge (Bjuland & Mosvold, 2015; Juhler, 2016). It is also used in teacher education programs (Carrier, 2011; Fernandez, 2010). In this direction, the lesson study is integrated into the science teacher education program in the current study to support preservice science teachers' PCK for STEM development.

1.2. Research Questions

The purpose of the present study was to investigate how preservice science teachers' PCK for STEM develops with respect to four components after participating in lesson study cycles. Additionally, the role of elements of lesson study on preservice science teachers' PCK for STEM development was investigated. The main research questions and sub-research questions that guided the present study are as follows:

1. How does preservice science teachers’ PCK for STEM develop in the context of lesson study?
    a. How does preservice science teachers’ knowledge of curriculum develop in the context of lesson study?
    b. How does preservice science teachers' knowledge of learners develop in the context of lesson study?
    c. How does preservice science teachers’ knowledge of instructional strategies develop in the context of lesson study?
    d. How does preservice science teachers’ knowledge of assessment develop in the context of lesson study?
2. Which elements in the Lesson Study cycle contribute to preservice science teachers' PCK for STEM?

The first time I encountered with PCK framework was in my master's thesis. As a graduate of the science education department and a research assistant who has been working in the same department, I realized that having strong knowledge of science did not mean being able to make knowledge accessible to middle school students. Reading more about the PCK framework attracted my attention, and I designed my master's thesis based on this framework and studied with preservice science teachers. After completing my master’s thesis, I became involved in several research projects about STEM education and enjoyed being a part of these projects. Then, I started thinking about combining the PCK framework and STEM education because the teachers in the projects were experiencing difficulty in writing objectives and preparing assessment in STEM lessons. STEM education was introduced to the science curriculum, but teachers were not ready to implement it. I thought that if I studied with preservice science teachers and aimed to improve their PCK for STEM, they might apply STEM lessons effectively in their future classrooms. These points motivated me to conduct this study.

1.3. Significance of the Study

Based on the research questions stated above, the present study would have some theoretical and practical significance. In terms of theory, very little research exists on how to most effectively prepare preservice teachers for “STEM-infused classrooms"

(Rinke et al., 2016, p. 301). Yip and Chan (2019) specified that preservice teachers take separate courses related to scientific inquiry, mathematics, or instructional technologies in teacher education programs. For that reason, existing teacher education programs suffer from supporting preservice teachers for teaching interdisciplinary concepts (Bartels et al., 2019; Fan & Yu, 2019; Radloff & Guzey, 2017). Because of a lack of experience, knowledge, and skills, it would be a challenging situation for preservice teachers when they are exposed to interdisciplinary teaching (The National Academy of Engineering [NAE], 2014; Fan et al., 2021). Moreover, engineering design practices are included in the recent science curriculum in Turkey and teachers experience difficulty in finding out ways to translate this change into practice (Timur & Inancli, 2018). In these situations, teachers generally learn how to teach the out-of-discipline content on their own through informal ways (Carlson & Daehler, 2019). Therefore, preservice science teachers need to be supported to gain an adequate understanding of the integrated nature of STEM education in teacher education programs and translate this understanding into their instructional practices when they are graduated. When the teacher knowledge bases are considered, pedagogical content knowledge as a framework is considered helpful (Abell, 2007) to provide valuable information regarding preservice science teachers' effective integration of STEM education in the present study.

PCK concerns "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p.8) and it has been studying intensively for more than thirty years (Shulman, 2015). The literature signifies the importance of studying PCK for STEM as one of the vital components of integrated STEM education (Johnson et al., 2016; Saxton et al., 2014; Srikoom et al., 2018). PCK for STEM refers to “how to meld engineering and their (STEM) disciplines effectively in classroom instruction. Teachers must have the PCK to help them expand beyond science or mathematics to include defining and delimiting engineering problems, designing solutions, and optimizing designs” (Lau & Multani, 2018, p. 196). However, there is a paucity of research that focuses on PCK for STEM framework (Allen et al., 2016; Honey et al., 2014; Vossen et al., 2019), and the literature needs further research. Besides, longitudinal studies that track PCK for STEM development are rare (Aydin-Gunbatar et al., 2020; Chan & Hume, 2019; Lau

& Multani, 2018; Wilson et al., 2019). The study aimed to design and apply several lesson study cycles to monitor preservice science teachers' PCK for STEM development to address the gap in the literature.

On the other hand, among the studies, some suggested new components to PCK for STEM (Allen et al., 2016; Saxton et al., 2014), while few utilized specific PCK models existing in the literature (Aydin-Gunbatar et al., 2020; Srikoom et al., 2018). The current study was grounded on Magnusson et al.'s (1999) PCK model by adapting it to PCK for STEM. Magnusson et al.'s (1999) PCK model is a well-known framework used frequently in science education (Abell, 2007; Henze & Barendsen, 2019). Therefore, this is a promising study in terms of using a particular PCK framework and covering four components of PCK for STEM (i.e., knowledge of curriculum, knowledge of learners, knowledge of instructional strategies, and knowledge of assessment).

Improvement of PCK is evolving process (Hume & Berry, 2011; Juhler, 2016; Ekiz-Kiran et al., 2021), and preservice teachers have little experience (Nilsson, 2008). Nilsson and Loughran (2012) asserted that "…situation could change if preservice teachers were offered meaningful ways of defining, assessing and explicitly developing PCK" (p.700). Teacher education programs provide experiences for preservice teachers to shape their PCK, and courses related to PCK are one of the major sources of PCK development (Evens et al., 2015; Hume & Berry, 2011). In these courses, preservice science teachers are given opportunities to get some experience through planning lessons, microteaching, and teaching practices in cooperating schools during their undergraduate education. Despite these efforts, teacher education programs suffer from assisting preservice teachers in transforming their theoretical knowledge into practice in a real classroom context (Bradbury & Koballa, 2007; Nilsson, 2008; Sims & Walsh, 2009; Van Driel & Berry, 2012). At this point, lesson study might provide a suitable context for linking theory and practice for preservice teachers (Dudley, 2015; Fernandez, 2005) and develop their PCK (Juhler, 2016; Sims & Walsh, 2009). Preservice science teachers should be provided support in acquiring the necessary knowledge and practices for planning STEM lessons in the first place in their teacher education program. If preservice teachers have strong PCK for STEM, they will have the opportunity to apply STEM education effectively in their future science classrooms (Vossen et al., 2019). One of the contributions of the present study is to integrate lesson study into science teacher education programs and extend preservice science teachers' meaningful experiences to improve their PCK for STEM.

Several strategies for PCK for STEM development which were components of lesson study cycles (e.g., collaborative planning, teaching, observing, and reflecting) were used to assist preservice science teachers' PCK for STEM development in the current study. Firstly, collaborative lesson planning is considered one of the powerful ways to enhance participants' PCK (Gess-Newsome, 2015). Teachers and preservice teachers could consider alternative strategies, probable students' answers, and ways of assessing students' learning in these collaborative meetings (Anfara et al., 2009) which then informed their PCK (Coenders & Verhoef, 2019; Faikhamta et al., 2020). Dudley (2015) addressed this process as "teachers to see, share, tap into and learn from usually invisible stores of tacit professional knowledge that are normally inaccessible as a learning resource" (p. 4). This study might be significant since it provides an environment where a group of preservice science teachers share and critique the reasons behind their pedagogical choices to plan a collaborative STEM lesson plan to implement in the actual classroom environment. Moreover, the current study utilized a particular lesson planning tool, Content Representation (CoRe) (Aydin et al., 2013) in the collaborative planning process. The literature emphasizes the importance of using CoRe with preservice teachers to strengthen their PCK (Aydin et al., 2013; Carpendale & Hume, 2019; Ekiz-Kiran et al., 2021; Hume & Berry, 2011; Nilsson & Loughran, 2012). However, the number of studies using CoRe in the lesson study research field is limited (Juhler, 2016; Pongsanon et al., 2011). Accordingly, this study merged lesson study and CoRe to fulfil the gap in the literature.

Furthermore, the data were collected in the actual classroom settings in this study. While one participant taught the commonly prepared STEM lesson plan, the other participants observed the lesson using observation protocol which was designed based on the components of PCK for STEM. Teaching (Akerson et al., 2017; Davis, 2004; Nilsson, 2008; Lau & Multani, 2018; Sickel, 2012) and observation of teaching (Barendsen & Henze, 2019; Ekiz-Kiran et al., 2021; Evens et al., 2016; Grossman, 1990) are two sources that contribute to the enhancement of PCK; therefore, an increased number of teaching experiences and observation of teaching by employing lesson study might be one of the significant sides of the present study. Moreover, reflection is considered another essential component of augmenting PCK (Akerson et al., 2017; Aydin-Gunbatar et al., 2020; Carlson et al., 2019; Henze & Barendsen, 2019; Nilsson, 2008; Nilsson & Karlsson, 2019; Zembal-Saul et al., 2002). Utilizing lesson study creates opportunities for reflective practices for preservice science teachers to a greater extent and assists the development of their PCK (Gess-Newsome, 2015; Marble, 2007). After teaching and observation of teaching, a comprehensive group discussion was held about commonly prepared STEM lesson plans in this study. Revisions were made based on teaching experiences and suggestions of preservice science teachers in the reflection part of the lesson study cycle by using the language of PCK for STEM. In this way, preservice science teachers are provided with the opportunity to reflect on the STEM lesson both individually and as a group. Park (2019) underlines that factors contributing to PCK development should be harmonized for effective teaching. Therefore, the results of this study are expected to contribute to the PCK literature by concentrating on STEM and employing a combination of a variety of strategies to portray and support preservice science teachers' development of PCK for STEM. Moreover, the current study could be accepted as unique since it combines lesson study and PCK for STEM, which is scarce in the literature (Lertdechapat & Faikhamta, 2021).

Finally, from the practice aspect, this study also might provide valuable contributions to using lesson study in teacher education programs. Although the majority of the lesson study research was conducted with in-service teachers (Kotelawala, 2012; Lee & Tan, 2020; Verhoef et al., 2015), studies carried on with preservice teachers have been increasing in recent times (Boz & Belge-Can, 2020; Juhler, 2016; Ni Shuilleabhain, & Bjelland, 2019). Lesson study professional development program is well applicable to teacher education programs as well (Akerson et al., 2017; Bjuland & Mosvold, 2015; Cajkler & Wood, 2013; Sims & Walsh, 2009). Grossman and McDonald (2008) argue that "prospective teachers should engage in intensive, focused opportunities to experiment with aspects of practice and then learn from that experience" (p. 189-190). These points were well-matched with the structure of the lesson study. The current study has aimed to incorporate lesson study into the science teacher education program through Practice Teaching in Science course and provide rich experiences for preservice science teachers. The iterative cycles of lesson study were conducted several times and considered as crucial to respond to the need for ongoing support to enhance preservice teachers' PCK for STEM beyond their undergraduate education and previous experiences. Therefore, the present study has shed light on how lesson study in teacher education programs connects the theory and practice gap (Gess-Newsome, 2015) and contributes to the improvement of preservice science teachers' PCK for STEM.

1.4. Definition of the Terms

STEM education: "the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies" (Bryan et al., 2015, p.24). There is no standard definition of STEM education (English, 2016; Honey et al., 2014) and the main features of STEM education utilized in this study are: (1) science is the lead discipline; other disciplines are embodied in science, 2) the real-life problems (e.g., designing a car with the highest speed, designing thermos) are solved through the engineering design process, (3) science and/or mathematics disciplines are used to solve the engineering problem.

Pedagogical content knowledge: "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8).

Pedagogical Content Knowledge for STEM: "how to meld engineering and their (STEM) disciplines effectively in classroom instruction. Teachers must have the PCK to help them expand beyond science or mathematics to include defining and delimiting engineering problems, designing solutions, and optimizing designs" (Lau & Multani, 2018, p. 196). PCK for STEM is measured with interviews, content representation, observation protocol and video-recorded meetings in the present study.

Lesson Study: "a systematic investigation of classroom pedagogy conducted collectively by a group of teachers rather than by individuals, with the aim of improving the quality of teaching and learning" (Tsui & Law, 2007, p. 1294). One cycle of lesson study is consisted of collaborative planning, teaching, reflecting, re-teaching, and re-reflecting phases in the current study.

CHAPTER 2

LITERATURE REVIEW

The purpose of this study is to examine preservice science teachers' PCK for STEM development in the context of lesson study. Therefore, the literature review included three major parts: STEM education, PCK, and lesson study. Firstly, STEM education and its main characteristics were given. Then, how I conceptualized STEM education based on the review of the literature was provided. The second part presented PCK, which serves as the theoretical framework of the present study. Different PCK models existing in the literature were explained, and how the PCK for STEM was described in this study was provided. Moreover, the studies on PCK for STEM and PCK development of preservice teachers were summarized. The final part introduced lesson study and the use of lesson study in teacher education programs.

2.1. STEM Education

STEM Education is still considered a messy construct since plenty of different definitions are available in the literature (Bybee, 2013; Herschbach, 2011; Martin-Paez et al., 2019; Moore et al., 2020). The definition of STEM needs to reflect more than one area; students' and teachers' understanding of STEM, curriculum, and educational system; therefore, it gets more complicated to agree upon one standard definition (English, 2016; Honey et al., 2014). Similarly, Breiner et al. (2012) indicated that "operationally, defining a common conceptualization of STEM for all stakeholders may provide language that fosters a clearer understanding,' but this would be difficult to achieve" (p. 10). Lamb et al. (2015) asserted that the definition of STEM consists of more than one discipline, and each discipline has its epistemologies; thus, there are still ongoing debates on how to define it. Foremost, a consensus has not been reached about the number of disciplines that should be involved in STEM education. One line of research proposes that involving any of two STEM disciplines is enough for planning a STEM lesson (Brown & Bogiages, 2019; El-Deghaidy et al., 2017). For instance, Sanders (2009) explains that integrating four disciplines is not necessary for STEM education; including at least two is enough to prepare STEM lessons without mentioning any STEM disciplines. Similarly, Kelley and Knowles (2016) described STEM education as “the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context to connect these subjects to enhance student learning" (p. 3). Although any STEM disciplines are not mentioned in these definitions, Barth et al. (2017) indicate that science and engineering are the two frequently integrated disciplines in STEM education. In contrast, another group of researchers points out that four disciplines should be integrated into STEM education (Burrows et al., 2018; Moore & Smith, 2014). For example, Balka (2011) describes STEM education as “the ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex problems and to innovate to solve them” (p. 7). Similar to Balka’s definition, Slykhuis et al. (2015) referred to STEM education as “[it] combines all aspects of STEM: science, technology, engineering, and mathematics in a unique way that is dependent upon all of the fields” (p. 255). Moreover, some definitions in the literature are independent of the content and refer to incorporating multiple disciplines (Breiner et al., 2012; Honey et al., 2014). Honey et al. (2014) provided STEM definition as: "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines” (p.52).

On the other hand, the majority of the definitions emphasized the integration of engineering into STEM education (Dare et al., 2018; Guzey et al., 2016; Walker et al., 2018). For instance, Shaughnessy (2013) indicated that: “STEM education refers to solving problems that draw on concepts and procedures from mathematics and science while incorporating the teamwork and design methodology of engineering and using appropriate technology” (p.324). A similar and more comprehensive definition provided by Bryan et al. (2015) advocate that STEM education is “the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies” (p.24).

Parallel with the plenty of STEM education definitions given above, how to integrate STEM was interpreted differently by the researchers, and variations existed concerning the level of integration. For example, Vasquez et al. (2013) suggested a continuum for the different types of integration (Figure 2.1). The first level is disciplinary integration, in which knowledge and skills from each discipline are taught separately. The second one is multidisciplinary integration, which involves a greater understanding of integration. Knowledge and skills from each discipline are taught separately but within the boundaries of a common theme. For instance, the Solar system might be considered a common theme, and lessons from different disciplines are designed in the same grade level according to this pre-determined theme. Students learn the characteristics of each planet in the science classroom; at the same time, they learn how to measure distances between planets in mathematics classrooms (p. 61). The third level of integration refers to interdisciplinary integration. The boundaries between STEM disciplines are unclear at this level; for example, students could design telescopes and draw upon their knowledge of ratio and proportion and the engineering design process to finish their products (p. 64). Lastly, the most complicated one is transdisciplinary integration. The learning environments should be relevant to students' daily life experiences at this level of integration. For instance, the teacher might start a lesson by asking, "How would a meteorologist forecast the weather on Planet X" (p. 72). While students work on this question, the boundaries between disciplines are blurred. Students are expected to address knowledge and skills from different disciplines and recognize careers in STEM while seeking answers to the question.

Similar to Vasquez et al. (2013) continuum, Bybee (2013) proposed another continuum that includes eight different perspectives towards STEM integration. The one side of the continuum demonstrates that STEM integration only refers to science discipline. On the opposite side of the continuum, there is a transdisciplinary approach that concentrates on solving problems affecting society, such as global warming or the consumption of energy resources. Different disciplines are incorporated to solve the given problems at the highest level of integration (Figure 2.2). Bybee (2013) used the analogy of a "quartet of musicians playing together" to refer to transdisciplinary integration (p. 79). Between these two opposite perspectives, the degree of STEM integration levels varies; for example, one perspective advocates that science encompasses other disciplines, whereas the other perspective defends technology/engineering act as connector disciplines that bridge science and mathematics disciplines. Bybee (2013) remarked that there is no single and best approach for STEM integration; each perspective has its benefits and drawbacks.

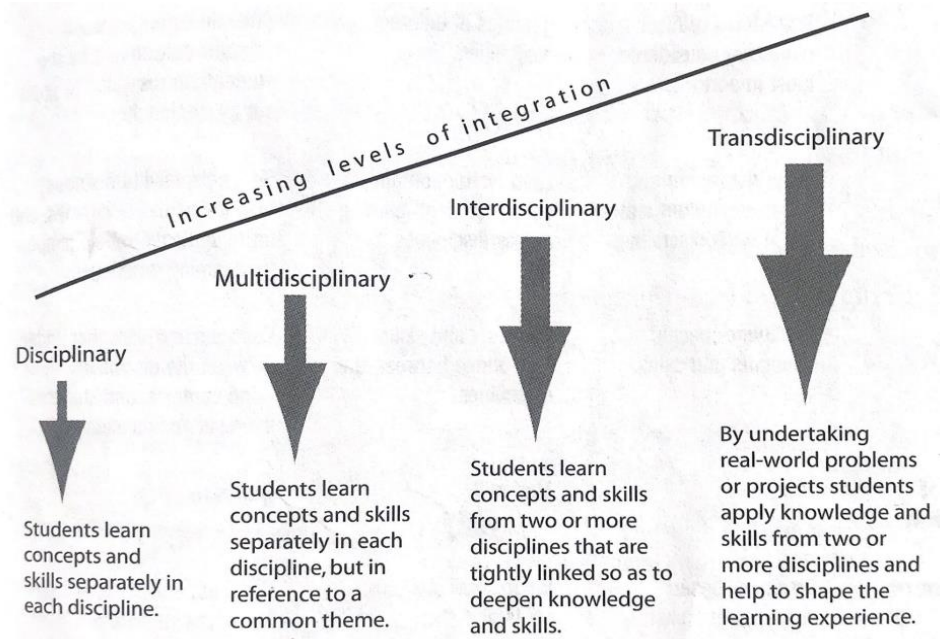


Figure 2. 1 The STEM Integration Continuum (Vasquez et al., 2013, p. 72).

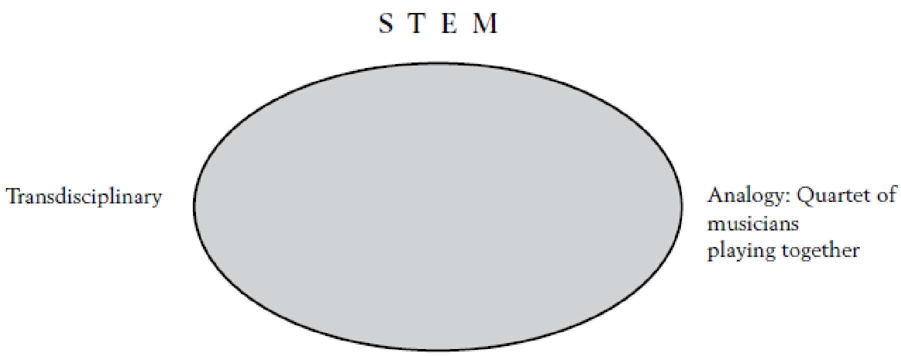


Figure 2. 2 The Transdisciplinary STEM Integration (Bybee, 2013, p. 79).

Moreover, Bryan et al. (2015) presented a comprehensive framework called "STEM Roadmap" for integrated STEM education. They emphasized that teachers need to seek ways to make the connection between STEM disciplines explicit in the already existing curriculum and create an environment for authentic learning activities. The other noteworthy point about their framework is that STEM education is not simply combining two disciplines, i.e., using mathematical formulas in science classrooms could not be considered a way to integrate STEM disciplines. The integration should be "more intentional" and "more specific" (p.23). Consequently, they brought forward three types of STEM integration: “content integration, context integration and supporting content integration” (p. 24). In the former, objectives from different STEM disciplines are blended while planning an activity. The activity aims to achieve multiple objectives from different disciplines. In context integration, the instruction of one STEM discipline incorporates the problem from another discipline. The main difference between content and context integration is that context integration aims to achieve the learning objectives of the dominant discipline. In the supporting content integration, objectives of one discipline (e.g., science) are considered the main content, and objectives from other disciplines (e.g., mathematics, engineering, technology) are used to promote the learning of the main content. It is the most common way of STEM integration in the classrooms, but the researchers recommended using content integration as much as possible to attain the goals of STEM education.

Additionally, Nadelson and Seifert (2017) used the term "spectrum" to describe the levels of STEM integration (Figure 2.3) The one side of the spectrum demonstrates that each STEM discipline is isolated from each other (e.g., typical physics lesson) which refers to the lowest level of integration. Direct instruction becomes prominent, the lesson is structured, and developing skills is not the main focus of the instruction at this level of integration. The other side of the continuum is centered on “problems that require an integrated STEM approach are typically ill-structured, with multiple potential solutions, and require the application of knowledge and practices from multiple STEM disciplines" (p. 221). The students’ knowledge and practices improve as they engage in the process of solving real-world-based, complex problems in integrated STEM. The project-based instruction is typical in this level of integration and aims to enhance students' skills, such as creativity and critical thinking.

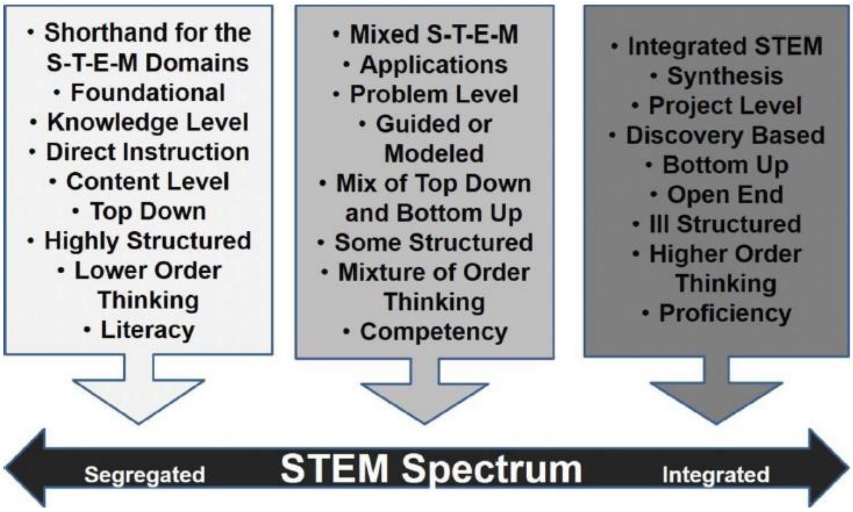


Figure 2. 3 The STEM Spectrum (Nadelson & Seifert, 2017, p. 222)

Another level of integration is proposed by Wang and Knobloch (2018). They mentioned three levels of integration for STEM education in their studies. The first level is “Exploring STEM Integration," which specifies that the emphasis on one STEM discipline is greater than the others. The planned activity does not require using subject matter knowledge in STEM fields, and objectives are derived from one discipline. The second level of integration is "Developing STEM Integration". There is more coherence among STEM disciplines at this level of integration compared to the previous one. The objectives of the instruction might be related to one discipline or include multiple disciplines implicitly, i.e., other disciplines are used to promote learning in the dominant discipline. The highest level is labelled as "Advancing STEM Integration". Solving the real-world problems in which students merge their knowledge from different STEM disciplines is the distinctive characteristic of this level of integration. Students have control over their learning, and the teacher is a facilitator.

2.1.1. Main Characteristics of STEM Education

Although STEM is conceptualized and integrated in different ways, some common characteristics of STEM education could be listed based on the studies in the literature. Firstly, STEM education is an interdisciplinary approach that brings different disciplines together. Bryan et al. (2015) suggested using the term "anchor disciplines" from which learning objectives are obtained (p. 25). They asserted that science and mathematics disciplines are generally considered anchor disciplines in STEM education, and students use the knowledge and skills from these disciplines to solve engineering problems. In other words, science and mathematics content are needed to integrate technology and engineering disciplines for STEM education (Dare et al., 2018; Guzey et al., 2014; Kennedy & Odell, 2014). Through STEM education, students develop a comprehensive understanding of the relationship between different disciplines. Shaughnessy (2013) pointed out that STEM education should not overemphasize one discipline, and students learning in different disciplines of STEM should be secured. Besides, if the STEM activities do not benefit from the knowledge and practices of science and mathematics, there is a possible risk of preparing "art and craft projects" at the end (Guzey et al., 2019, p. 25).

Moreover, including the engineering design process is underlined as one of the core characteristics of STEM education in the literature (Fan et al., 2021; Guzey et al., 2016; Guzey et al., 2019; Moore et al., 2015; Roehrig et al., 2012). The engineering design process is considered a *catalyst* to connect STEM disciplines (Kelley & Knowles, 2016, p. 5). The National Academy of Engineering [NAE] (2010) defined the engineering design process as an "iterative process that begins with the identification of a problem and ends with a solution that takes into account the identified constraints and meets specifications for desired performance" (p. 6-7). The well-prepared and authentic engineering design challenge enables students to solve the given problems by considering alternative solutions, criteria, and limitations (Guzey et al., 2016). When students engage in the iterative cycles of the engineering design process, they have a chance to reconsider their understanding of science concepts (King & English, 2016) and explicitly connect science, mathematics, and other disciplines (Byran et al., 2015, Guzey et al., 2016). Using relevant science and mathematics concepts to solve engineering problems is another important part of the engineering design process (Moore et al., 2014). Moreover, students are expected to develop an understanding of engineers and the work of engineers through the engineering design process (Guzey et al., 2019; Moore et al., 2015). Students should gain the necessary knowledge about branches of engineering, how engineers find a solution to the client's problems under some limitations, and that there is not only one perfect design that solves the problem. Additionally, learning from failure through the engineering design process is the other essential feature of STEM education (Guzey et al., 2016; Maiorca & Mohr-Schroeder, 2020). Cunningham and Carlsen (2014) state that "from an educational perspective, the process offers opportunities for student self-regulation and learning from mistakes" (p. 201). Students should be allowed to learn from their mistakes and reflect on the reasons for their failures (Moore et al., 2015).

Another characteristic of STEM education is providing real-world problems for students (Breiner et al., 2012, Guzey et al., 2019). Learning environments in STEM education should be organized to attract students' attention and give them a chance to relate the content to their everyday experiences (Moore et al., 2015). Solving complex problems that students confront in their daily life requires using knowledge from different disciplines. STEM education plays a crucial role in offering suitable and productive learning environments for students by utilizing multiple disciplines (English & King, 2019; Fan et al., 2021). Bryan et al. (2015) specified this issue as "opposed to cook-book labs in science or rote problem-solving in mathematics; real-world problems engage students in issues that are significant in everyday life and have more personal relevance" (p.25). Hence, STEM education offers a motivating and realistic context for students to draw upon their personal experiences, solve engineering problems, and apply engineering practices (English, 2016). Local or global issues are used to create realistic situations (Guzey et al., 2016).

Encouraging teamwork and working collaboratively is highlighted in many studies related to STEM education (English & King, 2019; Fan et al., 2021; Kelley & Knowles, 2016; Kloser et al., 2018; Thibaut et al., 2018). Students are contributing team members in STEM lessons (Moore et al., 2015), and they have individual responsibilities in the group (Peterman et al., 2017) in addition to involvement in group discussions (Guzey et al., 2016). Members in student groups share their ideas, criticize and negotiate to solve engineering problems (Capobianco & Rupp, 2014). Working in teams provides “to learn not only from their designs but also to work in groups and to learn from the efforts of others" in STEM education (Cunningham & Carlsen, 2014, p. 206). Moreover, communicating groups' design solutions is another distinctive feature of STEM education (Bryan et al., 2015). When solving real-life problems, team members work together and communicate their findings which reflect how engineers work in real life. The teams share their findings in several ways, through presentations, product overviews, charts, graphs, and mailing to the client (Maiorca & Mohr-Schroeder, 2020; Stohlmann et al., 2011).

Furthermore, instructional approaches that are centered on open-ended design challenges and utilizing problem-based, project-based, and inquiry-based approaches are another significant feature of STEM education (Breiner et al., 2012; Chan et al., 2019a; Fan & Yu, 2019). Project-based learning enables using local problems in engineering design challenges, and students might work on the issue for several weeks. Through problem-based learning, students are given an ill-structured engineering problem, generally from the global context, and they design a product or solution to solve the problem (Moore et al., 2015). Inquiry-based approaches use engineering design problems to increase students' interest in science and mathematics concepts, and later students participate in various inquiry activities to solve the problem (English, 2016; Fan et al., 2021). These instructional approaches are "embedded in STEM lessons provide students with experiences of how to integrate and apply concepts across disciplines in real-world situations" (Fang & Hsu, p. 198) and provide student-centered learning environments (Dare et al., 2018; Guzey et al., 2016); therefore, compatible with STEM education.

Additionally, STEM education fosters the development of 21^{st}-century skills (Johnson, 2013; Moore et al., 2015; Rinke et al., 2016; Thibaut et al., 2018). Although the relevant studies advocate promoting 21^{st}-century skills, a few explicitly discuss these skills. When the P21 Framework is considered (Partnership for 21st Century Learning, 2016), STEM education mainly emphasizes 21^{st}-century skills, such as knowledge construction, critical thinking, collaborative working, creativity, adaptability, and communication (Stehle & Peters-Burton, 2019). Students are encouraged to think from different perspectives, evaluate and criticize alternative ideas with their advantages and disadvantages to reach a solution, and create prototypes in STEM education that contribute to developing these skills (Honey et al., 2014; Wendell et al., 2017). Furthermore, students develop life and career skills and develop an understanding of global awareness, and environmental literacy through STEM education which are parts of 21^{st}-century skills (Bryan et al., 2015).

Moreover, STEM education highlights using various formative assessment methods (Teo & Ke, 2014). Learners' understanding of knowledge and practices in STEM disciplines are assessed, and the assessment results are used to make revisions to the implementation of STEM lessons (Guzey et al., 2016). Harwell et al. (2015) pointed out that the assessment should encompass science, mathematics, and engineering disciplines in STEM education. Similarly, Aydin-Gunbatar et al. (2020) advocated that assessment should be focused on both the engineering design process and learners' product through the use of the criteria list or rubrics in STEM lessons. On the other hand, Gao et al. (2020) approach the issue from a different point of view and mention the importance of alignment between the objectives and assessment as a crucial part of STEM education.

Lastly, technology integration is another feature of STEM education. The way of integrating technology is ambiguous in STEM education (Dare et al., 2018; Moore et al., 2014; Rinke et al., 2016). However, Ellis et al. (2020) categorized these different points of view as follows: "(1) technology refers to the product of engineering" (p. 476), (2) "technology refers to instructional technology to support students' learning" (p.479), (3) "technology refers to coding or computational thinking" (p. 481), and (4) "technology as tools used by science, mathematics, and engineering practitioners" (p. 483)". Therefore, it could be inferred that technology can be integrated into several ways in STEM education.

By considering different approaches and general characteristics, STEM education is conceptualized in the present study as follows: 1) science is the lead discipline; other disciplines are embodied in science, 2) the real-life problems (e.g., designing a car with the highest speed, designing thermos) are solved through the engineering design process, (3) science and/or mathematics disciplines are used to solve the engineering problem, (4) technology is used as "instructional technologies". Since the engineering design process is one of the key components of STEM education according to my conceptualization of STEM education, details about it are given below.

2.1.2. Engineering Design Process

One of the major goals of engineering is described as "to solve problems that arise from a specific human need or desire. To do this, engineers rely on their knowledge of science and mathematics, as well as their understanding of the engineering design process" (NRC, 2012, p. 27). The Next Generation Science Standards (NGSS, 2013) and the latest Turkish science curriculum (MONE, 2018a) feature the infusion of engineering into science instruction. Guzey et al. (2019) described several science and engineering integration perspectives in their study. The first one is the "*add-on*" approach. Put differently, engineering is added to science instruction in this perspective. Engineering is considered "a trial-and-error method" instead of a well-planned and organized process of solving problems (p. 25). Science and engineering are not fully integrated; the science and engineering content is isolated from each other according to this perspective. The second one is labelled as *explicit* integration. The main idea behind explicit integration is that science is taught in the context of the engineering design process. The learning environment where students use their scientific knowledge to solve engineering problems is created in this perspective. The connection between these two disciplines is strong. The add-on and explicit integration perspectives are on opposite sides of the continuum. In the middle of these perspectives, *implicit* integration is located. The engineering design challenge is integrated into science instruction to some extent in this perspective. For instance, an engineering design challenge might be introduced at the beginning of the lesson and then re-visited only at the end of the lesson. The engineering design challenge is not fully connected to the science content and is not the primary purpose of the lesson in the implicit integration (Peterman et al., 2017).

The engineering design process has iterative nature. Iterative is described as "building a prototype, testing it, and improving the design based on the tests" (Crismond, 2013, p. 52). Various frameworks have been suggested for defining the engineering design process (Cunningham, 2009; Fan & Yu, 2019; Massachusetts Department of Education, 2006; Wheeler et al., 2014; Wendell & Kolodner, 2014). For instance, Cunningham (2009) suggested five steps of the engineering design process: (1) ask, (2) imagine, (3) plan, (4) create, and (5) improve. On the other hand, Fan and Yu (2019) described four main components of the engineering design process: "(1) problem definition and analysis; (2) solution planning and forecasting; (3) the practice modelling and testing of final products; and (4) review and optimization" (p. 107). Among the different models of the engineering design process, the eight-step engineering design process suggested by the Massachusetts Department of Education (2006) was used in the present study to implicitly integrate the engineering design process into science instruction (Figure 2.4). This model is based on the understanding of “analysis—synthesis—evaluation”. The first three steps are related to "analysis", the fourth and fifth are related to “synthesizing”, and the last three of them are related to “evaluation” (Hynes, 2012, p. 346).

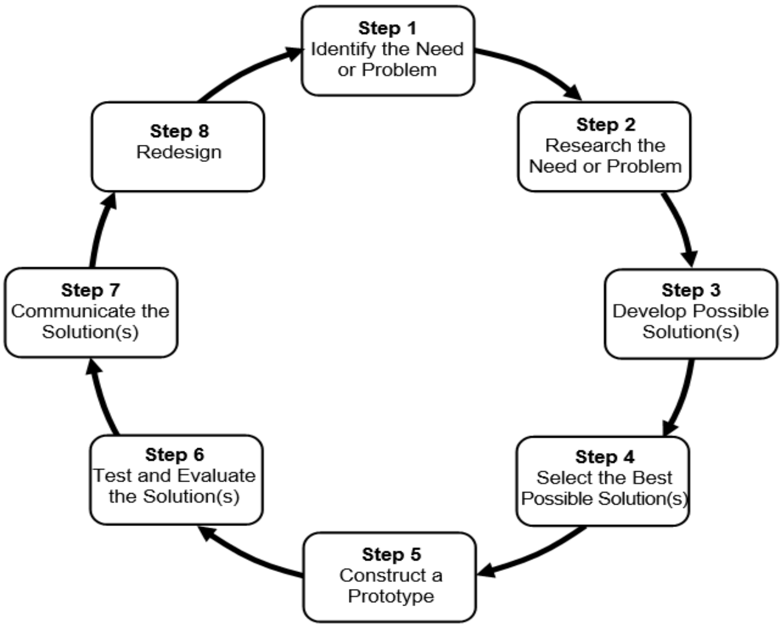


Figure 2. 4 The Eight-Step Engineering Design Process Model (Massachusetts Department of Education, 2006, p.84)

The engineering design process cycle begins with identifying the need or the problem. The real world-based, ill-structured problem is presented to the students at the beginning of the cycle. Students are expected to identify the client's criteria to solve the problem and the limitations imposed on the problem. The students need to grasp that the client's needs for the problem lead them to solve it as engineers do (Maiorca & Mohr-Schroeder, 2019). The problem should be open-ended and provide several alternative solutions for students. It is crucial to note that there should not be only one way to solve engineering problems (Hynes et al., 2011). One of the misconceptions regarding design challenges is that they are closed-ended engineering problems where students can only come up with one correct answer (Crismond, 2013). Moreover, the engineering design challenge should include an authentic problem instead of a “contrived problem/phenomenon created for the purpose of the lesson only” (Peterman et al, 2017, p. 1918).

Then, the cycle continues with researching the problem step. The students should research to gain the necessary background knowledge about the given engineering problem and brainstorm ideas. The current situation about the problem might be investigated through the internet, textbooks, written documents, activities, experiments, etc. Students might also examine similar cases and prior solutions to the problem (Crismond & Adams, 2012). The research should be “student-driven”, and the construction of prototypes right after defining the problem without researching should not be allowed (Crismond & Adams, 2012; Hynes et al., 2011).

The third step is developing possible solutions. Students should be encouraged to consider as many possible alternative solutions by considering relevant scientific and mathematical concepts in teamwork. This step fosters students' creativity and communication skills (Crismond & Adams, 2012). Students consider novel ways to solve the problem following the criteria and limitations and are provided with opportunities to learn in a group (Hynes et al., 2011).

The fourth step is choosing the best solution among the alternatives. Which of the solutions solves the engineering problem better than others is determined in this step. Several alternatives should be weighted with their advantages and disadvantages. To what extent the solutions meet the criteria and limitations should be discussed and justified in the group for decision-making about the final solution. In other words, the strength of solutions and trade-offs should be considered. Students learning should be scaffolded in this process because students might tend to think, "Why should I brainstorm more when I already have an idea worth trying" (Crismond, 2013, p. 53). The teachers might choose "explanation-based designing" by asking continuous questions and encouraging students to explain to support their learning. The other possible way could be using "decision diagrams" which facilitate the decision-making process about the ultimate solution in this step (Crismond & Adams, 2012, p. 762). Moreover, science and mathematics concepts are applied while choosing the best solution and students think critically in this step (Peterman et al., 2017).

The fifth step is constructing a prototype. The prototypes show "some functionality or look" of the proposed solution in the form of a "physical, virtual, mathematical model" (Hynes et al., 2011, p.11). The decided solution is constructed in two or three dimensions in this step. Creating a sketch of a solution before constructing a prototype is common in this phase (Crismond, 2013). The next step is testing and evaluating the solutions. The main concern of this step is "Does the prototype work? Does it meet the original design limitations?" (Massachusetts Department of Education, 2006, p. 84). The students collect and record their data to determine the effectiveness of their design in this part.

The seventh step is communicating the solutions. This step includes presentations of the tested solutions by explaining how the design solution solves the problem given in the first step. The presentation should involve the criteria and limitations of the problem as the way engineers do. The student groups share their findings and try to market their products while peers provide feedback (Hynes et al., 2011).

The last step is re-designing. The design solutions are re-considered in light of data collected in the testing phase and feedback from others. Crismond (2013) notes the essential questions to be asked in this step: "(1) What would you call the problem you saw? (2) Why is this problem happening? (3) How would you fix it" (p. 52-53). This step could be achieved in two ways. Students might conceptually re-design their solutions and defend their reasons to improve. On the other hand, students might re-create their prototypes and re-test (Peterman et al., 2017).

2.2. Pedagogical Content Knowledge

The pedagogical content knowledge framework guides the present study. Shulman (1986) offered three categories of teacher knowledge in his work "Knowledge Growth in Teaching": subject matter content knowledge, pedagogical content knowledge, and curricular knowledge (1986, p.7). According to his definition, subject matter knowledge consists of substantive and syntactic knowledge, while curricular knowledge includes knowledge about the curriculum, the materials used for teaching subjects, and vertical and horizontal curriculum. He defined PCK as a distinct knowledge category for the first time as follows: "the most useful forms of content representation, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p.9). He continued to search for the answers to some questions like "What are the sources of the knowledge base for teaching? In what terms can these sources be conceptualized?" in his following works (Shulman, 1987, p.1). Then, he extended the categories of teacher knowledge into seven: “(1) content knowledge, (2) general pedagogical knowledge, (3) knowledge of the curriculum, (4) pedagogical content knowledge, (5) knowledge of learners and their characteristics, (6) knowledge of educational contents and (7) knowledge of educational aims, goals, values, and philosophical and historical foundations" (p.8). He emphasized the importance of PCK since it combines both content and pedagogy.

After Shulman's definition of PCK, many scholars conducted research on PCK. They studied PCK in different ways by proposing new definitions and adding new components. Details of some PCK models are given below.

A year later, Tamir (1988) described PCK as "subject matter-specific pedagogical knowledge" based on Shulman's (1987) work and proposed four components of PCK. These components are knowledge of student, curriculum, instruction, and evaluation. The evaluation was added as a new component in Tamir's model compared to Shulman's study.

Later, Grossman (1990) put forward another model for teacher knowledge that involves four categories: subject matter knowledge, general pedagogical knowledge, pedagogical content knowledge, and knowledge of context. Unlike the previous scholars, Grossman indicated the reciprocal relationship between PCK and other categories of teacher knowledge as given in Figure 2.5. Grossmann categorized PCK into four components: conceptions and purposes of science teaching, knowledge of students' understanding, curricular knowledge, and knowledge of instructional strategies. He considered the "conceptions and purposes of science teaching" component as an umbrella term that encompasses other categories. Grossman's PCK model did not involve assessment as a part of the PCK component compared to Tamir's PCK Model. Additionally, Grossman (1990) pointed out the possible sources that contribute to PCK development as follows: (1) courses in teacher education programs, (2) observation, (3) teaching experience, and (4) professional development programs.

In the following year, Cochran et al. (1991) suggested an alternative PCK model which accepted PCK as a knowledge base integrated from four different components: knowledge of the subject matter, knowledge of students, knowledge of environmental contexts, and knowledge of pedagogy. The researchers asserted that "…theoretically, the four components become so integrated and interrelated that they no longer can be considered separate knowledges" (Cochran et al., 1991, p.12). Apart from Shulman's model, they added and highlighted knowledge of environmental context as a component of PCK. Later, they improved their model and used the term "Pedagogical Content Knowledge Knowing" (PCKg) (Cochran et al. 1993). They underlined that PCK evolves with experience and how PCK improves in the model is shown with arrows, as seen in Figure 2.6

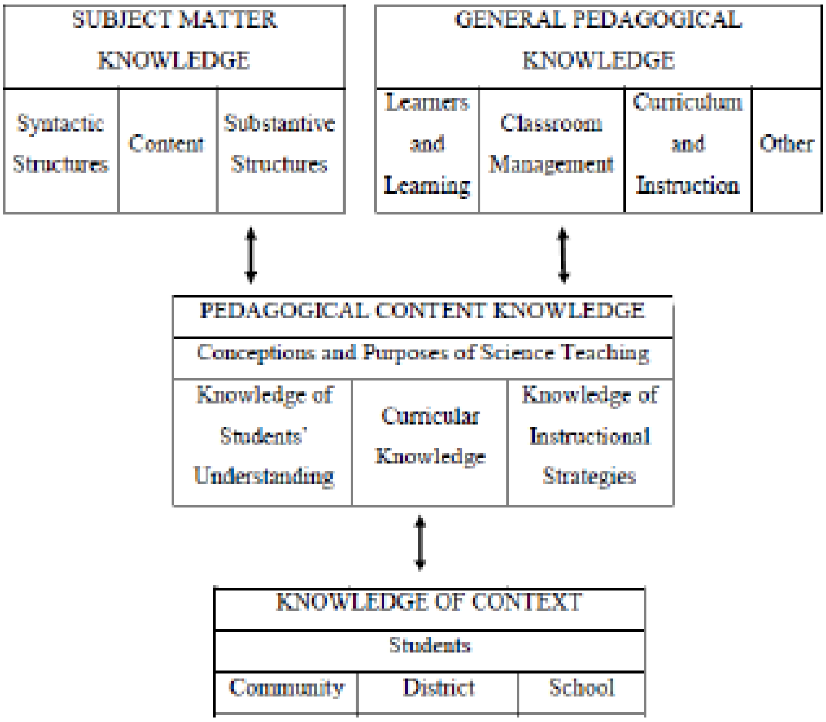


Figure 2. 5 Teacher Knowledge Model (Grossman, 1990, p.5)

Later, Gess-Newsome (1999) approached PCK literature from a different perspective and attempted to categorize existing PCK models into two: integrative and transformative models. In the former, PCK is not a separate knowledge base; instead, it is at the intersection point of subject matter knowledge, pedagogical knowledge, and contextual knowledge. On the contrary, PCK is a new knowledge base in transformative PCK models referring to synthesized knowledge of subject matter knowledge, pedagogical knowledge, and contextual knowledge, as seen in Figure 2.7 To make it clear, Gess-Newsome (1999) proposed an analogy that is widely used to make a differentiation between these two categories. The integrative model is regarded as a mixture since it does not form a new substance. In contrast, transformative models are regarded as compounds because PCK combines three other knowledge bases, and as a result, a new knowledge base is formed.

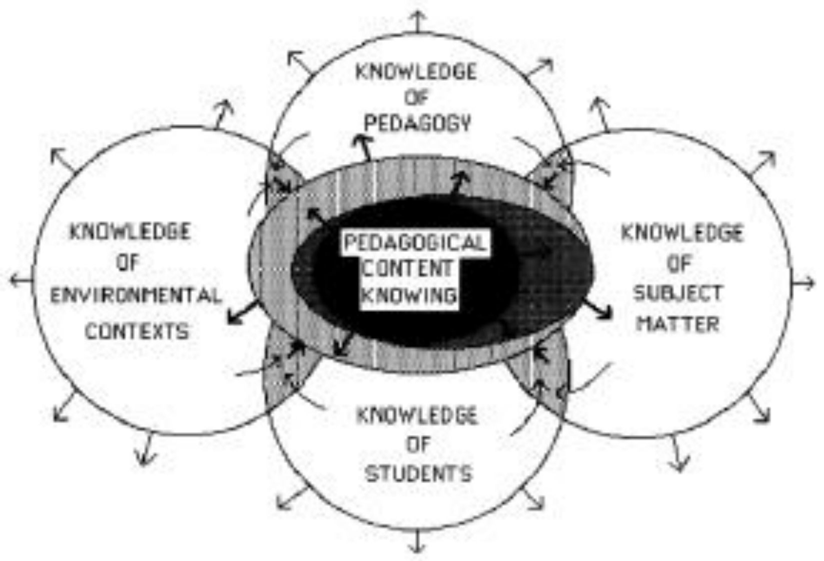


Figure 2. 6 Cochran et al.'s (1991) PCK model

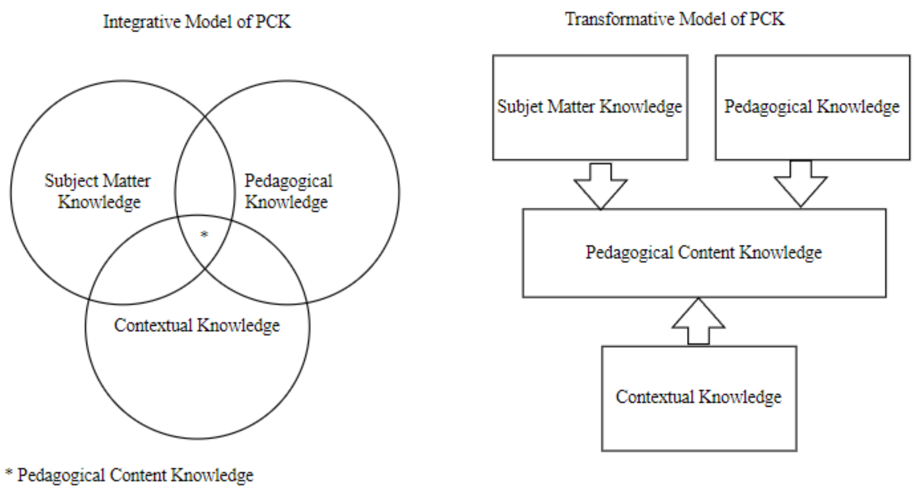


Figure 2. 7 Comparison of the Integrative Model and Transformative Model of PCK (Gess-Newsome, 1999, p. 12)

In the same year, Magnusson et al.'s (1999) proposed an alternative teacher knowledge model. They took a transformative perspective and recommended that there are four different teacher knowledge bases, as Grossman (1990) suggested. These knowledge bases are (1) subject matter knowledge, (2) pedagogical knowledge, (3) PCK, and (4) knowledge of the context (Figure 2.8). Two-way arrows between knowledge bases indicate how they interact with each other. Different from previous studies, Magnusson et al.'s (1999) attached beliefs to their model and used the "knowledge and belief" term together, i.e., knowledge and belief about science curriculum.

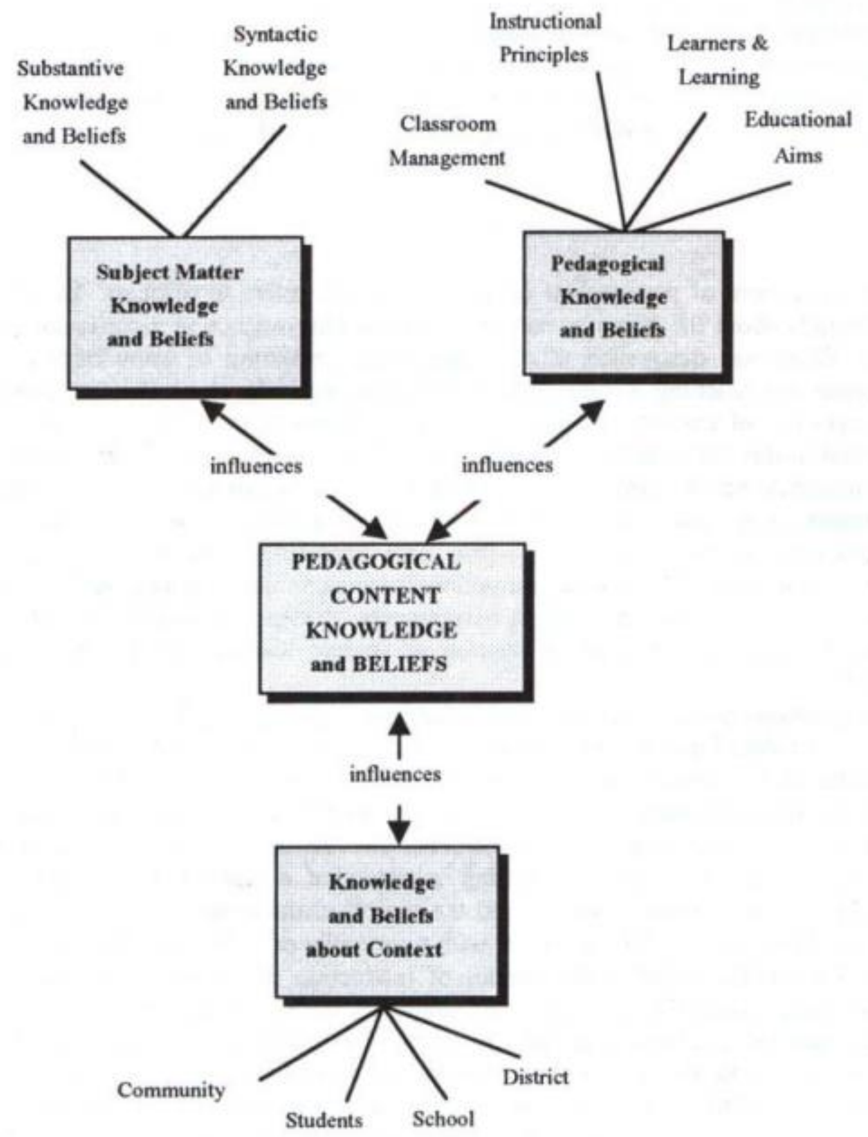


Figure 2. 8 Teacher Knowledge Model (Magnusson et al., 1999, p. 98)

Magnusson et al.'s (1999) benefited from previous PCK models and proposed 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 (Figure 2.9). Following Grossman's model (1990), they labelled "conceptions" as "orientations" in their model. Furthermore, different from Grossman's model, they added knowledge of assessment component inspired by Tamir (1988). PCK components of this model are explained below.

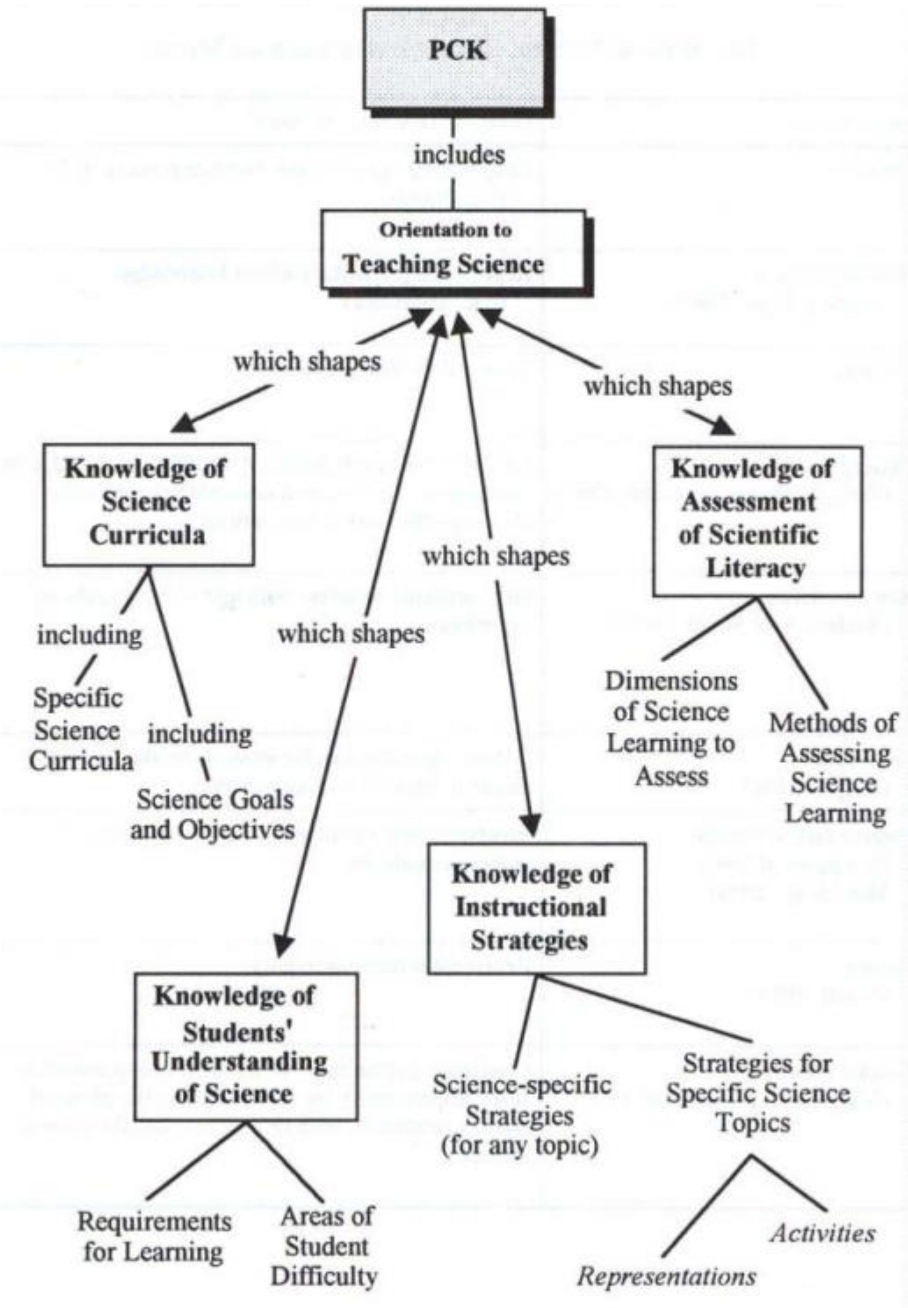


Figure 2. 9 Magnusson et al.'s (1999) PCK Model (p. 99)

Firstly, orientation to the teaching science component is described as "teachers' knowledge and beliefs about the purposes and goals for teaching a subject at a particular grade level" (p. 97). This component is considered as eyeglasses in which teachers look through science teaching, as seen in Figure 2.9. It is placed at the top of the other four components, which means it shapes them. Science teaching orientations influence on teachers' instructional decisions and choices and guide the teaching process. Magnusson et al.'s (1999) categorized science teaching orientations into nine: "(1) process, (2) academic rigour, (3) didactic, (4) conceptual change, (5) activitydriven, (6) discovery, (7) project-based, (8) inquiry and (9) guided inquiry” (p.100-101).

Knowledge of science curriculum is accepted as a separate teacher knowledge base in Shulman's initial work (1987), but then Grossman (1990) added it as one of the PCK components in her work. Magnusson et al. (1999) followed Grossman's work and described the curriculum as a PCK component. Knowledge of curriculum includes two sub-components. The first one is related to science goals and objectives. It refers to the knowledge of horizontal curriculum and vertical curriculum. Horizontal curriculum underlines the connection of the topics in the same grade level, whereas vertical curriculum is related to the connection of topics with previous and following grade level topics. The second other sub-component is specific curricular programs and materials. It is the knowledge that teachers have while using the curriculum, choosing activities to reach the objectives of the lesson, and choosing which materials are required for teaching the objectives.

The third component is knowledge of students' understanding of science which is related to how teachers help students to learn science concepts. It has two sub-components: knowledge of requirements of learning and knowledge of areas in that students have difficulties. The first one consists of teachers' knowledge about what prerequisite knowledge and skills are required for students to learn science concepts. Moreover, the teacher should be attentive to the developmental differences among the students and accommodate the learning environment according to the different needs of students. The second one consists of teachers' knowledge about the difficulties that students might experience while learning science concepts. Teachers should be knowledgeable about the causes of students' difficulties. Abstract science concepts, relating concepts with daily life, and misconceptions that students hold are the possible sources of why students might experience difficulty.

The fourth PCK component of the model is knowledge of instructional strategies, which comprises two further sub-categories: knowledge of subject-specific strategies and knowledge of topic-specific strategies. Both of the categories could not be considered separate from each other; however, the extent of the categories shows variances. The former implies more comprehensive and general strategies (learning cycle, conceptual change, etc.) utilized while teaching science. This sub-component is reasonably related to the orientation of the teaching science component. The latter implies a more narrow-scoped category, and the teacher uses topic-specific strategies while teaching specific science topics. Teachers should be knowledgeable in terms of using analogies, models, illustrations, and examples and should use them at the appropriate time of the lesson. Furthermore, this category includes using activities such as demonstration, experiments, role-play, and problem-solving to help learners to grasp specific science concepts. For instance, using technology-supported activities to teach the difference between temperature and heat could be an example suitable to this sub-category (Magnusson et al.,1999, p. 113).

The last category is the knowledge of assessment which involves two sub-categories. The first one is knowledge of dimensions of science learning to assess. It refers to knowledge of which dimension of science learning (knowledge, science process skills, etc.) should be focused on while planning an assessment. The other category is the knowledge of methods of assessment. It is related to the “how to assess” question. In other words, it is the knowledge of using appropriate assessment instruments specific to science learning. It consists of portfolios, laboratory exams, poster presentations, rubrics, written tests etc., to assess student learning. Teachers should be aware of the advantages and disadvantages of varying assessment methods and be knowledgeable about which method is more suitable to assess students learning of specific science concepts.

Magnusson et al. (1999) stressed that having strong knowledge of one component of PCK does not mean a teacher has a solid PCK in total. Researchers embraced a holistic view regarding PCK and expressed that teachers should develop their knowledge in all components of PCK for effective teaching. Moreover, they underlined the importance of the relationship between PCK components and how the interactions between them shape teachers' practices should be examined in PCK studies.

Different from Magnusson et al.’s (1999) linear way of the PCK framework, Park and Oliver (2008) proposed a new model in pentagonal shape given in Figure 2.10. to study the interactions of the components. They employed the same components in Magnusson et al.’s (1999) model. Alternatively, they put PCK at the centre of the model and indicated that improving one component of PCK might influence improving other PCK components. In the same manner, if there is no compatibleness among PCK components, it might restrain the development of PCK in total. Moreover, the researchers developed the model by examining PCK in two dimensions: understanding and enactment. Understanding is related to how teachers recognize students' difficulties and misconceptions and how they decide what are the most effective instructional strategies and assessment methods for teaching specific science topics. On the other hand, enactment is related to how teachers translate their understanding of PCK into the real classroom environment. In addition to these, Park and Oliver (2008) added "reflection on action" and "reflection in action" into the centre of the model. They advocated that reflection is a crucial component for improving understanding and enactment of PCK. Park and Oliver (2008) conducted a study with three experienced teachers to reconsider their proposed model. Based on the results of the study, the sixth component of PCK emerged and was named "teacher efficacy." Therefore, Park and Oliver (2008) include an affective component as a part of their PCK model. They found that if the teacher had high self-efficacy, it was reflected in their understanding and enactment of PCK. Lastly, Park and Oliver (2008) attracted attention to the idiosyncratic nature of PCK. They stressed that PCK is specific to each teacher and how teachers interrelate PCK components is unique to different teachers.

Many PCK models in the literature are rooted in Shulman's work (1986, 1987). However, Shulman (2015) mentioned some limitations of his model regarding its' definitions and conceptualization. To illustrate, he indicated that the first PCK model lacked affective components. The social and cultural contexts were not described as influential factors that might affect the improvement of PCK, and the relationship between PCK and student learning was missing in his original work. Moreover, as previously mentioned, researchers showed great interest in the notion of PCK, and as a result, many different interpretations of PCK appeared in the literature over the years. Shulman pointed out the need for gathering PCK researchers together to reach a consensus on PCK-related issues because of variations in PCK models (Gess-Newsome, 2015). An event called "PCK Summit" was organized to form a consensus model of PCK in science education, use the shared language in PCK research, and determine the direction of future research in PCK fields by 2012 (Carlson et al., 2015). Twenty-two researchers from the science education field, including Shulman, attended the Summit to discuss the conceptual framework of PCK, its' definition, and methods used for measuring PCK. A new PCK model named "Teacher Professional Knowledge and Skill” (TPK&S) was proposed at the Summit in light of the discussions among PCK researchers. PCK is re-defined as "both a knowledge base used in planning for and the delivery of topic-specific instruction in a very specific classroom context, and as a skill when involved in the act of teaching" (p. 30). With this definition, skills are highlighted differently from the first PCK models, and classroom practice is given more importance. According to the model (see Figure 2.11), teacher professional knowledge bases (TPKB) are placed as an overarching component. TPKB comprises assessment knowledge, pedagogical knowledge, content knowledge, knowledge of students, and curricular knowledge. Assessment knowledge is related to using formative and summative assessment methods and knowledge of using the results from assessment to make adjustments in teaching. Pedagogical knowledge involves managing the classroom, preparing for the lesson, planning, and so on. Content knowledge addresses principles, facts, and theories in a specific discipline and sufficient knowledge of science and engineering practices. Knowledge of students covers how students learn differently and how teachers modify the instruction based on the varying needs of students. Lastly, knowledge of curriculum encompasses the purpose of curriculum, the design of curriculum, and how topics are aligned and connected in the curriculum. There are two-way arrows between TPKB and topic-specific professional knowledge demonstrating that "TPKB informs and is informed by topic-specific professional knowledge (TSPK)" (Gess-Newsome, 2015, p.30). TSPK includes knowledge of instructional strategies, content representations, student understanding, science and engineering practices, and the nature of science (NoS). Gess-Newsome (2015) stated, "it sounds much like the knowledge that has been previously associated with PCK, but there is an important and critical difference. TSPK is clearly recognized as codified by experts and is available for study and use by teachers." (p33).

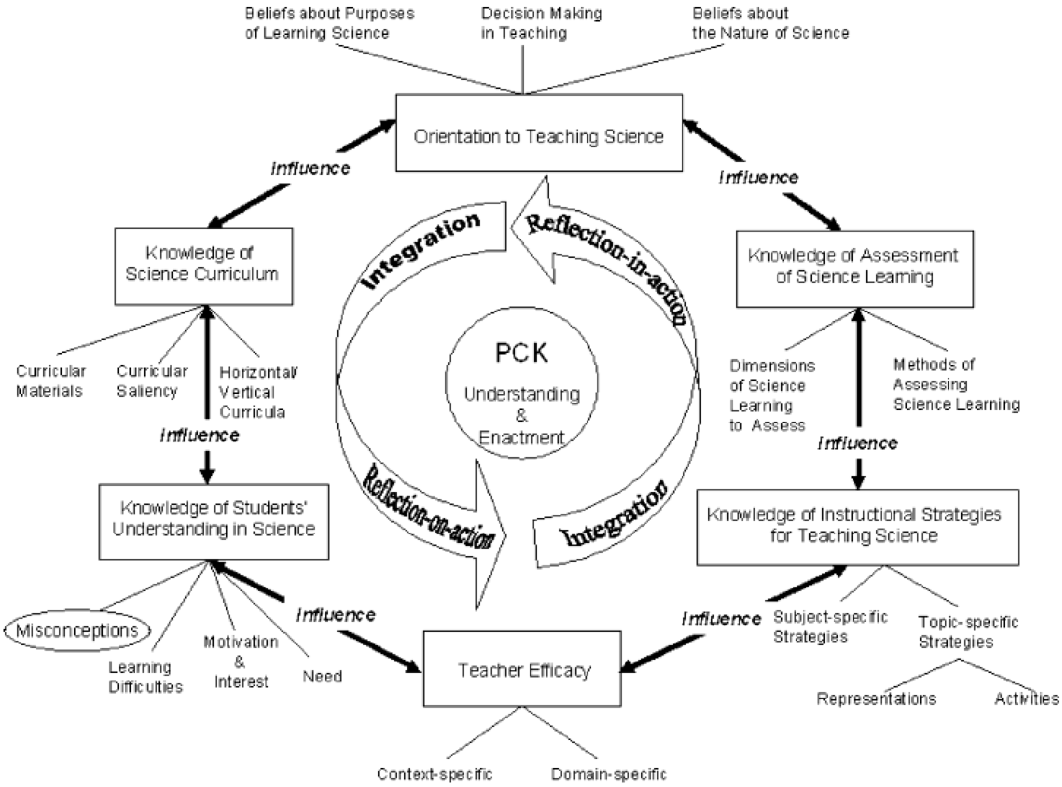


Figure 2. 10 Park and Oliver's PCK Model (2008, p. 815).

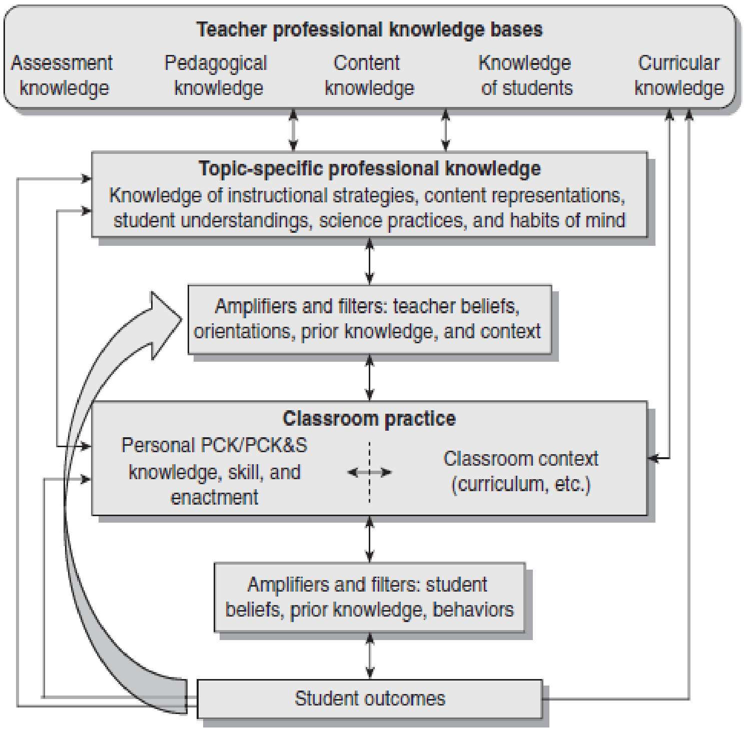


Figure 2. 11 Model of Teacher Professional Knowledge and Skill (Gess-Newsome, 2015, p.31)

There are some novel issues that the model contributed to the literature. Firstly, PCK is accepted as a knowledge base and skills. There is a differentiation between pedagogical content knowledge and skill (PCK & S). Gess-Newsome (2015) described knowledge base as "used in planning for and the delivery of topic-specific instruction in a very specific classroom context, and as a skill when involved in the act of teaching" (p.31). Therefore, it is argued that PCK should be examined in actual classroom practice. Moreover, teacher beliefs, orientations, and prior knowledge act as "amplifiers and filters." To illustrate, if the teacher has a strong belief in direct instruction, she might oppose utilizing the conceptual change approach in her teaching. It could be stated that beliefs behave as filters since the teacher learns the theoretical steps to apply the conceptual change approach, but she would not reflect her knowledge in classroom practice. Different from Grossman's (1990) and Magnusson et al.'s (1999) models in which "orientation to science teaching" is considered as an overarching component, this model subtracted it from the PCK construct based on the findings from previous studies.

Another point that Gess-Newsome (2015) emphasized is that while the teacher makes her instructional decisions in the classroom, her knowledge, beliefs, and understanding blend. According to this model, researchers reached a consensus on some definitions. Personal PCK is defined as "the knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (p.36). This definition puts emphasis on the personal and idiosyncratic perspective of PCK and underscores that PCK cannot be generalized; it is unique to each classroom environment. What the teacher planned and the rationale behind the planning process might be understood by considering this specific context. On the other hand, Personal PCK&S is described as "the act of teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (p.36). Teachers should reflect on their planning in the classroom context and consider the students' needs and unexpected events in the classroom and tailor their instruction based on these issues. Therefore, the model is considered unique since it proposes the idea of personal PCK and skills.

Abell (2007) pointed out some unanswered questions related to the connection between PCK and student learning in the existing PCK models and the TPKS model includes student outcomes obviously in the model. Chan and Hume (2019) asserted that the relationship between PCK and student outcomes in the model is theoretically accepted but not relies on empirical data. As a result, a new and powerful model of TPK&S is provided for PCK research and professional development.

Afterwards, the second PCK Summit was organized in 2016 with 24 researchers who were interested in PCK research to carry forward the collaborative work in the previous Summit. The Refined Consensus Model (RCM) of science PCK was introduced (Carlson & Daehler, 2019) at the end of the Summit. The RCM aims to make a differentiation between enacted PCK, personal PCK, and collective PCK, which are the uniqueness of the model. The model is explained as "centered around the practice of science teaching" (Carlson & Daehler, p. 82).

The RCM model of PCK is displayed in Figure 2.12 Enacted PCK (ePCK) is placed at the centre part of the model. Researchers stated that "that enactment in this model not only applies to the knowledge of and reasoning behind the act of teaching when interacting directly with students (reflection in action) but also to the acts of planning instruction and reflecting on instruction and student outcomes (reflection on action)" (p 84). The model advocates that pedagogical reasoning is specific to each teacher and each teaching segment. ePCK demonstrates the teacher's knowledge and practices to arrange the instruction to meet the student's needs in a specific science topic during planning, teaching and reflecting. ePCK become apparent in selecting instructional strategies for specific science topic, providing reasons for instructional decisions, and bringing other aspects together, such as the students' conceptions and misconceptions and how the curriculum is used to design a lesson on a particular topic. Researchers noted that ePCK is very specific to teaching segments, and one cannot refer to teachers' complete PCK based on their ePCK.

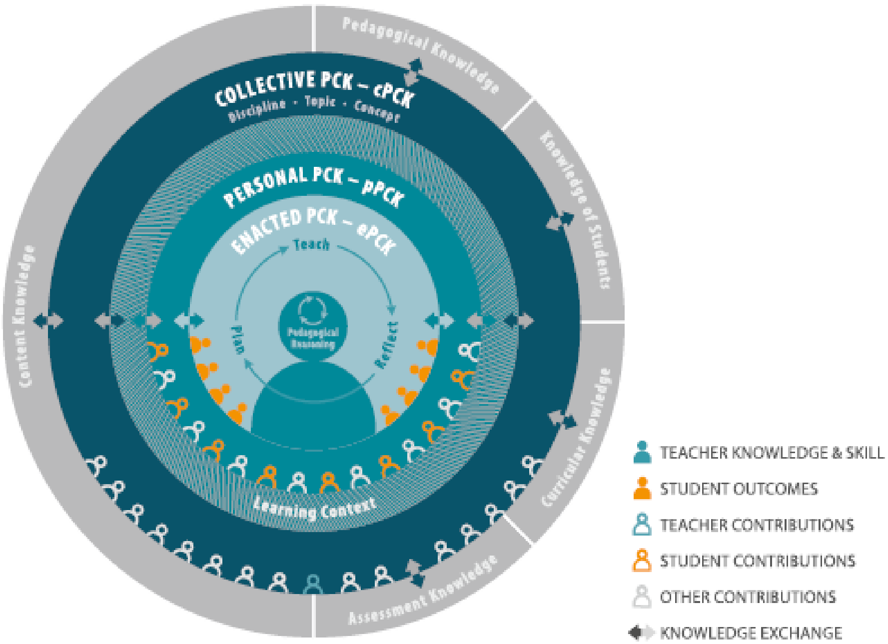


Figure 2. 12 Refined Consensus Model (RCM) (Carlson & Daehler, 2019, p. 83)

The second realm of PCK is personal PCK (pPCK) and defined as "cumulative and dynamic pedagogical content knowledge and skills of an individual teacher that reflects the teacher's self-teaching and learning experiences, along with the contributions of others" (p. 85). It is worth noting that teachers have a knowledge and skills repertoire and use the necessary knowledge from it according to the needs of the teaching environment. One cannot expect teachers to utilize all knowledge and skills that they have in one teaching moment of the lesson. Teachers draw on their previous experiences, educational background, peer advice, and students' responses and then choose the most relevant knowledge and skills from their repertoire for the particular learning context. Teachers use the knowledge from their pPCK, and it becomes ePCK in this situation when reflected in practice. In other words, pPCK encompasses ePCK. It could be inferred that pPCK is distinctive to each teacher because they have different classroom experiences and interactions. There is a continuum for PCK being private and public and it is apparent that ePCK is the most private one and pPCK is between private and public knowledge.

The last realm of PCK is called collective PCK (cPCK). It is identified as "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" (p. 88). It could be understood from the definition that cPCK does not belong to individual teachers and develops by means of empirical studies. Different from the canonical PCK (the knowledge obtained from research), cPCK also involves knowledge evolved in the group of science teachers in a school, professional development programs, and in a group of academicians, etc. Therefore, it is more public knowledge that is formed collectively and contains ePCK and pPCK as seen in Figure 2.12. To make it clear, Chan et al. (2019b) remarked on the differences between the realms of RCM as "the cPCK of a group of teachers (what a group of teachers know); the pPCK of a teacher (what a teacher knows); and ePCK (what a teacher does); and pedagogical reasoning (the reasons for his/her judgment and actions)" (p. 263). Double sided-arrows show the dynamic nature of PCK.

Another characteristic of the model is putting the learning context between pPCK and cPCK. Learning context includes factors such as classroom environment (student-teacher interactions in the classroom, materials used in lessons etc.) and students' characteristics (age, grade level, readiness etc.). Moreover, there are four professional knowledge bases in the RCM of PCK apart from PCK as follows: assessment knowledge, knowledge of students, content knowledge, pedagogical knowledge, and curriculum knowledge.

To summarize, PCK studies have a long history, and the robust discussion about its conceptualizations is still ongoing. Many models and components are rooted in Shulman's work (1987); however, two common components exist in all PCK models: knowledge of students learning and knowledge of instructional strategies (Alonzo et al., 2012). Another common point is that PCK is at the heart of teacher knowledge bases (Shulman, 1986; Baxter & Lederman, 1999; Gess-Newsome, 2015), and it is very context-specific (Carlson & Daehler, 2019; Kind, 2009). Moreover, one of the characteristics of PCK is that teachers' beliefs and orientations could act as amplifiers or filters (Gess-Newsome, 2015; Magnusson et al., 1999). PCK is considered a hidden construct, making it difficult to measure (Carpendale & Hume, 2019) because teachers might not recognize how they utilize their PCK while deciding their instructional choices (Baxter & Lederman, 1999). Among the different PCK models, the present study utilized Magnusson et al.’s (1999) PCK model and adjusted it to "PCK for STEM". The details are presented in the following section.

2.2.1. PCK for STEM

Although too much importance was given to STEM integration, how teachers and preservice teachers should be supported remains unclear (Rinke et al., 2016). Studies have started to concentrate on PCK for STEM in recent times and some new conceptualizations and components of PCK for STEM have emerged with the increased number of studies. Honey and his colleagues (2014) were among the first researchers to use the "STEM pedagogical content knowledge" notion in their study. They proposed a framework for integrated STEM education, and one of the primary purposes of the framework is to assist the development of teachers' STEM pedagogical content knowledge.

Afterwards, Saxton et al. (2014) addressed "STEM PCK" in their study. They asserted that the definition of PCK, even for one discipline, has not reached an agreement; thus, defining it for multiple disciplines is challenging. Based on the PCK models presented in the previous section, they proposed three components for STEM PCK: “(1) teachers' knowledge of student thinking about specific STEM topics, (2) teachers' use of strategies for specific STEM topics, and (3) teachers' use of technology to provide the authentic context in specific STEM topics” (p. 24).

Later, Allen et al. (2016) defined STEM PCK as "it is the knowledge to recognize and gauge their students' STEM-related conceptual development, inquiry processes and real-world connections to intentionally alter their instruction in productive ways" (p.218). They utilized STEM PCK components based on Saxton et al. (2014) conceptualization as follows: "(1) students' thinking about STEM-related topics, (2) instructional strategies for engaging students in inquiry processes, and (3) real-world STEM-related connections" (p. 218).

Different from the previous studies, An (2017) proposed "Interdisciplinary Pedagogical Content Knowledge" to integrate science and mathematics effectively based on Shulman's (1987) study (see Figure 2.13). She advocates those three main categories: pedagogical knowledge, content knowledge-A, and content knowledge-B. Teachers should have PCK for content A and content B separately, resulting in interdisciplinary pedagogical content knowledge at the end (p. 239).

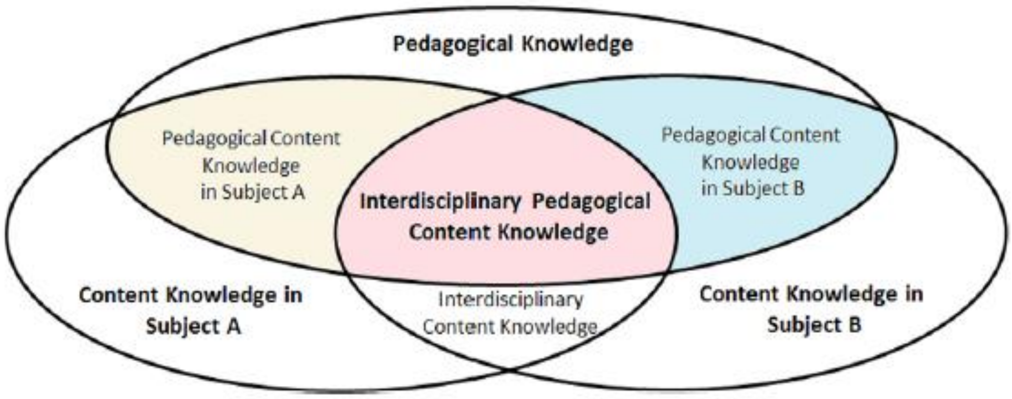


Figure 2. 13 Interdisciplinary Pedagogical Content Knowledge (An, 2017, p. 239)

Fan and Yu (2019) focused on the characteristics of teachers' PCK when teachers were subjected to implementing an engineering-focused STEM curriculum. The researchers considered engineering at the centre of STEM education. Based on the relevant literature, they proposed seven components of PCK for STEM as follows: (1) curriculum-oriented knowledge: teachers should be aware of content and context integration and have necessary knowledge regarding engineering design process, (2) knowledge of educational purposes and curricula: teachers should be knowledgeable about the purposes of out of discipline curricula, (3) content knowledge: have adequate knowledge in each STEM discipline, (4) knowledge of teaching strategies: have adequate knowledge in terms of various student-centered, constructivist strategies, (5) knowledge of educational context: creating authentic and motivating learning environments to explore concepts, (6) knowledge of learners: have the necessary knowledge about students' engineering knowledge to use the engineering design process, and (7) knowledge of learning assessment: use the variety of formative assessment instruments to assess the process and product (p. 108).

In another study by Chan et al. (2019a), PCK for STEM framework was developed based on Allen et al. (2016) and Magnusson et al.'s (1999) models. The researchers preferred to use the "Practical Knowledge for STEM" notion instead of PCK for STEM. They adopted four components: students (difficulties, misconceptions, prerequisite knowledge, and affective characteristics), assessment (what to assess and how to assess), curriculum (objective, program, and curricular saliency), and pedagogy (instructional strategies and representations) as given in Figure 2.14 (p.45) They discussed that the boundaries between these four components of the model are not evident in practice and teachers' beliefs play a key role using their PCK in a classroom context.

As seen above, studies in the literature utilized different terms to combine STEM education and pedagogical content knowledge. Additionally, although they draw upon the similar PCK models available in the literature, their conceptualization and definitions of PCK for STEM might vary. On the other hand, different from the earlier conceptualizations mentioned above, some researchers utilized existing PCK frameworks in their study. For instance, Srikoom et al. (2018) grounded their studies in Magnusson et al. (1999), Grossman (1990), and Saxton et al. (2014) PCK models and modified and named it "PCK for STEM". They involved five components as in the original model: “(1) orientations toward teaching STEM, (2) knowledge of STEM curriculum, (3) knowledge of students' understanding of STEM, (4) knowledge of instructional strategies and representations in STEM and (5) knowledge of assessment in STEM learning” (p.315). They re-defined each component by considering the features of STEM education. For instance, the knowledge of learners component refers to the "teachers' knowledge and belief about students' prerequisite knowledge for learning a STEM lesson and areas of student difficulty refers to teachers' knowledge of the STEM concepts or topics that students find difficult to learn including students' misconceptions" in their study (p. 315).

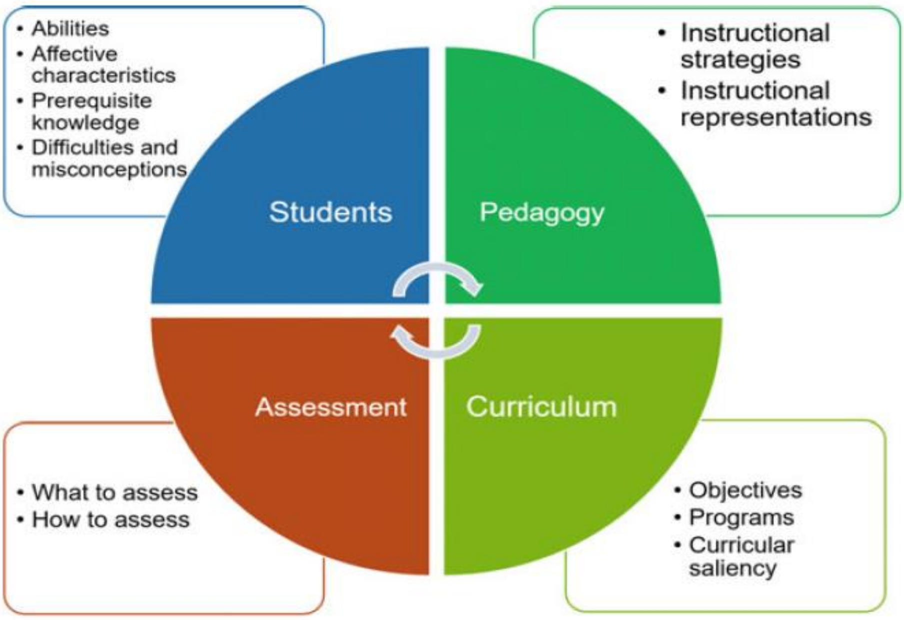


Figure 2. 14 Teachers' Practical Knowledge for STEM (Chan et al., 2019, p. 45)

Similarly, Aydin-Gunbatar et al. (2020) used an existing framework (Magnusson et al., 1999). They employed four components except for orientation to teaching science component (learner, curriculum, instructional strategy, and assessment) in their studies to study PCK for STEM. They defined each component by examining the PCK and STEM education literature. To illustrate, they described knowledge of learner component as "knowledge about possible difficulties learners may face during the design of a product or the use of a scientific concept for the design, and alternative concepts that may hinder their learning and/or design of a product" (p. 1065). It could be inferred that although researchers employed the same existing PCK framework, they interpreted components of PCK for STEM differently. How PCK for STEM is conceptualized in the present study is provided below.

2.2.2. Conceptualization of PCK Framework for the Present Study

PCK framework was used in different contexts in various studies: PCK for SSI Teaching (Bayram-Jacobs et al., 2019), PCK for Nature of Science (Hanuscin et al., 2011), PCK for Argumentation (McNeill et al., 2016), PCK for Engineering Design Process (Hynes, 2012) and PCK for Researching and Designing (Vossen et al., 2019). These studies follow different approaches regarding the nature of PCK. When the literature is examined regarding the nature of PCK for STEM, one unanswered question can be encountered: In which category should PCK for STEM be placed? PCK literature shows different types of PCK: general, discipline-specific, and topic-specific (Vossen et al., 2019). In his book chapter, Shulman (2015) pointed out some difficulties related to the description of domain-specificity. He asked, "What counts as a domain? Is it a discipline, specific topics or problems within a traditional discipline, a broad hybrid space encompassing several disciplines, a field of practice, or policy? It's different in different settings, in different kinds of schools and cultures and what functions as a domain will depend on the interaction of all those factors" (p. 8). In their study, Vossen et al. (2019) advocated that PCK for STEM is domain-specific rather than subject-specific or topic-specific. In this study, we approached the issue by taking Shulman's (2015) and Vossen et al.'s (2019) broader perspective that advocates that PCK is domain-specific and considers STEM a domain. Because PCK is generally reported as topic-specific, such as PCK of behavior of gases (Adadan & Oner, 2014), but STEM education consists of integrating different disciplines. Therefore, the content of PCK for STEM in the current case is science, technology, engineering, and mathematics, which is the reason for using PCK in a broader perspective.

Magnusson et al.'s (1999) PCK model serves as a theoretical framework for the present study. It is the most prevalent model preferred in studies in the science education field (Henze & Barendsen, 2019). This model is transformative in nature, and as a researcher, I think that PCK is a separate knowledge base among teacher knowledge. Magnusson et al.'s (1999) PCK model is adapted for PCK for STEM as displayed in Table 2.1. The model is a guideline for me to design the data collection instruments and analyze the obtained data. There are five PCK components in Magnusson et al.'s (1999) original PCK model, and science teaching orientations were not included in the present study. Literature was checked to see how other researchers deal with the science teaching orientation component. Friedrichsen et al. (2011) reported some problems in describing the orientations component and highlighted that these problems were reflected in measuring this component. Moreover, Henze and Barendsen (2019) indicated that "we consider orientations to be less content-specific than the other components, and Magnusson et al. themselves present orientations as an underlying influence on the components knowledge of curriculum and knowledge of assessment" (p. 205). Some PCK studies also removed the orientation component from Magnusson et al.'s (1999) framework (Aydin-Gunbatar et al., 2020; Juhler, 2016). Moreover, orientations to the teaching science component was considered amplifiers and filters in the recent PCK models (Gess-Newsome, 2015; Carlson & Daehler, 2019). Therefore, I did not include the orientation to the teaching component in the present study. The descriptions of PCK for STEM components, namely, knowledge of curriculum, knowledge of learners, knowledge of instructional strategy, and knowledge of assessment, are provided in Table 2.1.

2.2.3. Research on PCK for STEM

Few studies focus on preservice science teachers' development of PCK for STEM. Relevant studies found in the literature are presented below.

Benuzzi (2015) studied with preservice elementary teachers in her dissertation and investigated the effectiveness of a two-semester-long STEM professional development program. The researcher's main goal was to improve participants' PCK and confidence while integrating STEM education into their teaching. The researcher attempted to join the PCK model and adult learning theory and used this combination as a conceptual framework in her study. Which PCK model used in the study was not provided. Participants of the study were ten preservice teachers, five master's teachers, and one university supervisor who participated in "Raising the Bar for STEM Education" in the California program. The program was enriched with STEM content and pedagogy. The format of the program was based on a co-teaching model; two preservice elementary teachers and a master teacher formed a study group and discussed, gave feedback to each other, and prepared lesson plans. Data were collected through interviews, observation, documents (lesson plans based on the 5E learning cycle, peer coaching forms, journals, and reflections), a STEBI (Science Teaching Efficacy Beliefs Instrument) and MTEBI (The Mathematics Teaching Efficacy Beliefs Instrument) was implemented as pre and posttest. The observation was made by means of the video-recorded lesson, and participants were asked to reflect on their instruction and classroom management. The main findings of the study suggested that the STEM-enriched professional development program helped improve participants' confidence and pedagogical knowledge. The researcher mentioned that the integration of STEM disciplines remained limited, the connection between STEM disciplines was not coherent, and the development of understanding in each STEM discipline was uneven after the study. It was concluded that STEM professional development programs should target to development of PCK for STEM of preservice teachers, engineering should be the central part of the integration, and adult learning theory should be employed in future studies.

On the other hand, Hynes (2012) studied with six middle school teachers to examine their subject matter knowledge (SMK) and PCK when integrating the engineering design process. The PCK components used in the study were not presented. Participants were not subjected to engineering education in their undergraduate education. They participated in a 15-hours workshop that focused on learning how to teach engineering concepts before the implementation. Eight-step EDP by Massachusetts (2006) was utilized in the study. Teachers were required to complete three engineering design lessons and a final project during the study. Follow-up interviews were used for data collection at the end of the study. Results suggested that teachers’ understanding of the engineering design process showed variances at the end of the intervention. The most developed parts of the participants' knowledge were related to constructing a prototype and redesigning parts of the engineering design process. Most of the teachers were able to understand the idea of a prototype and the reasons for testing it. Moreover, participating teachers started to support their instruction with relevant examples and analogies to teach the engineering design process. The researcher concluded that participants’ PCK for the engineering design process was developed to some extent due to intervention.

Table 2. 1

Components of PCK for STEM Conceptualized in the Present Study

Components of PCK for STEM	**Explanations**
Curriculum	Teachers’ knowledge about setting objectives in STEM lessons (objectives for science curriculum and other STEM disciplines) (e.g., writing goals for science content and engineering design process) and relating the science objectives with other STEM disciplines.
Learners	Teachers' knowledge about possible difficulties and misconceptions that learners might experience while designing a product and using science and mathematics concepts
Instructional strategy	Teachers’ knowledge about appropriate strategies used in STEM education (e.g., 5E learning cycle, problem-based learning), implementing design-centered teaching practices, and using representations and activities in STEM lessons.
Assessment	Teachers’ knowledge about which part of student learning should be worth to be assessed in STEM lessons (e.g., science content, engineering process, and product, 21st-century skills etc.) and knowledge about choosing the appropriate assessment method (portfolio, rubric, peer evaluation, multiple choice, poster presentation etc.)

Lau and Multani (2018) explored STEM teachers' development for PCK for STEM in the context of museum-based field experience. Novice science and mathematics teachers who enrolled in The Mathematics and Science Teacher Education Residency (MASTER) program were the participants of the study. The Design Lab field at the New York Hall of Science experience was planned as a part of a master's program and intended to foster participants' use of the engineering design process. No particular PCK framework was used in the study. Experiencing and reflection strategies were used to assist participants' PCK development. The field experience mainly includes three parts: design challenge activities, reflection activities, and instructional design process. The data-driven noticing protocol was the primary data collection source utilized in the study. The findings indicated the importance of scaffolding and studying with mentors to integrate engineering into lessons. Additionally, researchers found that reflection activities were essential for developing science and mathematics teachers' PCK for STEM, especially when teachers had to teach out-of-discipline content. The researchers suggested that future studies might utilize design studies in different contexts, such as summer professional development programs or museums, to improve teachers' PCK for STEM.

Srikoom et al. (2018) were the researchers who conceptualized Magnusson et al.'s (1999) PCK model for STEM in their study. They modified and redefined the PCK components by considering the features of STEM education. The study aimed to examine how teachers understand STEM education and how they implement it in real classrooms in the Thailand context. Five components of PCK for STEM were utilized. The study was designed as a case study. The workshop, which lasted three days, was organized to increase participating teachers' PCK for STEM. Among the teachers who participated in the workshop, six teachers were chosen as participants in the study. The teachers' backgrounds differed; three were science education graduates, while others graduated from the curriculum, education management, and animal science. Several data sources were utilized as follows: a survey, STEM lesson plans, observation of instruction, student artefacts, interviews, teachers' reflections, and recordings of group meetings. The main findings suggested that participants had difficulty in integrating engineering discipline, and particular training was needed to support teachers. Many of the participants did not implement the engineering design process properly. Similarly, integrating mathematics was sometimes challenging for participants. They had difficulty in determining relevant mathematics objectives about the content of the STEM lesson. Participants' PCK for STEM progressed, especially regarding students' understanding and assessment components. Teachers with strong knowledge of instructional strategies applied inquiry-based strategies, and teachers with solid knowledge of learners regarding STEM topics benefited from multiple ways to engage students with STEM lessons. Moreover, findings also showed that teachers need to create authentic learning context, understand students' need to engage them in lessons, use the engineering design process and connect the topic with other STEM disciplines for effective STEM integration. It was recommended that which factors were influential in teachers' decision-making in STEM lessons should be further investigated. In addition, researchers implied that knowledge gained in teacher education programs had a strong influence on teachers' practices in terms of STEM education, and teacher education programs and professional development programs should support preservice and in-service teachers with the necessary knowledge and skills for effective STEM integration.

Similarly, Faikhamta et al. (2020) studied in-service teachers to examine the effect of a PCK-focused professional development program on their perceptions of STEM and applying STEM activities in the Thailand context. The researchers modified Park and Oliver's PCK model (2008) and used it in their study. The action research was employed and 101 in-service teachers from biology, chemistry, physic, and general science major participated in the study. The participants were presented with STEM education and involved in STEM activities at the beginning. Then, they identified the problems while implementing STEM lessons in the classroom (i.e., use of engineering design process, students working collaboratively in the group). The participants with similar problems were grouped and asked to develop a research proposal to remedy the determined problem. Participants prepared a STEM lesson based on their proposal, developed data collection tools, and were given an example STEM lesson plan at this point. The researchers provided continuous feedback throughout the process. The participants taught these lesson plans in their classrooms and collected data from their students. Finally, they reflected on their lesson by using the data collected. The survey, observation, lesson plans, and reflective journals were the data collection instrument of the study. The findings of the study demonstrated that participants' knowledge about STEM education increased at the end of the study. They started to integrate mathematics that was missing in their plans before the study. Moreover, participants' focus was on science objectives before the study; however, they began to consider objectives related to the engineering design process, critical thinking, and collaborative skills at the end of the study. In relation to engineering, as the participants elaborated on their understanding of engineering, engineering design process, and engineers, they began to use the engineering design process more appropriately. They started to pay attention to the criteria, and limitations, researching the problem, and other steps to solve the problems instead of thinking just about creating artefacts while integrating engineering. It was recommended that collaborative work with others, teaching in an actual classroom, reflecting on the teaching with other teachers, and studying with mentors played a significant role in terms of augmenting PCK for STEM.

Unlike Faikhamta et al.'s study (2020), Aydin-Gunbatar et al. (2020) conducted a study with preservice chemistry teachers. They investigated participants' PCK for STEM development in the context of an elective STEM course offered in the undergraduate program in Turkey. Magnusson et al.'s (1999) PCK model was employed and revised as PCK for STEM. Among the PCK for STEM components, orientation to the teaching science component was excluded from the study. Researchers utilized the LESMER model, which stands for Learn, Experience, Study with Mentors and Reflection, and integrated this model into the elective course in the teacher education program. Participants were introduced to STEM education, engineering, and engineering design process and PCK framework at the beginning of the course. Then, they participated in STEM activities, studied with mentors, and examined some existing STEM lesson plans together. They reflected on every activity and prepared a STEM lesson plan with mentors. The study was planned with a qualitative design, and thirteen preservice chemistry teachers who took the elective course were included as participants. Data were collected through Content Representation (CoRe) and applied before taking the course and after completing the course. Moreover, individual interviews were implemented at the end of the semester, and weekly reflection papers were collected during the semester. Data were analyzed through inductive and deductive approaches. Three categories were formed to track participants' PCK for STEM levels at the end of the data analysis: (1) PCK-A for topic-specific PCK, (2) PCK-B for transitional PCK for STEM, and (3) PCK-C for PCK for STEM, which refers to more coherence among STEM disciplines. The results of the study showed that all participants had topic-specific PCK before taking the course, and their CoRes did not show the main characteristics of STEM education. After implementing the LESMER model in the course, all participants' PCK for STEM was enhanced; however, the degree of improvements displayed differences. Most of the participants' PCK was significantly improved, and they integrated at least two STEM disciplines in their CoRe (PCK-C); five of the participants' PCK for STEM improved moderately (PCK-B) after 13 weeks of training. For knowledge of curriculum, participants in the PCK-B category did not set objectives for the engineering design process although they integrated it into their CoRes. On the other hand, participants in the PCK-C category established objectives for at least two STEM disciplines. Regarding the knowledge of learners, some participants focused more on chemistry-related difficulties and misconceptions (PCK-B) but the majority of them provided detailed explanations for misconceptions and difficulties in more than one discipline of STEM (PCK-C). Additionally, with respect to knowledge of instructional strategies, participants in the PCK-B category utilized some characteristics of STEM education with limitations and used one strategy, such as project-based learning, in their CoRes. On the other hand, participants in the PCK-C category used authentic context, applied the features of STEM education, and used at least one extra strategy, such as, "reverse engineering" in addition to inquiry-based strategies. Lastly, some participants' focus was on chemistry content with respect to assessment (PCK-B), while the majority of them concentrated on chemistry content, students' products, and other STEM disciplines (PCK-C). The researchers concluded that participating in integrated STEM education courses and activities, studying with mentors, and reflecting were the sources that contributed to participants' PCK for STEM development.

Sarkim (2020) focused on developing teachers' PCK for STEM in the context of design-based research in the Indonesian context. The researcher proposed a PCK model based on Magnusson et al.'s (1999) study and used it as a framework for the study. He emphasized disciplinary study, educational study, and experience as contributing factors to the development of PCK in his modified model. According to the model, there are five components of PCK for STEM: knowledge and beliefs about teaching objectives, curriculum, teaching methods, students, and learning assessment. The design of the study included three main parts: preparing, experimenting, and retrospective analysis. Ten science and mathematics teachers from different schools participated in the study. The main data collection instruments were a questionnaire, focus group discussion, interview, and observation. Based on the findings of the study, it could be inferred that participating teachers' understanding of STEM education was improved. Moreover, participants were able to integrate objectives from the curriculum into STEM lessons and foster students' learning in STEM lessons at the end of the study. As a result, the researcher recommended using design research in professional development programs and more studies should be conducted using the PCK framework to translate teacher knowledge into practice in STEM lessons.

Different from the studies among PCK for STEM, Yildirim and Sahin-Topalcengiz (2019) conducted a quantitative study that aims to develop the STEM PCK Scale. They proposed a model named "STEMPCK" and constructed the items of the scale based on this model. STEM PCK model consisted of content knowledge, integration knowledge, pedagogical knowledge, 21st-century skills knowledge, and context knowledge subdimensions. Participants of the study were chosen from different departments: elementary science education, early childhood education, elementary mathematics education, and classroom teaching. Two different analyses were run in the scale development process. Exploratory factor analysis was conducted with 443 preservice teachers, and confirmatory factor analysis was carried out with 212 students. Results suggested six factors for STEM PCK Scale as follows: 21st-Century Skills, Pedagogical Knowledge, Mathematics, Science, Engineering, and Technology. It includes 56 items in total and is rated on a 5-point scale. The findings revealed that the scale was valid and reliable scale to measure preservice teachers' PCK for STEM from different branches. The researchers suggested that future studies might utilize the scale with preservice teachers from different departments (physics education, computer education etc.) and with in-service teachers.

The other study on PCK for STEM was conducted in the Turkish context (Delen et al., 2020). The researchers suggested a new framework named "design-based pedagogical content knowledge” (DPCK) to promote STEM education in science teacher education programs. DPCK framework was rooted in Honey et al. (2014) framework of integrated STEM education and offered to make connections between design challenges, crosscutting concepts, and pedagogy of design. For this purpose, the researchers tested the DPCK framework for two years and these three courses were connected to: physics, physics laboratory, and science method. For instance, the topic in physics was optics, and multiple experiments in optics were carried out in the physics laboratory. Then, creating a telescope design challenge was given to the participants in the science method course. The science method course focused on integrating science and engineering practices to solve design challenges. Thirty-two preservice science teachers were involved in the study. Participants were asked to carry out design challenges and form an integrated STEM learning environment in the method course. According to the findings of the study, DPCK is a promising framework to connect existing courses intentionally and explicitly in science teacher education programs for integrated STEM education. It was concluded that utilizing one design challenge was not enough to foster DPCK; therefore, several design challenges focusing on problems in different topics should be planned coherently while using this framework in teacher education programs.

One of the recent studies that investigated the preservice teachers' PCK for STEM development was conducted by Lertdechapat and Faikhamta (2021). They used PCK as a conceptual framework and rooted their studies in Hanuscin et al. (2018) and Srikoom et al. (2018) PCK models. In order to assist preservice teachers' PCK progress, the researchers used lesson study as a professional development program. Multiple case study design was employed, and four preservice teachers, four cooperating teachers, and three instructors participated in the study. Four lesson study groups were formed, and preservice teachers worked collaboratively with teachers and instructions from the university in these groups. The data collection instruments of the study were: field observations, post-lesson discussions, and follow-up interviews. Participants' PCK for STEM development was investigated through post-discussions. According to the results of the study, the development pattern among PCK for STEM components showed dissimilarity for the participants, i.e., six out of sixteen subcomponents did not significantly change at the end of the study. The knowledge of instructional strategies and knowledge of learners components demonstrated the most development, whereas knowledge of curriculum and assessment were the least developed components. It was concluded that lesson study is an effective method to contribute to preservice teachers' PCK for STEM; however, the researchers mentioned some difficulties, such as not implementing the re-teaching phase because of setting the common schedule. Including preservice and experienced teachers in lesson study groups was suggested at the end of the study. Among the lesson study elements, reflection on teaching and teaching experiences was found as the most effective way to improve participants' PCK for STEM. Additionally, the researchers underlined that one of the significant parts of lesson study was "learning from each other" in terms of planning and carrying out STEM lesson plans.

Huang et al. (2022) examined the effect of professional development on science, technology, and mathematics teachers' understanding of STEM education. The main parts of professional development were observation, discussion, and reflection (ODR).

82 teachers from different backgrounds participated in the study. Teachers were expected to develop STEM lessons on four science topics. Then, the lesson plans were implemented in the classroom while the group of teachers observed and then reflected on the lesson. Several instruments were used to collect data: STEM literacy questionnaire, interview, observation, and group discussions. The main results of the study suggested that participating teachers' STEM literacy was improved, and their PCK for STEM began to develop. The ODR approach was found influential in shaping participants' STEM understanding. More specifically, the observation made teachers understand the nature of STEM education and learn how to use the engineering design process. The discussion helped them share their knowledge and experiences, and the reflection part supported them in developing problem-solving skills.

Lange et al. (2022) prepared a "STEM Collaboration Project" for preservice teachers who taught at the preschool and elementary levels and examined the effect of this project on participants' self-efficacy and PCK. The main parts of the project are: "(1) collaboration, (2) authentic problems, (3) professionalization opportunities, (4) scaffolded feedback, and (5) reflection and applied projects (p. 2). This project was implemented as a part of a course requirement for a semester for three years. No particular PCK framework was mentioned in the study. A mixed-methods design was utilized, and there were 164 participants for the quantitative part of the study, while six participants were involved in the qualitative part. Data were collected through The Science Teaching Efficacy Belief Instrument (STEBI), STEM PCK Test, reflection, and focus group interview. The findings of the study revealed that participants' self-confidence in integrating STEM increased regardless of their different academic backgrounds. Similarly, participants' PCK scores improved at the end of the course. Qualitative data displayed that the collaboration, reflection, feedback, and engagement with students in microteaching sessions were influential in participants' increased PCK.

Lastly, Correia and Baptista (2022) aimed to investigate the impact of STEM-based professional development programs on the preservice primary teachers' content knowledge and PCK in terms of a sound concept. No particular PCK framework was addressed in this study. The participants of the study were 18 preservice primary teachers attending the science methods course. The participants were introduced to

STEM education, participated in STEM activities, and then developed a STEM lesson plan as a group at the end of the study. Data were gathered through lesson plans, field notes, and focus group interviews. The data were analyzed using the categories suggested by Thibaut et al. (2018). Moreover, the integration of STEM was determined as either content or context integration using Roehrig et al. (2012) descriptions. The findings related to content knowledge revealed that participants had some misconceptions about sound concept. With respect to PCK, participants rarely used design-centered teaching practices and integrated engineering design processes. Similarly, participants experienced difficulty in assessing the outcomes of STEM lessons, and only a few groups applied assessments that included rubrics. On the other hand, all groups used problem-based or inquiry-based learning and emphasized group work in their STEM lesson plans. The researchers recommended focusing on engineering practices in primary teacher education programs and the relationship between content knowledge and PCK in STEM activities.

2.2.4. Research on PCK Development of Preservice Teachers

Since the main purpose of the present study is to examine preservice science teachers' PCK for STEM development, the studies regarding PCK development of preservice teachers were examined in this section.

Nilsson (2008) aimed to explore preservice teachers' PCK development in the teacher education program. Within this context, four preservice teachers from the science and mathematics fields participated in the study and attended the "Journey of Knowledge in Physics" project that lasted one year. Participants were asked to teach six lessons on different physics topics in pairs. The data collection instruments of the study were: video-recording of teaching and stimulated recall interviews. The results of the study pointed out that the coherence between the PCK components should be strong to have a robust PCK. Moreover, reflection was a significant factor contributing to participants' PCK; participants reported that sharing their experiences and arguing over them increased their knowledge of teaching compared to individual teaching of the lesson.

Brown et al. (2013) conducted a longitudinal study to explore preservice biology teachers' PCK development in the teacher education program. They utilized

Magnusson et al.’s (1999) PCK model and used three components: orientations to teaching science, knowledge of learners, and knowledge of instructional sequence. The study employed multiple case study where each preservice teacher constituted a case. Four preservice science teachers were chosen through purposeful sampling. Data were gathered through a lesson planning-task (van der Valk & Broekman, 1999), a semi-structured interview, observation, field notes, and documents. Based on the findings of the study, participants were not aware of learners' difficulties prior to the study; however, they became aware of learners' difficulties in genetics over the course of time. Furthermore, all participants planned instruction by transmitting knowledge to the learners or reviewing the concepts at the beginning of the study. Although their knowledge of instructional strategies was improved, and they started to use alternative strategies such as the 5E learning cycle, they kept transmitting knowledge to the students to teach the concepts before implementing other alternative strategies. Moreover, the researchers concluded that experience is an essential factor contributing to the coherence between knowledge of instructional strategies and knowledge of learners. It was suggested that future studies using all components of PCK were needed to understand preservice teachers' knowledge development for teaching.

Adadan and Oner (2014) studied with preservice chemistry teachers to examine their progression in PCK representations in the "behaviour of gases" topic in the context of the Teaching Methods in Chemistry course. They utilized Magnusson et al.’s (1999) PCK as a theoretical framework to monitor participants' PCK progressions. Multiple case study was employed, and two senior preservice chemistry teachers were involved in the study. The data collection instruments of the study were CoRe and interviews. The data were coded by using a constant comparative approach. Participants' PCK progression level was identified using Schneider and Plasman's (2011) criteria, which included four levels (from 1 to 4). The results of the study demonstrated that both participants' PCK representations were limited at the beginning of the study. Some PCK components met the features of the highest criterion level, while some of them remained in level 2 and level 3 at the end of the study. In other words, the components of PCK were developed unevenly. For instance, knowledge of curriculum component showed less improvement among the other components of PCK for two cases. On the other hand, both participants' knowledge of learners reached the highest criterion level at the end of the study. They could talk about the possible origins of misconceptions, and the number of identified misconceptions was extended at the end of the study. Regarding assessment, their PCK was not robust at the beginning; however, they were able to employ different assessment methods to assess the specific science objectives at the end of the study. On the other hand, there were also some differences between participants' PCK representation progressions with respect to knowledge of instructional strategies. For example, one participant's representation was consistent with level 2 and more teacher-directed, while the other reached level 3 and used inquiry-based methods. The researchers implied that CoRe was an effective tool to support PCK development and progression criteria by Schneider and Plasman (2011) might be used in future studies that aimed to track participants' PCK development.

Another kind of study was related to examining the preservice chemistry teachers' development of interaction of PCK components conducted by Aydin et al. (2015). Three preservice chemistry teachers enrolled in a practicum course participated in the study. The participants were expected to teach chemistry concepts in cooperating schools and at the faculty of education. The practicum course was enriched with CoRe, PCK framework, and educative mentoring. CoRe and semi-structured interviews were used to collect data. Data were analyzed through content analysis and the constant comparative method. The major findings of the study demonstrated that participants' understanding of PCK components was fragmented at the beginning of the course; however, the coherence between PCK components increased to some degree at the end of the semester with the use of CoRe and educative mentoring. It was found that the development of the connection between components was specific to each participant, i.e., referring to the idiosyncratic nature of PCK. Moreover, the number of connections of knowledge of curriculum and other PCK components increased the most at the end of the study. On the other hand, the connection between the knowledge of instructional strategies and knowledge of assessment was not coherent at the end of the study. The researchers suggested the explicit use of PCK through educative mentoring and the CoRe tool in teacher education programs to improve the development of interactions between PCK components.

In the same year, Barnett and Friedrichsen (2015) investigated the effect of educative mentoring on preservice teachers' PCK development. Situated learning theory, Magnusson et al.'s (1999) PCK model, and educative mentoring frameworks were utilized in the study. The intrinsic case study approach was preferred, and one mentor teacher and one preservice teacher participated in the study. The conversations between the mentor and preservice teachers were audio-recorded for 15 hours. Moreover, observation and field notes were also applied. An open coding strategy was utilized to analyze the data. The findings of the study showed that educative mentoring positively affected the participant's knowledge of instructional strategy development. Moreover, participants' knowledge of learners concerning misconceptions was also improved. On the other hand, the findings showed that the pairs' conversations were not focused on knowledge of curriculum and knowledge of assessment throughout the study.

Juhler (2016) attempted to investigate preservice teachers' PCK development in the Norwegian context in the field practice course. The researcher grounded his study on Magnusson et al.'s (1999) PCK model by using the four components except for orientation to teaching science. Moreover, lesson study as a professional development program was used to support participants' PCK development. The study was planned as a longitudinal study, and data were collected through two years. Two lesson study groups were formed; one included four preservice teachers and a mentor, and the second group comprised three preservice teachers and a mentor. One group was used as a control group and was not subject to the intervention. Data were collected in all phases of lesson study, planning, teaching, and reflecting. The data collection instruments of the study were: CoRe, video recordings of teaching, and teacher documents such as their presentations. Deductive and inductive methods of analysis were used to analyze the data. According to the results of the study, the intervention group was better at understanding the scope and sequence of the curriculum. Moreover, participants in the lesson study group mentioned learners' difficulties and misconceptions three times more than the control group. The researcher attributed this finding to the use of CoRe combined with lesson study in the intervention group. Additionally, the participants in the lesson study group prepared the lesson by using more learner-centered strategies. Finally, preservice teachers in the lesson study group were able to use various assessment methods and were aware of the purposes of assessment more compared to the control group. The researcher concluded that lesson study incorporated with CoRe was influential in shaping preservice teachers' PCK development and focusing on all constituting components of PCK.

Bahcivan (2017) conducted a study with preservice science teachers and examined their PCK development in the context of the Science Teaching Laboratory Applications course. The researcher integrated microteaching lesson study into the course in which a group of preservice teachers worked together, applied a lesson plan to their peers, and then reflected on it. The researcher took an integrative model perspective with respect to PCK. The study was planned as action research, and 15 participants were involved. Content analysis was used to analyze the data. The data were gathered using video-recordings of teaching segments, pre-group reports, post-individual reports, group interviews, and field notes for seven weeks. According to the results of the study, the participants' subject matter knowledge was improved at the end of the study. Moreover, participants' knowledge of learners slightly improved. The researcher attributed this situation to the deficiencies in participants' subject matter knowledge and implementation of the lesson plan to the peers, which might create an artificial environment. Participants' knowledge of representations was enhanced compared to other PCK components. Therefore, the researcher interpreted that participants' PCK developed to some extent parallel with the integrative PCK conceptualization of the study. Lastly, the presence of the researcher in the lesson study, watching video segments, and reflecting on them were the most influential factors that contributed to their development of subject matter knowledge and PCK.

One of the studies on preservice teachers' PCK development utilized the recent PCK framework, the Refined Consensus Model (RCM), in their study (Boz & Belge-Can, 2020). The researchers aimed to investigate preservice chemistry teachers' collective PCK (cPCK) development in solubility concepts and investigated the effect of micro-teaching lesson study on participants' PCK development. Three preservice chemistry teachers enrolled in the School Experience course were involved in the study. The lesson study process was integrated into this course (micro-teaching lesson study), and participants were required to prepare a shared lesson plan, teach the lesson in 30 min. to their peers, and evaluate and modify the lesson. Another preservice teacher carried out the modified version of the lesson plan in the lesson study group. The process was repeated, and the third version of the lesson plan was taught by the last preservice chemistry teachers in the lesson study group. Data were collected through lesson plans, semi-structured interviews, observation, and field notes. The lesson plan format was prepared by using CoRe. According to the findings of the study, the participants’ cPCK did not improve regarding learners' difficulties but developed in terms of learners' misconceptions. Furthermore, participants' cPCK regarding knowledge of curriculum was found to be advanced at the end of the micro-teaching lesson study. As they revised the lesson plan, participants wrote new objectives. Another component, knowledge of instructional strategies, was improved at the end of the micro-teaching lesson study. In the first version of the lesson plan, participants used a conceptual change strategy but revised the lesson using the 5E learning cycle in the third version. Participants indicated that they had limited knowledge regarding the strategy, hence they did not prefer to use it at the beginning of the study. Lastly, participants' cPCK did not slightly improve in terms of how to assess component. However, the time of using assessment showed development. Additionally, the researchers found that the reflection part of the lesson study contributed more to preservice chemistry teachers' improvement in their knowledge of learners and knowledge of instructional strategies. The study suggested using microteaching lesson studies in teacher education programs to strengthen preservice teachers' PCK.

One of the recent studies on PCK development was conducted by Ekiz-Kiran et al. (2021). The purpose of their study was to explore preservice chemistry teachers' PCK development in the context of the School Experience course. The content of the School Experience was subjected to modification for the study. The researchers used CoRe as a lesson planning tool and observation form prepared by considering the PCK components of the Magnusson et al.'s (1999) model in the context of this course. The study was planned as action research. The participants of the study were four preservice chemistry teachers in their final year of undergraduate education. They were asked to prepare CoRe on chemical equilibrium, taught to 11^{th} grade, and use observation form to observe their peers. Then, participants reflected on the lesson with their peers and mentors. CoRe, observation forms, field notes, reflection papers, and interviews were used to collect data. The result of the study suggested that three participants' knowledge of curriculum developed at the end of the semester, while one of them did not significantly change. Preservice teachers' understanding of the scope of the curriculum and objectives was enhanced. The researchers attributed the improvement in knowledge of curriculum to the use of CoRe and observation forms. Secondly, all participants' knowledge of learners progressed at the end of the study. They were aware of students' misconceptions and difficulties, and they benefited from their experiences and related literature to explain the possible sources of them at the end of the semester. Participants referred to the usefulness of CoRe and observation form to explain their development. Thirdly, participants' knowledge of subject-specific strategies did not show any changes at the end of the study. They preferred to use the 5E learning cycle; however, their reasons for choosing this strategy were augmented. On the other hand, their understanding of topic-specific strategies was advanced, and they started to use real-world examples, analogies, and simulation by giving content-specific details. Lastly, participants' development of knowledge of assessment displayed differences. For instance, three participants' understanding regarding how to assess component were improved, whereas two participants showed development in terms of how to assess sub-component. All participants mentioned that utilizing CoRe and observation forms contributed to their PCK development. The researchers suggested using these tools to assist preservice teachers' PCK development in teacher education programs.

In his dissertation, Reynolds (2020) investigated preservice teachers' PCK development in their final year of undergraduate education. The researcher employed the Refined Consensus PCK Model (Carlson & Daehler, 2019) and the Pentagon Model (Park & Oliver, 2008). The case study was employed, and six preservice teachers taking science methods course were involved in the study. The data collection instruments of the study were observation, interview, documents, surveys, and researchers' field notes. The data were analyzed using content analysis, enumerative approach, and constant-comparative method. According to the results of the study, the PCK components did not evolve simultaneously, i.e., uneven development was observed. Moreover, the most frequent connection was found between the knowledge of instructional strategies and the knowledge of learners at the end of the study. Participants' knowledge of learners was developed with the teaching experience. On the other hand, the connections between knowledge of assessment and other components of PCK were limited. The researcher suggested using CoRe with the PCK map approach in future studies.

In a more recent study, Belge-Can and Boz (2022) studied preservice chemistry teachers and examined their PCK development throughout two years in the effect of temperature on reaction rate topic in the teacher education program. The study was rooted in Magnusson et al.'s (1999) PCK model, and five components were considered. The case study was employed, and two participants were involved in the study. The vignette and semi-structured interviews were utilized as data collection instruments. The vignette about a problematic classroom situation was given to the participants, and then they were asked some PCK-related questions, such as whether the teacher of the lesson followed the objectives in the curriculum etc. There were four different time zones to collect data: (1) participants did not take any PCK course, (2) after they took curriculum development, science teaching method courses, (3) after they took school experience, measurement and evaluation, material development courses and (4) after practice teaching course. Deductive analysis was used while analyzing the data. Based on the findings of the study, PCK development showed differences with respect to the PCK components. In other words, improvement in one component did not result in improvement in overall PCK. When the PCK components were considered, participants' knowledge of curriculum was expanded at the end of the study. They were able to write and evaluate objectives in the curriculum. On the other hand, the relation of the topic to the other science topics showed different development patterns for participants, referring idiosyncratic nature of knowledge of curriculum. Secondly, both participants' knowledge of learners progressed and showed similar patterns concerning difficulties, and time 3 was the turning point related to the knowledge of learners. Regarding misconceptions, although both participants showed improvement, their levels of development differed. The situation was similar to the knowledge of assessment, where one participant demonstrated more improvement. Lastly, the development of knowledge of instructional strategies showed similar development patterns for the participants. The researchers concluded that lesson planning, using CoRe, observing peers, microteaching, teaching in an actual classroom, and feedback from the instructors were influential in enhancing PCK.

Subramaniam (2022) studied with 22 preservice teachers to track their PCK development in an elementary science methods course for 15 weeks. Magnusson et al.'s (1999) PCK model was used as a theoretical framework for the study, and participants' PCK development in five components was investigated. The participants enrolled in the methods course were expected to prepare a lesson plan on a physical science topic, teach it in microteaching sessions, and reflect on it. A narrative approach was employed in this study. The data were collected through narratives, field notes, and video recordings, and deductive analysis was utilized. The results suggested that orientation to the teaching science component influenced the development of other PCK components. The development of knowledge of curriculum was not presented in the study because objectives were given to the students by the course instructors. Regarding the knowledge of learners, participants started to consider additional strategies to engage students in the lesson. Similarly, participants started to pay attention to alternative assessment strategies to engage students more at the end of the course. Lastly, participants utilized more student-centered teaching strategies after participating in the study. It was concluded that methods course, lesson planning, microteaching, and reflecting were the significant sources that contributed to participants' PCK development.

In summary, the literature review on preservice science teachers' development of PCK indicated that the studies were generally conducted in the context of science methods courses or field experiences courses where preservice teachers were required to teach a lesson in cooperating schools or at the faculty of education. Moreover, the majority of the studies were qualitative in nature. Capturing the development in preservice teachers' PCK took time; therefore, longitudinal studies were observed while reviewing the literature. Additionally, Magnusson et al.’s (1999) PCK model was highly utilized in these studies, and CoRe, interviews, and observations were used frequently to articulate preservice teachers' PCK.

2.3. Lesson Study

Designing effective professional development programs is a complicated issue because the researchers need to consider the variety of interacting components (Hewson, 2007). The programs in which teachers have the passive role and the researchers have the active role was found to be ineffective (Luft & Hewson, 2014). Moreover, the literature underlines the need for enhancing programs that increase teachers' practical skills (McCann et al., 2012). Desimone (2009) developed a theoretical framework consisting of five elements for effective professional development. These elements are: “(1) collective participation, (2) active learning, (3) coherence with policies implemented in schools, (4) duration of professional development, and (5) improving subject matter knowledge” (p.183-184). Firstly, it is pointed out that if a group of teachers in the school participates professional development program together, their practices are changed and sustained more. Secondly, the "sit and get" type of professional development program is not effective in changing the practices of teachers (Hunzicker, 2011, p. 177). What is planned on the paper might not work in the actual classroom environment, and teachers need ongoing support during this process. It is also recommended that teachers should practice the new activities with their colleagues in the context of the professional development program. Additionally, support for teachers should be continuous throughout an academic year, and it is also explained that if teachers need help during this process, the professional development program could be able to provide opportunities for instant support (Desimone, 2009). Johnson et al. (2016) stressed abovementioned elements are also essential for effective STEM professional development programs since teachers confront the new type of PCK in integrating STEM into their lessons. Accordingly, the lesson study meets the elements of an effective professional development program and is integrated into the teacher education program in the present study. Detailed information regarding the lesson study and its' use in teacher education programs are presented in the following sections.

2.3.1. The Elements of Lesson Study

Lesson study is one type of professional development approach, and it is defined as "a systematic investigation of classroom pedagogy conducted collectively by a group of teachers rather than by individuals, with the aim of improving the quality of teaching and learning" (Tsui & Law, 2007, p. 1294). The origin of lesson study emerged in Japan (Lewis, 2002), and it is the major and the most common way of the professional development program in Japan (Dudley, 2015; Fernandez & Yoshida, 2004).

The lesson study does not aim to design a perfect lesson; instead, it seeks practical ways to maximize students' learning (Leavy & Hourigan, 2016). What makes lesson study different from other professional development programs is explained by Lewis (2002). He discussed that there is a hierarchal relationship passing from trainer to teacher in the traditional form of professional development. In contrast, reciprocal relationships become prominent, and the communication shared among teachers is crucial in lesson study. The main characteristics of lesson study are described as follows:

> Teachers organically come together with a shared question regarding their pupils' learning, plan a lesson to make pupil learning visible, and examine and discuss what they observe. Through multiple iterations of the process, teachers have many opportunities to discuss pupil learning and how their teaching affects it" (Murata, 2011, p. 2).

The main emphasis is on student learning in lesson study, and observation of student learning enables teachers to improve their own knowledge (Bjuland & Mosvold, 2015; Dudley, 2013; Lewis, 2002). Furthermore, teachers attempt to investigate why and how the collaboratively designed lesson plan enhances students' understanding (Wang-Iverson & Yoshida, 2005). As Lewis (2002) indicated, "teachers see instruction through the eyes of the students" in lesson study (p.21). The main elements of the lesson study used in the present study are provided in Figure 2.15.

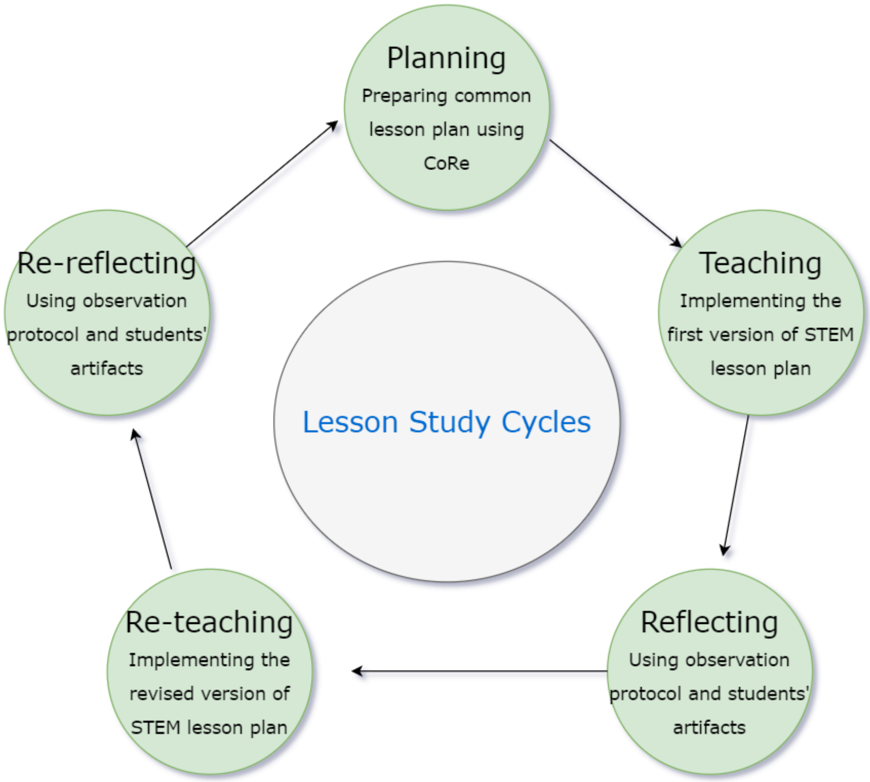


Figure 2. 15 The Main Elements of Lesson Study Cycles used in this Study

Lesson study has an iterative process with three compulsory main steps: planning, implementing and reflecting (Dudley, 2015; Lewis et al., 2009). In the planning phase, four to six teachers in the lesson study group generally come together to determine the goals of the lesson. They start to plan collaboratively lesson plans, which is named "research lesson". Teachers in the lesson study group share their ideas and suggestions in the planning meetings. Several meetings are held during this process. Teachers consider students' difficulties and misconceptions and discuss extensively how to engage students in the research lesson during the planning phase (Takahashi & Yoshida, 2004). For instance, the goal might be related to the teaching topic that students experience difficulty with or implementing a new approach in the curriculum (Bridges, 2015). In our case, we preferred to lesson study because STEM education is recently integrated into the science curriculum (MoNE, 2018a). Planning meetings also discuss how to collect data and determine the curriculum materials required for the lesson. Coenders and Verhoef (2019) reported that teachers learn a lot of alternative ideas from their colleagues in these planning meetings.

In the current study, minor differences have been made in the planning phase. Firstly, the planning phase is enriched with Content Representation (CoRe) different from the original lesson study cycle. The CoRe is used as a lesson planning tool; details are provided in the data collection instruments section (see section 3.4.2). Furthermore, the term "research lesson" was replaced with "the first version of STEM lesson plan" in the teaching part and "the revised version of STEM lesson plan" in the re-teaching part of the present study.

The second central part of the lesson study is teaching. One of the teachers from the team carries out the commonly prepared lesson plan while other members with appropriate time schedules observe the lesson and collect data. The observations are centered on teaching and student learning, not on the *teacher* in this process (Coenders & Verhoef, 2019; Dudley, 2015). It is common to videotape the lesson, write field notes, collecting students' artefacts and products to provide evidence for the areas that need modification in the research lesson. The other team members are not included in the flow of the lesson; however, they are expected to be present in the classroom and observe the instruction. Since the present study was conducted with preservice teachers, the teaching phase was applied in cooperating school, and all participants attended the observation of the lesson.

The third main part of the lesson study is reflecting on the lesson. The lesson study group meets again right after the research lesson in the third phase. The implemented research lesson is evaluated in this phase by considering the whole data and experiences of teachers. Generally, the teacher of the lesson starts to share his/her experiences, and then other group members contribute. They discuss how to revise lessons to foster students' learning. What has worked during the lesson and what could be done for a better lesson are determined in this phase. Based on these discussions, teachers could make changes in the instructional methods, assessment, and so on to achieve lesson goals (Lewis et al., 2009; Xu & Pedder, 2015).

Re-teaching the revised research lesson is an optional phase but recommended by the researchers (Lewis et al., 2009; Dudley, 2015). If it is decided to apply re-teaching, the revised lesson plan is taught by a different teacher in the lesson study group in a different classroom. The other phases are the same as the process mentioned above. The re-teaching phase was utilized in the present study, as shown in Figure 2.15.

Reflecting on re-teaching is also another optional phase of lesson study (Fernandez & Yoshida, 2004). Teachers meet again right after implementing the revised lesson plan and reflect upon whether modifications of the lesson plan have worked and provided further suggestions to revise the lesson plan similar to the previous reflecting meeting. Reflecting on re-teaching was included in the scope of the present study, as seen in Figure 2.15.

A group of teachers usually sign a "lesson study group protocol" to make the group work more effective. Moreover, there should be an understanding among teachers that "It is our lesson, not my lesson" (Lewis, 2002, p. 70). If something undesirable happens during teaching, the responsibility does not belong to the individuals because the research lesson is the group's lesson (Dudley, 2015; Sims & Walsh, 2009). Moreover, it is recommended to include outside researchers to make a contribution to the process in terms of shaping the research lesson, observing and collecting data, commenting on the lesson, etc. (Lewis, 2002; Lewis et al., 2006).

The underlying reason for employing a lesson study is not about designing a "perfect lesson" (Lewis, 2002). The lesson study is more than preparing a joint lesson plan or workshop (Fujii, 2014). The lesson study creates "data-driven" and "research-based" lesson plans (Lewis, 2002, p.8). Moreover, attending lesson study groups deepens teachers' knowledge in terms of student learning, the subject matter being studied, and instructional strategies (Juhler, 2016; Lewis, 2002; Lewis et al., 2009; Murata et al., 2012). Moreover, it contributes to the interpersonal relationship among teachers in the same school, resulting in improved instruction (Lewis et al., 2009). Finally, many studies in the literature suggest that lesson study is an effective type of professional development program that develops teachers' and preservice teachers’ PCK in science education (Grove, 2011; Juhler, 2016; Lucenario et al., 2016; Tan, 2014).

Although its' benefits are mentioned above, some challenges of using lesson study are reported in the literature. Completing a lesson study takes time; therefore, teachers might not show interest in participating in the lesson study process because of a lack of time (Caskey & Lenski, 2010; Chassels & Melville, 2009). Moreover, arranging a common schedule for teachers might be challenging (Fernandez, 2002). Planning, teaching, observing, and reflection phases require working in collaboration; however, teachers have their own classes, and especially arranging a time for observation of the teaching phase would be difficult. The other constraint might be related to teachers’ concerns about “being observed by a peer” since they are not familiar work collaboratively (Fernandez, 2002; Stigler & Hiebert, 1999).

2.3.2. Lesson Study in Teacher Education Programs

Research using lesson study generally focuses on in-service teachers (Bravo & Cofré, 2016; Elkomy & Elkhaial, 2022; Lee & Tan, 2020; Wang et al., 2019). On the other hand, lesson study has the potential to provide effective ways for learning when integrated into teacher education programs (Bjuland & Mosvold, 2015; Leavy & Hourigan, 2016; Sims & Walsh, 2009), especially for establishing a connection between methods courses and field experiences (Cajkler et al., 2013). When the relevant literature is examined, it could be said that lesson study is integrated into different ways in teacher education programs. Some examples of the adaptation of lesson study in teacher education programs are provided below.

The first research line unites characteristics of microteaching and lesson study, which is called "microteaching lesson study" (Fernandez, 2010). The main difference between lesson study and microteaching lesson study could be explained as microteaching lesson study requires the implementation of a research lesson to a small group of peers instead of implementing it with middle or high school students in a real classroom environment. The amount of time is restricted to approximately 30 minutes in microteaching lesson studies. The video-recoding of the research lesson is recommended to make the reflecting phase easier. The inclusion of instructors as a mentor in this process is helpful for the criticism of the research lesson (Fernandez et al., 2003). For instance, Fernandez (2010) studied with preservice mathematics teachers in a teacher education program and pointed out the importance of learning through extensive discussions, planning, teaching, and re-teaching, revising and studying with a mentor were the crucial sources that influenced preservice teachers' knowledge for teaching in micro-teaching lesson study. Similar to Fernandez's study, Carrier (2011) used microteaching lesson study in a science teaching methods course; however, the researcher used the term "lesson study" instead of microteaching. The preservice teachers were expected to collaboratively prepare a lesson by using the particular lesson plan format and teaching it to their peers. The teaching process was video-recorded, and the researcher posted the recordings in an online environment where preservice teachers had a chance to access them. They debriefed on their teaching process through video recordings and created their reflection reports as a part of the course requirement. The preservice teachers valued the importance of collaborative working, team teaching, and constructive feedback among peers after completing the micro-teaching lesson study. Many studies in the literature utilized microteaching lesson studies with preservice teachers (Bahcivan, 2017; Boz & Belge-Can, 2020; Karlström & Hamza, 2019; Matthew, 2018).

Another line of research integrated lesson study into the methods courses or field experience courses in teacher education programs and implemented research lessons in an actual classroom setting. For instance, Marble (2007) divided preservice teachers into a group of three and asked them to plan, teach and revise three lesson plans in the context of the methods course. The preservice teachers are provided with opportunities to implement their integrated science and mathematics lesson plans in elementary schools. The researcher concluded that planning and creating lesson plans in lesson study contributed to participants' understanding of relating the content to the standards, engaged them with students, and increased the quality of assessment. Similarly, Belge-Can (2019) infused lesson study into teaching practice courses. Preservice teachers prepared a lesson plan on heat and temperature, taught it in 8th-grade, and revised it. Differently, the second and third versions of research lessons were prepared after the revisions in this study. The researcher suggested integrating lesson study combined with CoRe in teacher education programs to enhance participants' PCK at the end of the study. Chassels and Melville (2009) were the other researchers that utilized lesson study in the practicum course. Firstly, they formed lesson study groups and these groups learned about lesson study through informative readings. The groups planned a lesson in a team and implemented it in cooperating school. The other group members observed and reflected on the lesson. The re-teaching and re-reflection elements of the lesson were applied in this study. Although the preservice teachers reported the benefits of lesson study, such as developing an understanding of the curriculum, teaching strategies, and learners' needs, some constraints were also mentioned while using lesson study in teacher education programs. The major issues were the amount of required time to complete one cycle, the difficulty in arranging a time for implementation, and the lack of experience of teachers in lesson study in cooperating schools. Akerson et al. (2017) also combined lesson study and field experience-science methods courses to track preservice teachers' PCK for Nature of Science (NOS) development. She preferred to utilize lesson study because preservice teachers were experiencing difficulty in understanding and implementing NOS into their instruction. In the implementation process, preservice teachers came together, examined the standards, and created their research lessons with the help of the course instructor. Then, one preservice taught the lesson during the field experience course while the others observed. The preservice teachers debriefed on the lesson and modified it. Because of not arranging an appropriate time schedule, the researcher did not use the re-teaching and re-reflecting phases in her study. The researcher pointed out that lesson study helped promote their PCK for NOS development, and providing feedback had the most influential element in this process at the end of the field experience course. As seen from the studies mentioned above, some differences are observed in the implementation of lesson study in teacher education programs.

The studies regarding lesson study in teacher education programs indicate that lesson study has a positive effect on preservice teachers’ subject matter knowledge (Bahcivan, 2017; Leavy, 2010), self-efficacy levels (Mitchell, 2014), pedagogy (Cajkler et al., 2013; Chassell & Melville, 2009) and PCK development (Akerson et al., 2017; Boz & Belge-Can, 2020; Dudley, 2015; Juhler, 2016; Leavy & Hourigan, 2016; Lertdechapat & Faikhamta, 2021). Lesson study provides reflective practices among peers in a group. Preservice teachers are provided with the opportunity to experience and observe research lessons in the actual classroom environment and receive feedback from their peers and instructors in lesson study groups. They meet regularly to reflect on the lessons which later improve their PCK. In this sense, lesson study was integrated into the "Teaching Practice in Science" course to assist preservice science teachers' PCK for STEM development in the present study.

CHAPTER 3

METHODOLOGY

The present study mainly concentrated on how preservice science teachers' PCK for STEM developed in the context of lesson study. Moreover, how the elements of the lesson study had an influence on participants' PCK for STEM development was also investigated. In this chapter, firstly, the research design was provided. Then, in parallel with the research design, sampling, procedure of research, data collection instruments, data analysis, the trustworthiness of the study, ethical considerations, and limitations were explained in detail.

3.1. Research Design

Researchers might desire to investigate issues with a more holistic understanding by asking "how" questions rather than examining "to what extent" questions (Fraenkel et al., 2012). At this point, qualitative researchers are interested in collecting data in a natural context and how the phenomena are understood by people (Denzin & Lincoln, 2011). Since the primary purpose of the present study is to learn about how preservice science teachers' PCK for STEM developed in the context of lesson study, the qualitative research design was employed. Creswell (2013) defined qualitative study as follows:

> Qualitative researchers use an emerging qualitative approach to inquiry, the collection of data in a natural setting sensitive to the people and places under study, and data analysis that is both inductive and deductive and establishes patterns or themes. The final written report or presentation includes the voices of participants, the reflexivity of the researcher, and a complex description and interpretation of the problem (p. 44).

Qualitative researchers identified varying types of approaches to qualitative design. For instance, Merriam (2009) recommended six types: basic qualitative research, phenomenology, ethnography, narrative analysis, critical qualitative research, and case study, while Creswell (2013) suggested five as follows: narrative research, ethnography, phenomenology, grounded theory, and case study. It is obvious that there are overlapping points with regard to approaches of qualitative designs. Bogdan and Biklen (1998) underlined five common characteristics of qualitative research; (1) the researcher is the main instrument, and the natural setting is the direct source of data, (2) qualitative design is interested in words rather than numbers, (3) in addition to product, the process is and how things occur are essential, (4) researchers are concerned with inductive analysis instead of formulating and testing hypothesis and (5) how participants perceive their experiences are an essential part of qualitative designs. In addition to these points, Patton (2002) underlined the importance of purposeful sampling and the use of a variety of data collection sources in qualitative studies.

In the current study, I tried to portray the nature and complexity of preservice science teachers' PCK for STEM in detail, and interested in how this knowledge base was developed. Moreover, I am not only interested in the participants' PCK for STEM at the end but also in how it progressed during four-lesson study cycles. The study was conducted in the context of the "Practice Teaching in Science-1" course, which enables a natural setting for participants. In other words, no contrived context was used in this study. I also concentrated on learning how participants comprehend their experiences regarding PCK for STEM in different phases of lesson study. A variety of sources of data, including interviews, observations, video recordings, and CoRe, were utilized in this study to give a complete picture of preservice science teachers' development of PCK for STEM. The data were subjected to both inductive and deductive analysis, and I was interpretive as a qualitative researcher. Because of these reasons, the qualitative research design guided the current study.

3.1.1. Case Study

Among the abovementioned qualitative research design approaches, a case study was chosen in the present study. The purpose of using a case study is not to make generalizations (Stake, 1995), and the focus is not on the product (Merriam, 2009); instead, it aims to provide a complete picture of the phenomena being studied in a natural setting (Yin, 2009). According to Yin (2009), a case study is "… an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context when the boundaries between phenomenon and context are not clearly evident" (p.18). The cases might be a single person, organization, or program. Creswell (2013) described the main characteristics of case study as follows:

> Case study research is a qualitative approach in which the investigator explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audiovisual material, and documents and reports), and reports a case description and case themes. The unit of analysis in the case study might be multiple cases (a multisite study) or a single case (a within-site study) (p. 97).

In the present study, the issue (the development of PCK for STEM) was investigated through multiple cases (four preservice science teachers) within a bounded system (planning, implementing and reflecting on STEM lesson plans in the context of four lesson study cycles) by using multiple and in-depth data collection instruments (interviews, observation etc.).

Creswell (2013) classified the case studies into three: the single instrumental case study, intrinsic case study, and multiple or collective case study. In the first one, one particular and typical issue is selected to understand the phenomena better. The second one addresses studying a unique case, providing in-depth explanations about the uniqueness of the case. In the last one, the researcher selects more than one case to display different perspectives on the issue. Yin (2009) pointed out that the reason for conducting multiple case studies is replication. It means repeating the procedure with each case. In this study, multiple case study was employed, and each preservice science teacher constituted a case. Firstly, descriptions of each case within the scope of the lesson study were provided in detail. For this purpose, each participant's PCK for STEM was presented with respect to four components throughout four lesson study cycles. Then, four cases were compared and contrasted to gain insights into participants' development patterns regarding four components of PCK for STEM. In this way, the differences and similarities between the cases were displayed, and common and unique points about their PCK for STEM development patterns were identified at the end of the study.

3.2. Sampling and Participant Selection

Participants were selected through purposive sampling in the present study. Patton (2002) indicated that "information-rich cases are those from which one can learn a great deal about issues of central importance to the purpose of research" (p .46). There were some pre-determined criteria for participant selection. Being in the fourth year of the program and having completed the majority of the subject area courses (e.g., mathematics, chemistry, physics, astronomy, geology, biology, etc.), pedagogical courses (e.g., classroom management, instructional principles and methods, measurement and assessment, etc.) and pedagogical content knowledge courses (laboratory applications in science, science teaching, science curriculum, approaches to learning and teaching science) were one of the main criteria for participant selection. Participants of the study were expected to have solid subject matter backgrounds because subject matter knowledge is influential in having a strong PCK (Shulman, 1987). Participants in the fourth year of the program had already completed science courses, mathematics, and technology-related courses; therefore, they were chosen among the senior preservice science teachers.

Moreover, being a volunteer and prone to studying as a group was the other criteria for participating in the lesson study process. Completing one cycle of lesson study (planning, teaching, reflecting, and re-teaching phases) requires time. Therefore, being a volunteer is crucial for the results of the study. Participants had been taking their 4th grade courses and were preparing Public Personnel Selection Examination (KPSS) at the time of the study; therefore, I provided information regarding the lesson study process and underlined that the study would continue for more than four months in the introductory meeting. Their permissions were taken, and they were assigned to the same science teacher in the cooperating school. Detailed information about the participants is given below.

Four preservice science teachers enrolled in the Practice Teaching in Science-1 course in the science education program participated in the study. One of the elements of lesson study is "teaching" and participants were required to implement STEM lesson plans in a real classroom environment in the context of the present study. Since Practice in Science Teaching courses consist of the implementation of lesson plans in cooperating schools, I decided to conduct the study within this course. This course is in the 7th and 8th semesters of the teacher education program and includes both theoretical and practice parts. Preservice teachers are asked to attend science courses at a middle school for six hours in a week throughout 12 weeks. This course aims to provide them field experiences in real classroom settings and an environment to implement their lesson plans.

It is recommended to involve three to six participants in the lesson study group (Lewis et al., 2006). It would be risky to study with three participants in case of data loss. On the other hand, studying more than four participants might not be feasible because of the intensity of the lesson study process. As a result, I decided the conduct the study with four participants to get intense and deeper information about each of them. Pseudonyms were used instead of the real names of the participants as follows: Ada, Defne, Ece, and Deniz. Of the participants, one of them was male (Deniz), whereas three of them were female. Four lesson study cycles were carried out to monitor the development of preservice science teachers' PCK for STEM. Each participant was supposed to teach one first version of the STEM lesson plan and one revised version of the STEM lesson plan throughout the study.

All participants were willing to teach after graduation and were preparing for KPSS in their final year. Their GPAs at the beginning of the seventh semester were: 3.23 for Ada, 3.32 for Defne, 3.36 for Ece, and 3.49 for Deniz. They took similar courses in their undergraduate program; however, there were minor differences in terms of elective courses. For instance, Ada and Ece selected science elective courses regarding misconceptions in science and assessment in science, whereas Defne and Deniz took misconceptions in science and examining science textbook courses. Moreover, unlike other participants, Deniz was a former engineering student. He studied engineering for a semester, then decided to be a teacher and enrolled in a science teacher education program. The participants did not participate in any project regarding STEM education except for Ada. She was involved in a research project about the current trends in science education as a participant, and one session of the project was related to the engineering design process. The information about the participants is summarized in Table 3.1.

Table 3. 1

Demographic Information about the Participants

Name of the Participants	Gender	Grade	Prior experience in STEM	Elective Courses Taken
Ada	Female	4^{th}	Participated in a project, one part of the project was related to engineering design process	• Misconceptions in Science • Assessment in Science
Defne	Female	4^{th}	None	• Misconceptions in Science • Examining Science Textbooks
Ece	Female	4^{th}	None	• Misconceptions in Science • Assessment in Science
Deniz	Male	4^{th}	Studied an engineering for a semester	• Misconceptions in Science • Examining Science Textbooks

3.3. Procedure of Research

The summary of the data collection process of the dissertation is provided in Figure 3.1. Conducting the pilot study and main study took one year, as seen in Figure 3.1. The details about the pilot and main study are presented in detail below.

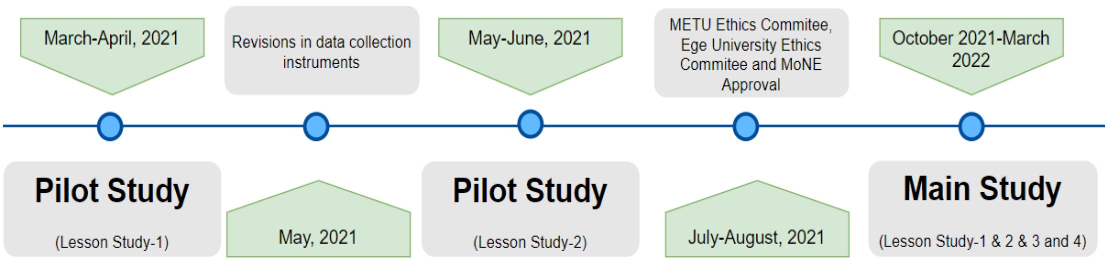


Figure 3. 1 The Summary of the Data Collection Process

3.3.1. Pilot Study

The pilot study was conducted before the main study. The pilot study was planned to be conducted in Spring 2020 in a face-to-face format; however, because of the Covid-

19 pandemic, middle schools and universities were closed and started online education in March 2020. Therefore, I had to suspend the study for a year and change the timeline of the pilot study. Later, we decided to revise the pilot study and decided to conduct it online in the Spring 2021 semester.

The implementation of the pilot study was subjected to some changes. First of all, preservice science teachers met on an online platform (Microsoft Teams) to prepare their lesson plans. They also implemented with other preservice science teachers through the online platform in the context of the Practice Teaching in Science course. There were two main reasons for implementing STEM lesson plans online with preservice science teachers instead of middle school students in the pilot study. The duration of science lessons in middle schools was limited to 30 minutes during the online education process. Additionally, the cooperating teacher indicated that some middle students had internet connection problems, and it was hard to manage the classroom in an online lesson. The students had to turn off their cameras as a school policy during the lesson. She added that they had to follow the science curriculum and yearly plan and complete it on time despite reduced lesson duration. Implementing a STEM lesson plan generally took three to five lesson hours, so conducting it on an online platform with middle students was not feasible. Moreover, cooperating school science teachers also stated that it was hard to apply group activities in an online classroom. For these reasons, I decided to implement STEM lesson plans with preservice science teachers and pilot both the process and data collection instruments. The other change in the pilot study was to increase the number of lesson study cycles from one to two. I conducted two online pilot studies during the spring semester of 2021.

Four preservice science teachers (three female and one male) were the participants of the pilot study who took the Practice in Teaching Science course. The real names of the participants were not used (Kaan, Pera, Eda, and Lara). The aim of the pilot study was to revise the data collection instruments and observe whether the lesson study process went as planned. Firstly, four students enrolled in the course were invited to the introduction meeting in the Teams program at the end of the Fall 2020 semester. The researcher informed participants about the requirements of the course and then gave information related to the pilot study process. Preservice science teachers were asked to prepare and present two STEM lesson plans within the scope of lesson study throughout the semester.

The lesson study cycles began with presenting a lesson study model. I gave necessary information about the cyclic nature of lesson study and explained my expectations from participants in each step of the process. I presented a video of lesson study implementation from Japanese classrooms to clarify the implementation process. Later, I provided two STEM lesson plan examples. Participants were asked to examine the lesson plans, determine the similarities and differences between the two lesson plans, how science and other disciplines connected, how the engineering design process was applied, etc. At the end of the introductory meeting, I shared the STEM lesson plan format with the participants. The format of the lesson plan was created by examining examples of STEM lesson plans in detail found in the literature (Akgunduz, 2018; Capobianco & Rupp, 2014; Gul, 2019; Johnson et al., 2016; Rinke et al., 2016). There were basically four main parts of the lesson plan format in the current study. Firstly, participants were asked to write background knowledge about the topic and the objectives related to science as the lead discipline and engineering, 21st-century. Moreover, they need to write objectives related to mathematics and technology if they decide to integrate these disciplines into their lesson plans. Then, they were expected to write the teaching procedure step by step, which methods and strategies they would use, the description of activities they use, etc., and specify the assessment methods. Then, I showed a diagram about which engineering design process model they needed to integrate into the lesson plan. Then, participants were given the task of examining the science curriculum and trying to choose objectives to design their STEM lesson plan. The researcher requested to choose objectives from 7th-grade since participants had attended 7th-grade online science lessons in cooperating school.

Participants met online several times to design the first STEM lesson plan. After the planning phase, online pre-interview questions were conducted individually. Then, the teaching phase was followed by the planning phase, and one preservice teacher was chosen based on a voluntary basis for the teaching phase. The research lesson was implemented as a micro-teaching study through an online platform. The lesson study group and other preservice teachers taking the Practice Teaching in Science course at the time of the study attended the research lesson. While Eda was teaching the lesson, other participants and I observed the lesson, filled out an observation form, and took field notes without interruption. In this way, participants gained experiences related to the observation form. I also asked them to note down if there were any items that could not be understood clearly in the form.

After the teaching phase, I conducted the first interview with Eda, who was the teacher of the lesson. Later, the other three participants were interviewed, and the study continued with the reflecting phase. In the reflecting phase, firstly, Eda shared her experiences with her friends, and every participant in the group followed the same process. The participants and I also benefit from observation forms and field notes while suggesting revisions. The group worked collaboratively to revise the plan.

After completing the first lesson study cycle, I transcribed interviews immediately and collected observation protocols. After the first lesson study cycle, several refinements were made to data collection instruments. Firstly, interview questions were subjected to some modifications. For example, how participants connected science objectives with other objectives of STEM disciplines was added to interview questions under the knowledge of curriculum component. Secondly, the observation protocol was revised. Participants indicated they had difficulty understanding some items while filling out the form during the implementation part of the lesson study. For example, they could not grasp what I meant by writing "using appropriate representations." The term representations were replaced by "content-specific analogies, models, drawings, etc." One of the significant changes was related to the lesson plan template. I had prepared a STEM lesson plan template before the study; however, I noticed that the template was unable to portray participants' PCK, especially concerning knowledge of learners and knowledge of assessment after the analysis of the pilot study. Participants did not pay too much attention to learners' difficulties and misconceptions and what to assess sub-component while planning their STEM lesson. Therefore, I decided to use a revised version of Content Representation (CoRe) as a lesson-planning format (Aydin et al., 2013). A detailed explanation of CoRe was presented in the Data Collection Instruments section. Then, refined versions of data collection instruments were administered in lesson study 2, and decided that the revised version of data collection instruments worked better. Moreover, I decided to request two more individual CoRes from each participant in the main study; one prior to the study and one at the end of the study. In this way, monitoring their PCK for STEM development would be more practical.

After completing the pilot study, there were also changes in the implementation process of the lesson study. Firstly, the example of lesson study videos at the introductory meeting was taken out since the available videos were related to mathematics teachers and the language in the videos was in English. Participants thought this part was unnecessary. Another main issue that emerged in the pilot study was that participants almost had no knowledge related to the engineering discipline. Since subject matter the knowledge influences the developing PCK (Magnusson et al., 1999) and having necessary knowledge regarding the engineering design process is crucial for STEM education (Fan et al., 2021) it was decided to pay attention to this issue in the main study. Participants stated that they heard about STEM education in their Science Teaching courses but had no detailed knowledge. This study did not concentrate on the subject matter knowledge; however, preservice teachers did not take any courses regarding engineering. For this reason, I decided to address the engineering and engineering design process before starting the first lesson study cycle to form a common language among the group in the main study. Since participants were expected to integrate engineering into their CoRes, they needed to know about fundamental concepts of engineering discipline. The details are provided in the Procedure of Research section.

I planned an introductory meeting that included who engineers are, what type of work they are doing, engineering practices, the engineering design process, and different models for the engineering design process, etc. I also realized that participants had the most difficulty in identifying criteria and limitations in the engineering design process, so more examples from the literature were involved in this introductory meeting. Moreover, I shared three examples of STEM lesson plans with the participants in the introductory meeting, and we reflected on the plans together before the first cycle began. However, I noticed that participants were influenced by these lesson plans and tried to do similar things in their first STEM lesson plan, so I decided to remove this part from the main study.

As a researcher, I also gained experience related to the implementation of lesson study and my role in the group after two implementations. First of all, I had some concerns about how much I should be involved in the planning process before the study. I handled the process better over the course of time. I experienced what kind of questions I would ask to generate a discussion in the group, how to manage time in meetings and what kind of sources and materials might be helpful for participants. For example, participants wanted to use problem-based learning as a teaching strategy in lesson study 4, but they indicated they had little knowledge and never used it while planning a lesson. They had difficulty translating their knowledge into practice, and I provided examples of science lesson plans based on problem-based learning. They examined them as a group and reflected on the sample plans, and then tried to integrate STEM education. I asked several questions to create a discussion environment at this point. Moreover, I experienced the importance of field notes since I had intense data. I realized that taking daily notes, especially during planning and reflection meetings, helped me to arrange my data.

3.3.2. Main Study

Four preservice science teachers were asked to prepare four STEM lesson plans for the 6th grade in the main study. Different from the pilot study, participants implemented their lesson plans through face-to-face instruction with middle school students in the main study. The middle school was chosen among cooperating school lists that the Provincial Directorate of National Education in Izmir supplied. The school is in the city center, and there are more than 1200 students at the time of the implementation. The average number of students in classrooms is 28. The schedule of the school is composed of six class periods. The lessons start at 08.40 a.m. and end at 2.15 p.m. Each class lasts 40 minutes, and there is 10 minutes break between class periods. There is no laboratory at the school, and a limited number of science-related equipment, such as thermometers and dynamometers, is held in the storeroom. All classrooms in the school have smart boards. However, students are not permitted to take their mobile phones, computers, or tablets to take school for educational purposes.

There are several reasons for choosing this particular cooperating school. I had studied at this school before and was familiar with the science teachers and school culture. The cooperating teachers were willing to help preservice teachers and eager to apply new approaches in their classrooms. Furthermore, the school is located near the university and in the city center; so it is easy to reach. Participants had limited time because of their busy schedules at university and preparing for KPSS, so transportation would not be a problem. I collaborated with cooperating Ezgi Teacher. Ezgi Teacher is an experienced teacher and has been teaching science in middle school classrooms for 18 years at the time of the study. I communicated with the teacher before the study and informed her about the purposes and process of the study. Ezgi Teacher explained that she would teach the 5^{th} and 6^{th} grades at the time of data collection. She had one class for 5^{th} grade and three classes for 6^{th} grade. I told Ezgi Teacher that I needed two classrooms at the same grade level, and implementing one STEM lesson plan took approximately three to four class hours. She suggested studying in 6K and 6L classrooms because she was also a teacher of the "Applications of Science" lesson for 6K and 6L as elective course. She added that school administrators generally mixed-up classrooms in elective courses before the pandemic. For example, there could be students from 6A, 6B, and 6K in the Applications of Science course. However, the school administrator wanted to decrease interaction between students due to the pandemic, and all students in the 6K classroom took the Applications of Science lesson with their classmates. Therefore, she offered to implement two hours of the STEM lesson plan in the regular science course and another one or two hours of the STEM lesson plan in the Applications of Science course. In this way, we created a common schedule because one of the primary purposes of the Applications of Science course is to develop an interdisciplinary approach to solving daily life problems and utilize inquiry-based, problem-based, and design-based learning (MoNE, 2018b) that fits with the purposes of the study.

Additionally, Ezgi Teacher suggested that participants would prepare and teach one STEM lesson for each unit during the semester. She had no STEM background; therefore, she was not fully participated in the reflection of STEM lessons. She briefly discussed some significant points that she realized during the flow of the lesson, such as how preservice science teachers reacted to students' questions, how they managed the classroom and handled group activities, etc., and made suggestions to improve these points. She was open to collaborating and very helpful in arranging a time to implement STEM lessons.

There were two introductory meetings before lesson study cycle 1 began, and details of these meetings are given in Table 3.2. The first meeting was held online through the

Microsoft Teams platform because face-to-face meetings were risky due to the pandemic at the time of the study. I presented the purpose of the study in detail and explained my expectations of the participants. I took the participants' permission to collect data through video-recorded meetings, interviews, observations, and some written documents. Then, the lesson study was presented, and what would participants were asked to do in every stage of the lesson study was specified. The CoRe was introduced to the participants since nobody in the group was familiar with it at the end of the first meeting. I supplied some examples of CoRe prepared based on different science topics. Then, participants were asked to prepare individual CoRes and integrate STEM education until the next meeting.

Table 3. 2

The Details of Introductory Meetings

Date	Activity	Duration
27.09.2021	• Introducing the purposes of the study • Introducing phases of lesson study • How to prepare CoRe	45 min.
01.10.2021	• Collecting individual CoRes • Discussing essential characteristics of STEM • Introducing the steps of the engineering design process	1h. 15 min.

The second introductory meeting started with discussions about the essential characteristics of STEM education. Since there are many definitions of STEM education, forming a common language in the group about STEM education was considered an important point. The researcher directed some questions to the participants to take their opinions and get an insight into their background knowledge regarding STEM education. The meeting continued with an interactive presentation using Mentimeter about engineering and the engineering design process. The researcher emphasized that there were different engineering design process models available in the literature, and they were going to use the eight-step model in this study. The group discussed every step in the engineering design process. Later, I introduced the engineering notebook and explained how they would utilize it in the present study.

I underlined that participants were free to develop an engineering notebook parallel with their purposes. This meeting lasted about 75 minutes.

The summary of the implementation of four lesson study cycles is given in Table 3.3. Multiple cycles were preferred to track the development of participants' PCK for STEM through different objectives. Each lesson plan was prepared based on different science units covered in the 6^{th} grade. During the study, the participants concentrated on the Solar eclipse, speed, thermal insulation, and sound insulation topics. It took nearly one month to complete one lesson study cycle.

Table 3. 3

Details of Four Lesson Study Cycles

Lesson Study Cycles	**Date**	**Topics Chosen for Lesson Plan and Engineering Design Challenge**
Cycle 1	06.10.2021-11.11.2021	Solar Eclipse and Designing Solar Eclipse Viewer
Cycle 2	16.11.2021-22.12.2021	Speed and Designing Race Cars
Cycle 3	23.12.2021-24.01.2022	Thermal Insulation and Designing Thermos
Cycle 4	01.02.2022-18.03.2022	Sound Insulation and Designing Soundproof Music Room

The four lesson study cycles were covered for more than five months in the current study. Each cycle includes planning, teaching, reflecting, and re-teaching phases. After completing one lesson plan, one preservice teacher from the group conducted a STEM lesson. Other preservice teachers filled out an observation protocol during the teaching phase and took field notes. I reminded participants that they would not assess their peers during observation; instead, they were required to observe what was working or not working in their lesson plans. The CoRe was completed between three to four hours of lesson periods in middle school. The summary of the implementation of lesson study cycles in the cooperating school is shown in Table 3.4.

Table 3. 4

Summary for Implementation of Lesson Study Cycles in Cooperating School

	Preservice Teacher (The First Lesson)	Classroom	Preservice Teacher (The Revised Lesson)	Classroom
Cycle 1	Deniz	6L	Ada	6K
Cycle 2	Defne	6L	Ece	6K
Cycle 3	Ada	6L	Deniz	6K
Cycle 4	Ece	6L	Defne	6K

After teaching the lesson, the group gathered for the reflection phase and made some improvements in the lesson plan in every cycle of the lesson study. They utilized observation protocol and their field notes to propose changes in the lesson plan. They also examined students' documents such as an engineering notebook, worksheets (budget sheet, etc.), and assessment results. Afterwards, different preservice teachers from the group taught the improved lesson plan to a different classroom, as seen in Table 3.4.

3.3.2.1. Lesson Study 1

Ezgi Teacher planned to move on to the second unit in the science curriculum named "Systems in Our Body" according to the yearly plan at the end of October when the first STEM lesson plan was intended to be conducted. I requested participants to prepare a STEM lesson plan based on this unit. Participants were given the task of examining the second unit of the science curriculum in the 6th grade individually and trying to choose objective(s) for their lesson plan at the end of the second introductory meeting. They were also asked to investigate and analyze engineering design activities found at the end of each unit in students' textbooks, make an investigation about what they need to prepare a STEM lesson plan, how they can develop an engineering notebook, and how they could integrate different disciplines in their lesson plans. Participants were required to take individual notes on these issues to be discussed in the next meeting. However, Ezgi Teacher tested positive for Covid-19, and she could not be able to attend her lessons for two weeks at this point. Because Ezgi Teacher fell behind on the yearly plan, we had to change our plans and choose a science objective from the first unit, which was about Solar System and Solar/Lunar Eclipses.

Participants had given the task of examining the first unit in the 6th-grade science curriculum. Each came to the meeting with their ideas. The science objectives in the first unit are related to planets and their characteristics, Solar eclipse, and lunar eclipse. The researcher took participants' ideas individually and triggered a discussion in the group about which objectives they would choose. The group had different opinions regarding engineering design problems, such as designing a device to be sent to other planets to collect data from their surfaces, designing glass for viewing Solar eclipses safely, and designing a rocket to be sent to different parts of Mars. The group concentrated on the Solar eclipse topic and decided to design a Solar eclipse viewer since they thought creating a prototype and testing it in the classroom environment would be more effective than other opinions at the meeting. After participants reached an agreement on objectives, they continued filling out CoRe. Participants discussed that the teacher should know the position of the Sun, Moon, and Earth during the eclipse, the relative sizes and motions of the Sun, Earth, and Moon, and the frequency of solar eclipses in one year as subject matter knowledge. In parallel with CoRe, they paid attention to potential misconceptions and difficulties students might experience during STEM lessons. They talked about students might have a confusion regarding the position of the Earth and Moon during a Solar eclipse. They also talked about students having difficulty differentiating between the motions of the Sun, Earth, and Moon and proposing multiple solutions for their solar eclipse viewer design. Then, they opted for the 5E learning cycle for the teaching procedure. They formed an engineering design challenge and added additional questions and tables to develop the engineering notebook. For example, they formed a decision table for choosing the best solution to a problem. They used the budget as a limitation, created a budget sheet, wrote every possible material that students would use in their designs, listed their prices, etc. The researcher encouraged collegial dialogues in the group and generated discussions using the prompts in CoRe. Finally, they agreed on using a rubric to assess whether students in the classroom reached the objectives of the lesson.

Participants met four different times for the planning phase of the first lesson study. Some meetings were held online through Teams, and some meetings were conducted face to face at the faculty of education. The last meeting of the planning phase was conducted face-to-face, and participants tried possible designs by using materials at the end of the meeting on their own. These meetings were video recorded. The timeline of lesson study 1 is depicted in Table 3.5. The planning phase lasted approximately four hours. Then, individual pre-interviews were conducted before teaching the lesson. The interviews lasted between 69 and 95 minutes.

Table 3. 5

The Timeline of Lesson Study 1

Phases of Lesson Study Cycle	Date	Activity	Duration
Planning	06.10.2021	1st meeting: Planning Lesson	56 min.
	11.10.2021	2nd meeting: Planning Lesson	35 min.
	14.10.2021	3rd meeting: Planning Lesson	45 min.
	20.10.2021	4th meeting: Planning Lesson	52 min.
	21.10-25.10.2021	Pre-interviews (individual)	69-95min.
Teaching	27-28.10.2021	Implementing Lesson Plan 1 and Observation	3 lesson hours
	01-02.11.2021	Post-interviews (individual)	51-96 min.
Reflecting	03.11.2021	1st meeting: Revision of Lesson Plan	44 min.
	04.11.2021	2nd meeting: Revision of Lesson Plan	51 min.
Re-teaching	05-08.11.2021	Implementing a Revised Lesson plan	3 lesson hours
Re-reflecting	11.11.2021	Revision of Revised Lesson Plan	27 min.

Deniz volunteered to teach the first research lesson based on the STEM education approach in the 6L classroom. There were 24 students in the classroom, and Deniz conducted the lesson plan in three lesson hours. Deniz made the classroom suitable for group work. There were four groups composed of six students. The materials were put in boxes and categorized into three: one includes materials for filters of solar glasses (X-rays, double-layer DVD, welder lens, sheet protector, 3D glasses, etc.), one for frames for glasses (abeslang, felt, plastic pipes, wire, etc.) and one for office supplies (scissors, glue, stapler, etc.). These boxes were placed on the teacher's desk. Deniz started the lesson using animation, directed some questions to understand students' prior knowledge of the Solar eclipse, and introduced an engineering notebook. Students were encouraged to define the problem, the criteria, and the limitations of the given scenario. A company named Sun Game was looking for engineers to design a solar eclipse glass in the scenario.

Preservice teachers prepared a brochure to attract students' attention and wanted them to solve the problem like an engineer. Later, students were asked to research the problem, develop possible solutions and choose among them. Information cards were distributed to students for searching the problem. Preservice teachers intended to use web 2.0 tools in their lessons, but as a school policy, computers, tablets, or mobile phones were not allowed during the lesson. Therefore, they had to change their plans. Students created their prototypes and tested them through the Solar eclipse model that preservice teachers prepared during the next two hours. Students presented their prototypes to their classroom mates and explained whether their design met the criteria and limitations or which filters were effective for viewing the Solar eclipse. Students used different filters for their designs and compared their designs with other groups. Deniz did not pay attention to discussing the strengths and weaknesses of students' designs and how to improve their designs in the engineering notebook.

The researcher and the other three preservice teachers sat in different parts of the classroom during the teaching phase of the lesson study. Each preservice teacher sat next to one student group, took field notes, and completed the observation protocol to discuss in the reflecting phase. They did not interfere with the lesson and student group discussions. They paid attention to whether there were differences in the planned and enacted lesson plan, students' prior knowledge and misconceptions, implementation of 5E and engineering notebook phases, and how science was integrated with other STEM disciplines and assessment parts.

After finishing the teaching part, the cooperating teacher made her suggestions related to the lesson. She pointed out the problems in student-teacher interactions, how Deniz responded to students' questions, and how he managed the classroom in her comments. She advised that Deniz should have presented the materials, especially the filters, in more detail before the design challenge. She added that one group was not given enough time to submit their prototypes, and every group should have the same time to present their work. Later, the lesson study group briefly discussed what went well and what could be done differently in the school guidance counsellor's room in the re-teaching part. This meeting was completed in approximately 15 minutes. The researcher conducted post-interviews in the following days, each of which lasted around one hour.

The participants met two times for the reflecting phase. Based on the post-interviews and observation protocols, the researcher took field notes about their individual suggestions for the revision phase. She started discussions by addressing each of their suggestions. The groups agreed on revising several points in the STEM lesson plan. For example, they realized students had difficulty understanding "who is an engineer" and added extra examples to emphasize different types of engineers. They also added more criteria and limitation examples since students had trouble understanding those terminologies. After the lesson, they collected students' artefacts, such as engineering notebooks and budget sheets, and examined and assessed them. They noticed some misconceptions they considered before teaching, such as watching the total Solar eclipse directly through binoculars and added additional questions to remedy this misconception in the lesson plan. Moreover, they realized students did not use the budget sheet as they intended. Students were expected to pick materials from the budget, list how many materials were needed for them, make calculations and form a total budget for designing a solar eclipse viewer. However, many of the budget sheets were empty. Participants said they needed to emphasize the limitations more in the engineering design challenge. They added how much money was left from their budget while presenting their prototypes to the classroom. Moreover, there were also minor changes in the objectives and assessment part. They had an intense debate regarding objectives and wrote new ones related to the engineering design process. They assessed engineering notebooks based on the rubric they prepared, and some items in the rubric were subject to change after assessing students' engineering notebooks. These types of revisions were made, and the lesson plan for the re-teaching was prepared. Reflecting meetings took nearly two hours.

Ada was the teacher of the revised lesson plan. She implemented the lesson plan in the 6K classroom in three lesson hours. There were 25 students in the classroom while implementing the revised lesson. Ada formed five groups composed of five students. She made the classroom proper to group work as in the first lesson plan. Other preservice teachers and researchers observed the lesson, filled out an observation protocol, and took field notes, especially related to changes in the revised lesson plan. Ada walked around the groups and facilitated group work. Students completed engineering notebooks and tested their prototypes. Ada had time management problems, and she preferred to skip the Elaboration part at the end of the lesson.

Ezgi Teacher provided her suggestions after the implementation. She indicated that the lesson plan became more coherent than the first one, and it was good to introduce the materials before students started to design their prototypes. She explained that Ada interacted with students positively and tried to include all of them in the activity. Like her previous comment, she suggested allocating more time for presenting the prototype.

Later, the researcher met with the lesson study group in the school guidance counsellor's room to shortly discuss the lesson. They examined students' artefacts and completed assessments. Later, the group met online after two days and discussed whether the revised part of the lesson worked well or not. Participants did not make any changes to the revised STEM lesson. They emphasized several points in the discussion, such as providing examples of criteria and limitations that worked well, and students utilized the budget as a limitation this time. Moreover, students proposed more than one solution to the problem and specified their reasons.

3.3.2.2. Lesson Study 2

The "Systems in Human Body" unit in the science curriculum was planned to be covered for the second lesson study cycle in parallel with the yearly plan. This unit was taught in October and November 2021 at the time of the study; however, the cooperating school and faculty of education schedule did not overlap during this month. Because it was exam week between 8-12 November 2021 and there was a fall break between 15-19 November 2021 in cooperating school, preservice teachers could not able to attend lessons in cooperating school this week. Then, exam week started at the end of November in the faculty of education, and preservice teachers had lots of work to do and could not spend enough time preparing a STEM lesson plan. Since the planning phase took too much time, it was decided to implement the second STEM lesson at the beginning of December. The Force and Motion unit was selected based on the yearly plan with the help of cooperating Ezgi Teacher.

Science objectives in this unit are related to the definition of force, balanced and unbalanced forces, and the definition and unit of speed. The participants were familiar with the lesson study and felt more comfortable about the process this time, and they came to the meeting with their ideas. The researcher took their opinions individually at first in the planning meetings. For example, Defne offered to concentrate on the force topic and designing seesaw as an engineering design challenge. Similarly, Ece discussed designing a bridge and indicated they could continue with balanced and unbalanced forces. Unlike these ideas, Deniz and Ada suggested covering the speed topic and utilizing designing a race car as an engineering design challenge. The group decided to continue with the speed topic at the end of solid discussions and wrote the science objectives of the lesson. They also wrote objectives related to engineering and mathematics. The researcher encouraged participants to fill out CoRe by asking for the prompts. Participants determined two big ideas for the lesson, one related to the definition of speed and the other related to drawing the distance-time graph. They talked about students might have difficulties in designing and proposing solutions to a problem, unit of speed, and drawing graphs. They also argued that students might have misconceptions regarding the difference between speed and velocity. They considered these points while planning the lesson.

Later, preservice science teachers talked about which teaching strategy they would use in this lesson plan. They first tended to use the 5E learning cycle; however, they used the REACT (Relate-Experience-Apply-Collaborate-Transfer) strategy. Several science lesson plans based on REACT were examined as a group, and then they decided how to use and develop an engineering notebook in their CoRe. The engineering design challenge in lesson study 2 was about designing a race car with the highest speed. Participants wrote a daily life scenario that included criteria and limitations and added information cards, a decision matrix, tables, and graphs into the engineering notebook. They agreed on preparing a 2-meter-long racetrack to test students' prototypes, and students would collect data to draw a graph while testing their designs. The criteria for assessing students' prototypes were also determined and included in the engineering notebook. The word association test and concept cartoon were prepared to detect and eliminate students' misconceptions about the speed topic. Participants prepared a rubric, concept cartoon, and short-answered questions for assessment. The timeline for lesson study 2 is displayed in Table 3.6.

Table 3. 6

The Timeline of Lesson Study 2

Phases of Lesson Study Cycle	Date	Activity	Duration
Planning	16.11.2021	1st meeting: Planning Lesson	52 min.
	22.11.2021	3rd meeting: Planning Lesson	44 min.
	25.11.2021	5th meeting: Planning Lesson	46 min.
	06.12.2021	7th meeting: Planning Lesson	40 min.
		Pre-interviews (individual)	42 to 61 min.
Teaching	09-10.12.2021	Implementing Lesson Plan 1 and Observation	4 lesson hours
	10-13.12.2021	Post-interviews (individual)	37 to 49 min.
Reflecting	14.12.2021	Revision of Lesson Plan	67 min.
Re-teaching	15-17.12.2021	Implementing a Revised Lesson plan	4 lesson hours
Re-reflecting	20.12.2021	Revision of Revised Lesson Plan	45 min.

Defne was the main teacher of the second STEM lesson plan. She implemented the first version of the STEM lesson plan in four lesson hours period. There were 24 students in the 6L classroom at the time of the implementation. The lesson started with a video, and Defne attracted students' attention to the lesson and asked several questions. Then, she handed out worksheets individually. In the first activity, people, horses, and dogs took the same distance at different times, and students were expected to compare their speeds and comment on the related questions. In the second activity, a plane, car, and ship traveled for five hours and travelled different distances. Students were required to explore the relationship between distance travelled and time in this part of the activity. Then, Defne implemented the word association test. She made students write five words when told "speed" and formed a sentence including the speed concept. She collected students' answers and read some of them aloud. Then, she continued with a worksheet concentrating on distance travelled-time and speed-time graphs. Then, an engineering notebook was introduced, and it was indicated that students were going to act as engineers like in the previous lesson based on the Solar eclipse. She showed some photos that included engineers at work and took students' opinions on what engineers were doing in the pictures. The engineering design challenge was about designing a race car with the highest speed that should complete the racetrack at the earliest based on some criteria and limitations. Students were expected to work as a group and follow the steps in the engineering notebook. They created and tested their prototypes and collected data while testing. They were asked to organize the collected data, calculate speed, and draw distance-time graphs based on their designs. One student per group presented their designs and calculated speed. Because of time limitations, the last activity of the Transfer phase in REACT was given as homework, and the concept cartoon could not be implemented.

Defne, the cooperating teacher, and I met right after implementing the STEM lesson plan to evaluate it in the school guidance counsellor's room. Ezgi Teacher suggested emphasizing the difference between speed and velocity more and advised using the Distance, Speed, and Time (DST) triangle for the revised lesson. She also added that using concept cartoons was critical, and more time should be devoted to implementing them. She enjoyed the group work and the way how Defne handled them. She indicated that presenting students' designs was also one of the powerful parts of the lesson, and more questions might be asked to students about their designs. Lastly, she provided suggestions for classroom management and student-teacher interaction.

I post-interviewed the participants in the following days. After completing them, the group met to revise the lesson. Firstly, they examined the students' artefacts, such as engineering notebooks, word association tests, and activity sheets. The group agreed on using the DST triangle, revised one objective of the lesson, and added it in CoRe because they considered mathematical equations as limitations of the science curriculum. Moreover, they observed that students had a misconception regarding the difference between speed and velocity and decided to use the Word association test at the beginning of the lesson. They also agreed that students struggled to draw the Speed-Time graph, determine speed from the chart, and interpret it. They decided to pay attention to analyzing data and improved the worksheet prepared for the experience phase of REACT. The group discussed that students had difficulty determining the unit of speed, so they added this point in CoRe and decided to highlight this issue by using the DST triangle and calculating the designed car's speed. They also noticed that some students had difficulty collecting and presenting data. They talked about drawing a big data table on the whiteboard, and every group should share their data and draw their graphs on it so that the whole classroom could see and compare the results of their designs. They did not change anything in the assessment part.

Ece was responsible for the revised lesson plan. She taught the 6K classroom for four lesson hours. Four groups composed of five students studied together during the lesson. Participants and researchers observed the lesson and took field notes. They specifically paid attention to the revised part of the lesson plan. She followed the steps of REACT and the engineering notebook as planned. Students chose the best solution and created their prototypes. They tested their designs on the racetrack, collected data, and presented them to the classroom. She utilized concept cartoons as a whole classroom activity. The last activity sheet was given as homework because of time limitations.

Suggestions from Ezgi Teacher were taken after the implementation of the revised lesson plan. She indicated that the lesson plan got better in the revised form. She talked about some students in the classroom being very active during implementation, especially those who did not typically participate in science lessons. She explained that allowing enough time for prototype presentation was one of the positive parts of the lesson. She discussed that one student created a Speed-Time graph wrong at the end of the lesson and how Ece could not notice it was wrong at first.

Later, the participants and researcher met and discussed the revised lesson plan based on their observations. They agreed that the revised parts of the lesson worked well. They discussed that the main problem they confronted was time limitation since there were many misconceptions regarding speed topic, and creating a prototype for race cars took longer than expected. Re-reflection on the revised lesson was completed, and participants moved on to the third cycle.

3.3.2.3. Lesson Study 3

The heat topic from the "Matter and Heat" unit was chosen with the help of cooperating teacher for the third STEM lesson plan. The science objectives in this unit consist of classifying materials as insulators or conductors, determining criteria for choosing insulation materials in buildings, developing alternative insulation materials, and discussing the effective use of resources in terms of thermal insulation. Participants were given the task of investigating and generating their ideas before the first meeting of lesson study 3. Participants met online and started discussions based on selecting objectives and composing engineering design challenges. The different ideas that emerged in the group were: designing a heat-isolated building, creating a thermos, designing thermal clothes, and designing a thermal-insulated animal house for cats or birds. They decided to continue developing thermos as an engineering design challenge at the end of the discussions. The details of lesson study 3 are presented in Table 3.7.

Table 3. 7

The Timeline of Lesson Study 3

Phases of Lesson Study Cycle	Date	Activity	Duration
Planning	23.12.2021	1st meeting: Planning Lesson	61 min.
	27.12.2021	2nd meeting: Planning Lesson	43 min.
	28.12.2021	3rd meeting: Planning Lesson	44 min.
	29.12.2021	4th meeting: Planning Lesson	52 min.
	03-04.01.2022	Pre-interviews (individual)	45-58 min.
Teaching	06-07.01.2022	Implementing Lesson Plan 1 and Observation	4 lesson hours
	08-09.01.2022	Post-interviews (individual)	36-54 min.
Reflecting	10.01.2022	Revision of Lesson Plan	36 min.
Re-teaching	12-14.01.2022	Implementing a Revised Lesson plan	4 lesson hours
Re-reflecting	17.01.2022	Revision of Revised Lesson Plan	29 min.

After deciding on science objectives, participants wrote objectives for engineering and mathematics. They agreed on writing objectives regarding career connections under engineering objectives. The collaborative CoRe was developed by discussing prompts in the next meetings. Participants thought that the teacher of the lesson should be knowledgeable in terms of heat, the difference between heat and temperature, conductors and insulators, and which engineering fields might use these principles in their designs. They determined the difficulties they might confront throughout the lesson, such as having difficulty specifying the design's limitations, proposing more than one solution to the given problem, choosing appropriate insulators among materials while designing thermos, reading thermometers, etc. Furthermore, they talked about possible misconceptions that could emerge during lessons. For instance, heat and temperature are the same things; insulators are the source of heat, cold is transferred, or there is only one successful design resulting from the engineering design process. Then, participants preferred to use the 5E learning cycle as a teaching strategy. Integration of the engineering notebook into the 5E learning cycle was also discussed. Participants used engineering design challenge to attract students' attention and prepared an animation to present engineering problems, including criteria and limitations in Engage part. The remaining parts of the engineering notebook were built into Explore and Explain parts of the lesson. Some examples of daily life applications of thermal insulation enriched with engineering were prepared in the Elaborate part. They added the life story of two Turkish engineers to raise students' awareness of engineering careers. Lastly, the diagnostic tree, Draw an Engineer Test, and a rubric were planned for assessment. Participants were pre-interviewed individually at the end of the planning phase, and these were completed between 45-58 minutes, as seen in Table 3.7.

Ada was the teacher of the first version of the STEM lesson plan in lesson study 3. There were 21 students in the classroom on the week of implementation. She formed four groups before starting the lesson. She directed some questions to understand students' prior knowledge about the heat. Then, the animation prepared by participants was shown to the students to present an engineering design challenge. Students were expected to define the problem, criteria, and limitations of the problem. Then, they investigated the materials used for thermal insulation and their fundamental characteristics in searching for the problem through information cards.

Later, they were supposed to propose more than one solution, choose the best one among them, decide which insulation materials they would choose, justify their choices, fill out a budget sheet, and calculate their budget for the design. The materials for the thermos body included glass, plastic cups, styrofoam cups, and cartoon cups. Moreover, students were given cotton, aluminium foil, cartoon, glass wool, fabric, felt, and bubble wrap as alternatives for insulation materials. They chose materials, constructed their thermos prototypes, tested them, and collected and organized their data. The hot water, approximately 60^{o}C, and 150 ml. were poured into the thermos. Data analysts of the group took several measurements every five minutes. The data were recorded on the table on the board and testing part of the engineering notebook. Then, the students discussed their designs in their small groups, and one student from each group presented their design, explained which materials they picked up, and demonstrated their budget. They also mentioned which part of their design should be improved or what combination of different materials could be used in the re-design part at the end of the third lesson.

The last lesson started with an activity based on the daily life application of thermal insulation and how engineers proposed solutions to everyday life issues both in buildings and other places. Students were given examples of how astronauts' spacesuits are resistant to extremely high and low temperatures in space. How principles of thermal insulation were applied in designing spacesuits to keep astronauts safe from too cold or too hot was emphasized. Moreover, "The World without Engineers" visuals were shown to students. For example, students were expected to develop an understanding that without engineers, we could not listen to music with our wireless headsets while walking. Moreover, two Turkish engineers' life stories were displayed. The diagnostic tree was completed as a group activity.

Ada, cooperating teacher, and I met right after the implementation to evaluate the lesson plan in the school guidance counsellor's room. Ezgi Teacher provided her suggestions related to lessons. She talked about using animation for engineering design challenges was practical, and the presentation of the prototypes part worked well. Moreover, she mentioned that Ada managed students' groups better than in her previous STEM lesson. She provided some suggestions related to teacher-student interactions, such as waiting time and asking follow-up questions.

Post-interviews were conducted individually in the following days. After the researcher got the participants' suggestions for revisions, the group met and improved the lesson. Firstly, Ada shared her experiences and suggestions. I asked questions based on the observation protocol and the field notes I took in the interviews to generate discussions in the group. Some revisions were made in CoRe. For instance, two more scientific misconceptions (heat cannot be measured directly, and thermal insulation only keeps objects warm, it was not applicable to keep things cold) were added to CoRe. The group discussed that the criteria regarding the thermos lid were unclear and revised it. There were slight changes in the assessment part. There were no changes in the objectives of the lesson plan.

Deniz implemented the revised lesson plan in the 6K classroom. There were 18 students in the classroom, and students were divided into four groups. Participants and the researcher filled out observation protocols and took field notes during implementation. Deniz made some changes in the flow of the lesson but paid specific attention to revisions made in the lesson plan. For example, he was aware of students' possible misconceptions and tried to eliminate them through explanations and by providing daily life examples. He experienced some problems with time management and could not apply the activities in Evaluate phase.

Suggestions from cooperating teachers were taken after the implementation of the revised lesson. Ezgi Teacher indicated that the teacher should give more precise directions regarding the activity, and time should be used more efficiently. She added that she wanted to see the application of the diagnostic tree toward the end of the lesson.

The group met online to reflect upon Deniz's lesson. Deniz shared his teaching experiences. The other group members discussed that Deniz handled the engineering-related misconception very well, which was unexpected. They revised the CoRe in terms of misconceptions and moved on to the final lesson study cycle.

3.3.2.4. Lesson Study 4

The next unit in the curriculum was related to sound concept. The objectives in this unit are related to how sound travels, the speed of sound, how the speed of sound changes in different media, and sound insulation. Preservice teachers were asked to examine the objectives individually. Later, participants discussed their ideas in the first meetings of lesson study 4. They all agreed on designing a lesson plan regarding the sound insulation objective. They discussed whether they should include acoustical applications and decided not to cover this concept in the lesson plan. Ada suggested designing a soundproof music room in the school as an engineering design challenge. Then, they started preparing CoRe and wrote objectives using mathematics and technology curricula. Next, the researcher triggered the discussion in the group about which teaching strategy they were going to choose in this lesson plan. There were different ideas: problem-based learning, project-based learning, and the 5E learning cycle. They talked about how the steps of problem-based learning fit into the steps of the engineering design process and chose problem-based learning.

Participants mentioned that teachers should be knowledgeable in terms of the characteristics of sound insulation materials, reflection and absorption of sound, how sound travels in solids, liquids, and gases, steps of the engineering design process, and creating and interpreting bar charts. They determined the possible difficulties that students might experience, such as proposing multiple solutions for designing a soundproof environment, drawing bar charts from the data they collected, understanding "decibel" as a unit to measure sound, etc. Later, misconceptions that might emerge during the lesson were discussed. For example, sound travels faster in the air than in solids; sound travels only in the air; sound travels in space; scientists and engineers are the same people and engineers work alone, etc. Multiple-choice questions, a rubric, and a word association test were prepared for the assessment of the lesson. Details of lesson study 4 are given in Table 3.8.

Ece implemented the first version of the STEM lesson plan. She formed four student groups, and preservice teachers sat next to one group. They listened to students' discussions and observed the lesson while cooperating teacher and I sat behind the classroom. Ece presented the engineering design challenge and distributed engineering notebooks. Students investigated the problem through the science magazine, determined the criteria and limitations, discussed possible solutions, and picked up one of them. The materials provided to students were an empty, close-lipped box representing the music room, an egg carton, fibre, sponge, cotton, styrofoam, felt, fabric, newspapers, bubble wrap, and wire sponge cleaner. These materials were set prices and put on the budget sheet. Students were expected to consider criteria and limitations while suggesting solutions to the engineering problem. Ece walked around the groups and facilitated the group discussion in this process. After students created their prototypes, Ece put a mobile phone into students' designs and opened a steady signal tone. She appointed one student from each group to measure and record the decibel values. The decibel values were measured in 15 seconds and three times through the application on her mobile phone. Students took the average of three measurements and constructed bar charts for their results and the other group's results in their engineering notebooks. Ece and one student also formed bar charts on the board. Then, discussions about the effectiveness of the design and the materials used in each design were discussed. At the end of the lesson, Ece implemented Kahoot, which included multiple-choice items. The students gave answers as a group, and Ece completed all the activities on time.

Table 3. 8

The Timeline of Lesson Study 4

Phases of Lesson Study Cycle	Date	Activity	Duration
Planning	08.02.2022	1st meeting: Planning Lesson	47 min.
	14.02.2022	2nd meeting: Planning Lesson	42 min.
	21.02.2022	3rd meeting: Planning Lesson	51 min.
	04.03.2022	4th meeting: Planning Lesson	36 min.
	05-06.03.2022	Pre-interviews (individual)	35-53 min.
Teaching	07-10.03.2022	Implementing Lesson Plan 1 and Observation	4 lesson hours
	10.03.2022	Post-interviews (individual)	36-57 min.
Reflecting	11.03.2022	Revision of Lesson Plan	27 min.
Re-teaching	14-17.03.2022	Implementing a Revised Lesson plan	4 lesson hours
Re-reflecting	21.03.2022	Revision of Revised Lesson Plan	25 min.

After the lesson, cooperating teachers shared her ideas in the school counsellor's room. She indicated that Ece managed the group work very well and answered students' questions adequately. She also appreciated the use of Kahoot and how Ece provided instant feedback about the questions in the test.

Then, I conducted the post-interview individually, and it took between 36 to 57 minutes. After completing post-interviews, the group gathered and reflected upon the lesson. Some minor changes were made in CoRe and the flow of the lesson. For instance, participants decided to add an empty box as a reference point that would not be insulated. In this way, the students would compare the effectiveness of their sound-insulated music rooms in a better way.

Defne carried out the revised version of the STEM lesson plan. Similar to previous lesson studies, observer teachers did not interfere with the flow of the lesson and filled out the observation protocol. There were 19 students in the classroom during the week of the implementation, and Defne formed four student groups. She was attentive to the revisions made in CoRe and implemented them as planned. She completed the STEM lesson plan in four lesson hours.

After the teaching process, the cooperating teacher indicated that adding a control box was a good idea, and the activity became more meaningful in this way. She liked the emphasis on creating bar charts with the data collected. Lastly, she added that Defne managed the classroom better than her previous STEM lesson plan. The participants met online after the day of implementation of the final STEM lesson plan. They did not make any changes in CoRe in the reflection meeting. In this way, four cycles of lesson study were completed.

3.4. Data Collection Instruments

Creswell (2013) pointed out the importance of using multiple ranges of data collection tools in qualitative studies in case studies to get a deeper understanding of the cases. Portraying PCK is not possible through a single data collection instrument in a short period of time (Abell, 2007; Baxter & Lederman, 1999; Loughran et al., 2004). To achieve the purposes of the study, the researcher collected different types of data over five months, as seen in Table 3.9. Data collection instruments included in the present study were: interviews, CoRe, observation protocol, field notes, and video-recorded group meetings. Research questions and the instruments used for each research question are provided in Table 3.9.

Table 3. 9

Research Questions and Data Collection Instruments

Research Questions	Data Collection Instruments
1. How does preservice science teachers' PCK for STEM develop in the context of lesson study?	Pre-Post-interviews CoRe Observation Protocol Video-Recorded Meetings
2. Which elements of lesson study contribute to preservice science teachers' PCK for STEM development?	Pre-Post-interviews CoRe

Interviews and CoRe were utilized as data collection sources for the first research questions. Moreover, data from observation protocol and video-recorded meetings helped to support these data for the first research question. For the second research question, interviews and CoRe were used.

The specific time points in which each data collection instrument was applied were presented in Table 3.10. Participants were asked to prepare pre-individual CoRes and integrate STEM education into it before beginning the first lesson study cycle. Then, the planning meetings were video-recorded and individual pre-interviews were conducted after the teaching phase. During the teaching phase, observation protocols were filled out. Afterwards, post-interviews were carried out individually, and the reflection meetings were video-recorded. Post-individual CoRes were requested from the participants at the end of the four lesson study cycles.

Table 3. 10

Data Collection Matrix

Phases of the Study	The Implementation Time of Data Collection Instruments
At the beginning of the study →	Pre-CoRe (individual)
Lesson Study 1, 2, 3 & 4	CoRe (collaboratively)
planning →	Video-recorded planning meetings Pre-interviews
teaching →	Observation protocol Field notes
reflecting →	Post-interviews Video-recorded reflection meetings
At the end of the study →	Post-CoRe (individual)

3.4.1. Interviews

Interviews provide valuable data when behaviors could not be directly observable (Patton, 2014). Moreover, interviews are considered one of the primary tools to portray participants' PCK in the studies (Chan et al., 2019a). They were carried out to understand how preservice science teachers' PCK for STEM develops in the context of four lesson study cycles in the current study. The interview questions centered on the four components of PCK based on the revised version of Magnusson et al.'s (1999) model enriched with the basic features of STEM education and the elements of lesson study.

Relevant literature on PCK (Henze & Barendsen; 2019; Hynes, 2012; Kutucu, 2016; Loughran et al., 2006; Park et al., 2011; Reynolds, 2020) STEM education (Aydin et al., 2018; Chan et al., 2019; Pimthong & Williams, 2018; Radloff & Guzey, 2017) and lesson study (Bridges, 2015; Coenders & Verhoef, 2019; Guner, 2017) were searched to prepare interview questions. After writing questions in light of relevant literature, the interview questions were given to five researchers to take expert opinions. The experts had experiences and studies related to PCK and STEM education and working at the science education department. They examined the questions in terms of content and quality. There were some changes in the interview questions after taking expert opinions. For instance, I had prepared the same post-interview questions to apply to the teacher of the lesson and observer preservice science teachers. However, I revised the questions and created two sets of post-interview questions with the help of experts' suggestions. After forming the final versions of interview questions based on the feedback and suggestions given by experts, a pilot study was conducted with four preservice science teachers. Then, interview questions were revised, and expert opinions were retaken. The final versions of pre and post-interview questions are provided in Appendix D.

Semi-structured interviews were conducted at different times during the study. Firstly, pre-interviews were implemented individually right after preparing the STEM lesson plan and before teaching. Since four lesson study cycles were completed in the present study, each participant was pre-interviewed four times. Pre-interview questions were used to elaborate on participants' knowledge of PCK components central to teaching

STEM lessons. Participants were also required to demonstrate how they connect different disciplines in their CoRe and justify their reasons in interviews.

Since PCK is unique to each teacher (Shulman, 2015), individual interviews were preferred to track participants' PCK for STEM development and elicit each participant's point of view for the planning phase. Participants might underline different experiences pertinent to the planning process. To illustrate, participants decided to use the 5E learning cycle in the planning phase after intense discussions in lesson study 1. I asked them to explain how this teaching strategy worked for a STEM lesson plan, why it is a better strategy to teach that lesson, and how this strategy helps students' learning in STEM lessons in pre-interviews. Participants provided different reasons for their choice of teaching strategies compatible with STEM education, and conducting individual interviews helped me to understand how their PCK for STEM was varied.

The pre-interviews also had several questions related to the second research question about lesson study. For example, I asked about the benefits of lesson study and how it contributed to their implementation of STEM lessons regarding each component of PCK. I also took field notes during the planning phase. I added essential questions into pre-interview questions to delve into participants' PCK for STEM in accordance with the use of semi-structured interviews when necessary.

Secondly, post-interviews were conducted with the participants right after the teaching of the STEM lesson. There were two sets of questions in post-interviews: one set was for the participant who taught the STEM lesson, and the one set was for the observer participants who observed the lesson. Post-interviews focused on participants' experiences and suggestions for revising CoRe based on STEM education. The first set of questions included items such as "whether there is a difference between planned and enacted lessons, was there anything unexpected during the lesson, what were the points that you experienced difficulty as a teacher etc.". The second set of questions was central to the observations of participants. For instance, "in what points did you observe the students' difficulty? Did the teacher of the lesson detect any misconceptions about science and other fields of STEM? What are the points that you want to discuss in the reflecting meeting about the teaching strategy based on your observations". I added some questions to the post-interview questions based on the observation protocol that I filled out during the teaching phase. Moreover, I collected the participants' observation protocols before conducting post-interviews and examined them. I also added new questions to the post-interview questions based on observation protocols to deeply understand participants' PCK for STEM. There are some questions related to the lesson study process at the end of the post-interview questions. Interviews were audio-recorded, taking the permission of the participants. They took approximately 45 minutes to 60 minutes to complete.

3.4.2. Content Representation (CoRe)

PCK is a tacit construct, and it is challenging to explicitly reveal teachers' reasons for their instructional choices (Loughran et al., 2001). Therefore, CoRe was initially developed by Loughran et al. (2004) to uncover teachers' PCK, and it is used for "how, why and what content to be taught with what they agree to be important in shaping students' learning and teachers' teaching" (Loughran et al., 2012). CoRe has a horizontal axis that includes big ideas or concepts that are considered crucial for students learning. On the other hand, the vertical axis includes factors that might influence teachers' instructional decisions, such as students' difficulties, specific teaching strategies, and activities that might support students' understanding of specific concepts or ways of assessing students' learning. The literature suggested using CoRe in lesson studies to support the development of preservice teachers' PCK (Juhler, 2016). Because of these two reasons, the CoRe was used in the present study as a lesson planning tool to represent participants' PCK for STEM development. CoRe was originally developed for in-service teachers; however, Aydin et al. (2013) adapted it to be used with preservice teachers. Therefore, this study utilized a revised version of CoRe since preservice teachers were required to prepare STEM lesson plans (Appendix E).

Participants were supposed to design a pre-collaborative CoRe in every lesson study cycle and then revise it in the reflection meetings, which was labelled as post-CoRe in the current study. In this way, four pre-CoRes and four post-CoRes were created as a group in the context of the study. Moreover, participants were asked to develop two individual CoRes and infuse the features of STEM education before and after the study. The first individual CoRes were designed after participants were explained how to prepare CoRe since they were unfamiliar with the language of PCK. The post-individual CoRes were prepared after completing four-lesson study cycles. It was aimed to monitor their progress with respect to PCK for STEM as a result of attending four lesson study cycles.

In addition to using CoRe as a lesson planning tool, I asked the prompts of the CoRe the participants during planning and reflection meetings to guide the discussions in the group. For instance, I triggered a discussion by asking, "what could be possible misconceptions related to the speed concept?" Participants discussed in the group reached an agreement about learners' misconceptions and wrote them into CoRe.

The CoRes prepared in the lesson study cycles were expected to include characteristics of STEM education; therefore, an "engineering notebook" was prepared. While doing this, relevant studies in the literature were searched (Engineering is Elementary, 2016; Hertel et al., 2017; Walton & Caruthers, 2016) to prepare an engineering notebook. Hertel et al. (2017) suggested that these written materials scaffold elementary students' learning and help them to organize the activity during the engineering design process. Similarly, the Massachusetts Department of Education (2016) pointed out that using scaffolding materials such as engineering notebooks was helpful for students in proceeding with the steps in the engineering design process. They advocated that "writing down the product design ideas, engineering challenges, and product testing data helps keep track of their ideas, what has been tested, and how well a particular design performed." The engineering design model by the Massachusetts Department of Education (2006) was utilized while preparing the engineering notebook. The engineering notebook basically includes the eight steps of the engineering design process (see Figure 2.4) adapted for the current study. Participants were expected to integrate engineering notebook into teaching strategies and activities as a part of CoRe. Participants were free to use the engineering notebook anywhere it fits in the lesson. Moreover, they might prepare and add additional activities, tables, graphs, questions, etc. to the engineering notebook.

3.4.3. Observation

Patton (2014) indicated the importance of observation as “to describe in depth and detail the setting that was observed, the activities that took place in that setting, the people who participated in those activities, and the meanings of what was observed from the perspectives of those observed” (p. 499). Accordingly, considering the complex nature of PCK and the difficulties of capturing it, utilizing observation is highly recommended in PCK studies (Baxter & Lederman, 1999; Carpendale & Hume, 2019). PCK is a hidden construct; therefore, observation provides invaluable data to portray PCK at the moment (Abell, 2008) in addition to the rich data that interviews provided. Moreover, the importance of "live observation" in lesson study studies was emphasized since any other alternatives, such as lesson plans, students' works, and documents, were not considered a substitute for understanding what really happened in the classroom (Lewis, 2002).

Pre-determined aspects of PCK might be helpful in the analysis of PCK (Chan et al., 2019b). Therefore, I prepared an observation protocol in light of the revised Magnusson et al.’s (1999) PCK model for STEM. The observation protocol enables the researcher and participants to determine which part of the instruction should be observed in parallel with the research purposes of the study. It was aimed to make participants focus on the PCK for STEM components in the present study and record their observations while observing the STEM lesson.

PCK literature that includes observation was investigated to develop an observation protocol (Alonso et al., 2012; Barendsen & Henze, 2015; Capobianco & Rupp, 2014; Carpaendale & Hume, 2019; Lee et al., 2007; Park et al., 2011). Furthermore, observation protocols in STEM education were also analyzed. Science and Engineering Classroom Learning Observation Protocol (Dringenberg et al., 2012), STEM Integration Curriculum Assessment Protocol (Guzey et al., 2016), UTeach Observation Protocol for Mathematics and Science (Walkington & Marder, 2018), Reformed Teaching Observation Protocol in Science and Mathematics (Sawada et al., 2002), Classroom Observation Protocol for Engineering Design (COPED) (Wheeler et al., 2018) and The Engineering-Infused Lesson Rubric (Peterman et al., 2017) were examined in detail to design observation protocol to be used in the present study. Firstly, the structure of the observation protocol was formed, and the items were written. Then, the observation protocol was presented to four science educators to take expert opinions. It was piloted during two lesson study cycles, revisions were made, and expert opinions were taken again. Finally, the observation protocol was ready for the main study and given in Appendix F.

There were three main parts to the observation protocol. In the first part, general information was asked, such as the name of the teacher of the lesson, duration of observation, number of students in the classroom, etc. The second part comprises five sections. Four of them were related to PCK components utilized in the current study (knowledge of curriculum, learners, instructional strategies, and assessment), and the last section was related to the basic features of STEM education. There were "yes", "no," and "partially" options for each item in the observation protocol. The observer preservice science teachers and I were supposed to choose one option, provide detailed explanations, and write exemplifying instances from the classroom to support our observations.

In the third part, observers were free to write additional notes if there was something unexpected or interesting during instruction that attracted our attention. Observers were required to propose at least three points to revise the lesson plan based on the components of PCK for STEM and write them down at the end of the observation protocol.

The observation protocol was used for triangulating the data from interviews and CoRe in the present study. Participants and I observed the instruction and filled out the observation protocol. Then, I utilized these observations to re-formulate post-interview questions, as Merriam (2009) suggested, to trigger discussions in the revision meetings. For example, the teacher of the lesson wrote some formulas on the board during teaching, and I asked why she preferred to do this, etc. Based on the observation of instruction, the lesson plans were improved in the reflection meetings in the present study.

Each STEM lesson lasted approximately three to four classroom hours. Participants and I observed 30 lesson hours in total and filled out the observation protocol. Moreover, I also took field notes while observing the instruction. These observations could not be audio-taped or videotaped because the school did not give permission.

3.4.4. Video-Recorded Meetings

Video-recorded meetings help the researcher capture the participants' interaction and understand their perspectives on the issue in the planning process, and they are useful in tracking participants' developments in lesson study studies (Lewis et al., 2006). The video recordings in the present study were used to catch participants' discourse regarding PCK for STEM in the planning and reflection meetings. It was used as a secondary source to triangulate the data.

Participants shared their ideas in the planning meetings regarding objectives, learners, instructional strategies, and assessment to design a CoRe enriched with STEM education. Then, each idea was discussed among the group members, and the dialogues between the participants were recorded. Participants generally came together three or four times in the planning meetings. The planning meetings for one cycle of lesson study lasted approximately four hours. Until the end of the study, four planning meetings were recorded. These meetings provided a fruitful environment to gain insight into participants' development of PCK for STEM.

On the other hand, participants reflected on their experiences and observations in the meetings conducted after teaching by using the observation protocol. Firstly, the teacher of the lesson mentioned his/her experiences and made suggestions for the improvement of the STEM lesson. Then, the observer preservice teachers shared their observations in the reflection meetings. Participants argued what could be done to modify the CoRe in these meetings and revised the CoRe for the re-teaching phase. There were two recorded reflection meetings for the first lesson study cycle, while there was one recorded reflection meeting in lesson study 2, 3, and 4. The duration of these meetings generally took one hour. As a result, these video-recorded meetings in the planning and reflecting phases helped me to gain an understanding of their PCK for STEM and were used to support to findings gathered from interviews and CoRes.

3.5. Data Analysis

3.5.1. Data Analysis of Preservice Science Teachers' Development of PCK for STEM

The data analysis of the interviews, CoRes, observation protocol and video-recorded meetings were content-analyzed below to answer the first research question.

The iterative cycle was employed in data analysis in the present study. Firstly, all interviews were transcribed verbatim, and the data were read. Then, I created a tentative coding scheme based on the modified version of Magnusson et al.'s (1999) PCK model for STEM. After forming the initial coding scheme, three interviews and two CoRes were coded by two researchers independently. The codes were placed under the components and sub-components of PCK, which are knowledge of curriculum, learners, instructional strategies, and assessment. Then, we came together and compared our coded interviews and CoRes. We identified discrepancies and reached a consensus after discussions. The tentative coding scheme was revised because new codes emerged during this process. Therefore, inductive and deductive analyses were conducted to analyze the interviews and CoRes (Patton, 2002). For instance, engineering-related misconceptions were an existing code from the modified version of PCK for the STEM model; however, revision in instruction based on assessment and strategies for engagement with engineering concepts were the new codes created after the first round of analysis. Moreover, one more interview was coded separately based on the revised version of the coding scheme. Two researchers met again and decided that the coding scheme was adequate for further analysis. The final version of the coding scheme is provided in Table 3.11. Then, I coded the remaining interviews, CoRes, and observation protocol using the final version of the coding scheme.

Table 3. 11

The Final Version of the Coding Scheme

PCK Components	Codes and Examples
Curriculum	**Setting objectives** (e.g., setting objectives for science, engineering and engineering design process, mathematics, technology) **Relation to other topics** (e.g., relation to the other topics in science, relation to the science content to other STEM disciplines
Learners	**Misconceptions** (e.g., science-related misconceptions, engineering and engineering design process-related misconceptions, mathematics-related misconceptions) **Difficulties** (e.g., science-related difficulties, engineering and engineering design process-related difficulties, mathematics-related difficulties)
Instructional Strategy	**Teaching strategies compatible with STEM (**e.g., using 5E, REACT, problem-based learning) **Design-centered teaching practices (**e.g., providing scientific rationale for a design solution, re-building products) **Strategies for engagement with engineering concepts (**e.g., utilizing engineering terminology, using authentic problems related to science and engineering) **Representations and activities (**e.g., using representations and activities specific to science, specific to engineering, specific to mathematics)
Assessment	**What to assess (**e.g., focusing on product, science content outcomes) **How to assess (**e.g., using alternative assessment, traditional assessment) **Revision in instruction based on assessment (**e.g., revising the objectives after the assessment)

The next step was using the codes to form categories for the development level of PCK for STEM (Patton, 2002). PCK for STEM categories formed with the help of Aydin-Gunbatar et al. (2020) categories in the present study. The participants' level of PCK for STEM development was identified through these categories (Figure 3.2).

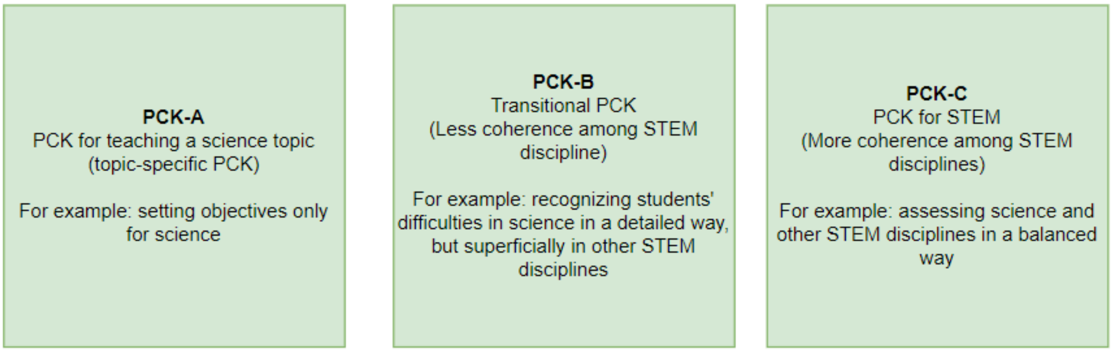


Figure 3. 2 Categories for PCK for STEM Development

The first category is PCK-A which does not include the basic elements of STEM education. This level of PCK focuses only on the science content; there is no attempt to integrate STEM disciplines, and the engineering design process is not used. Therefore, it is labelled as a topic-specific PCK for teaching science (TSPKC). On the other hand, PCK-B and PCK-C categories consisted of characteristics of STEM education. While PCK-B involves problematic integration, PCK-C refers to the complete and balanced integration of STEM education. PCK-B is called transitional PCK, whereas PCK-C is named PCK for STEM, as seen in Figure 3.2. For instance, with respect to knowledge of instructional strategies, design-centered teaching practices were used to some extent (i.e., conducting research to solve the problem or re-designing parts were missing) in the PCK-B category. PCK-C category includes many design-centered teaching practices along with the appropriate representations and activities. As a result, three categories emerged by putting all data from individual and collective CoRes, interviews, and observation protocols in the present study. Detailed information about the PCK for STEM categories concerning each component is provided in Table 3.12.

Table 3. 12

The Detailed Information about PCK for STEM Categories regarding Each Component

PCK for STEM	PCK-A PCK for teaching a science topic (Topic-specific PCK)	PCK-B Transitional PCK (Less coherence among STEM disciplines)	PCK-C PCK for STEM (More coherence among STEM disciplines
Curriculum	Setting objectives only for science and limited connection to other topics in science	Setting objectives for science and other STEM disciplines, but the emphasis is on science objectives and less-details for objectives in other STEM disciplines, relating to other STEM disciplines with some limitations	Setting objectives for at least two STEM disciplines explicitly, giving detailed explanations about the objectives and relating to other STEM disciplines sufficiently
Learners	Providing difficulties/ misconceptions only in science	Providing difficulties/ misconceptions in one STEM discipline in a detailed way, superficially in other STEM disciplines	Providing difficulties/ misconceptions in at least two STEM disciplines in a detailed and balanced way
Instructional Strategy	Using teaching strategies and representations/activities for teaching a science concept only	Using teaching strategies compatible with STEM education with a limited understanding, implementing representations/activities in one STEM discipline in a detailed way, superficially in other STEM disciplines, applying design-centered teaching practices with some limitations	Using teaching strategies compatible with STEM education with a comprehensive understanding, implementing representations/activities in science and other STEM disciplines in a balanced way, applying many of the design-centered teaching practices

Table 3. 12 (continued)

The Detailed Information about PCK for STEM Categories regarding Each Component

Assessment	Assessing only science content outcomes	Assessing one STEM discipline more (i.e., engineering) and assessing other STEM disciplines superficially, limited use of different assessment methods	Assessing both science and other STEM disciplines sufficiently and in a balanced way, using a variety of assessment methods

Regarding the analysis of video-recording meetings, the videos were analyzed without transcribing. The researcher took field notes during the planning and reflecting meetings, and specific instances were determined with the help of these notes. These instances were focused mainly on participants' discussions about curriculum, learners, instructional strategies, and assessment with respect to STEM education. Then, the timeline was generated, and relevant video segments were labelled using the final coding scheme of PCK for STEM (see Table 3.11). Lastly, the video segments of interest were transcribed and used to triangulate the data from interviews and CoRes.

In the last part of the first research question, I focused on how participants' PCK for STEM regarding the four components showed variability throughout the process. I prepared the summary tables for each case and illustrated them at the end of each case. Then, I compared and contrasted to understand whether there were any similarities and differences in participants' PCK for STEM development patterns throughout the four lesson study cycles. The cross-case analysis was done component by component for each case.

3.5.2. Data Analysis for Contribution of Lesson Study for PCK for STEM Development

The second research question is related to how the elements of the lesson study contributed to participants' PCK for STEM development. Within this respect, I analyzed pre and post-interviews and used CoRes to support the data. I asked directly which experiences of the lesson study helped them to improve their implementation of STEM lesson plan types questions in the interviews. Firstly, I listed the elements of lesson study utilized in the present study as: planning, using CoRe, teaching, observing, and reflecting. I determined the participants' statements regarding the elements of lesson study in the interviews in each lesson study cycle. I also checked the data in pre and post-CoRes while doing this. For example, one participant mentioned that the observation of the lesson had an effect on her knowledge of learners with respect to engineering related-difficulties, and I examined the post-CoRe whether this was added as a leaners' difficulty in the revised CoRe. Then, the number of participants who mentioned the specific elements of the lesson study concerning each PCK for STEM component was counted. For instance, how many participants underlined the significance of the collaborative planning of CoRe helped to improve their knowledge of instructional strategies were calculated and transferred to the table (see Table 4.6). Finally, I chose example statements to enhance insight into participants' PCK for STEM development according to elements of the lesson study.

3.6. Trustworthiness

Different terminologies are used to refer to validity and reliability in qualitative and quantitative studies. Lincoln and Guba (1986) stated that “credibility as an analog to internal validity, transferability as an analog to external validity, dependability as analog to reliability, and conformability as an analog to objectivity” (p. 76-77). Three criteria of trustworthiness, credibility, dependability, and transferability are presented in detail below.

3.6.1. Credibility

Creswell (2013) mentioned eight strategies to increase credibility and suggested using at least two of them in qualitative studies. Four of them were utilized to ensure credibility in the present study as follows: triangulation, member check, peer debriefing, and prolonged and persistent observations.

Firstly, Patton (2002) explained the logic behind triangulation as "…the premise that no single method ever adequately solves the problem of rival explanations" (p.555). Triangulation is one of the alternatives that intensify the results of the study. There were four different triangulation methods reported by Patton (2002): data triangulation, investigator triangulation, theory triangulation, and methodological triangulation. Data triangulation was employed in the present study by using different data collection instruments, such as interviews, CoRe, observation protocol, and video-recorded meetings. In this respect, I had a chance to cross-check the data. For instance, I compared the participants' post-interviews with the observation protocol and CoRe. How a variety of data collection instruments were applied at a specific time of the study was provided in the main study part. Moreover, investigator triangulation was achieved by including multiple observers during the teaching phases of the lesson study. Besides me, three preservice science teachers were involved in the observation process. Before starting the study, they were presented with the PCK construct and its components. Then, PCK for STEM observation protocol was introduced to them prior to the observation process. 30 hours of STEM lessons were observed by the researcher and three preservice science teachers. After observation, the group came together and shared their observation with the aid of the observation protocol. The discussions were centered on the four components of PCK for STEM, and a consensus was reached regarding observations in these meetings.

Secondly, member check is another strategy used in the present study. It requires involving participants in the process of checking categories and interpretation of the data (Creswell, 2013). After completing the analysis of the data, I met online with the two participants of the study separately. Instead of giving the raw data, I showed them the summary tables and categories of their PCK for STEM development levels (see Table 4.2 and Table 4.4). I shared the general findings with them and asked them to examine the interpretation and accuracy of their data. Participants agreed with the interpretation of the findings, which increased the credibility of the data.

Thirdly, peer debriefing was applied in the present study. The involvement of outsiders in the research process for checking and stimulating questions is recommended for credibility (Creswell, 2013). Two experts from science education provided feedback throughout the study. Besides, two other professors in science education tracked the whole process on a regular basis. Lastly, another researcher was involved in the data analysis process and helped me interpret the data.

Fourthly, prolonged engagement and persistent observation are the alternative strategies to achieve credibility. Creswell (2013) expressed this issue as the "closeness of the researcher to the participants" (p. 250). I had known participants from the laboratory courses that I had assisted as a researcher assistant before conducting the study. Additionally, I spent nearly six months with the participants during the data collection process. We met several times in the planning phase, observed the first and revised versions of STEM lesson plans, and reflected upon our experiences and observations in the reflection meetings in four lesson study cycles. The data collection process was intense, and we were in touch throughout the process. This provided developing trust and rapport. Thanks to long-term engagement, I had a chance to monitor their development of PCK for STEM.

Lastly, different from Creswell (2013), Patton (2002) pointed out the importance of the "credibility of the researcher" in enhancing the credibility of the study (p. 552). As a researcher, I did not take any courses related to qualitative analysis; however, I read fundamental books in the field. Moreover, I was involved in scientific research projects in which we conducted qualitative studies. I had a chance to gain experience in data collection, data analysis, and data interpretation in qualitative studies. With respect to PCK, my master thesis was about preservice science teachers' perceptions of PCK, and I was familiar with the construct. Concerning STEM education, I participated in workshops and seminars and conducted studies related to STEM education. Lastly, implementing a pilot study before the main study contributed to my understanding of PCK for STEM. The abovementioned points were considered significant to advance the credibility of the present study.

3.6.2. Dependability

Dependability refers to “rather than demanding that outsiders get the same results, a researcher wishes outsiders to concur that given the data collected, the results make sense- they are consistent and dependable” (Lincoln & Guba, 1986, p. 206). There were some strategies to enhance the dependability of the study, which were used in common with credibility. For instance, data triangulation and investigator triangulation were employed in the present study, and they were explained in the previous section. Furthermore, interrater reliability was established by using the formula suggested by Miles and Huberman (1994):

Number of agreements/(Number of agreements + number of disagreements) x 100

According to this formula, interrater reliability was calculated as %81 for interviews after the first round of data analysis which was an acceptable value. It was realized that the researchers detected different codes or skipped some statements to code in this process. These discrepancies were identified, and an agreement was reached at the end of the first round of analysis.

3.6.3. Transferability

This term matches with external validity in quantitative studies; however, making a generalization is not the focus of the case study. Transferability in qualitative studies is defined as "the extent to which the findings of a study can be applied to other studies." (Merriam, 2009, p.223). There were some cautions to ensure the transferability. Firstly, thick descriptions were provided in the present study. The participants of the study were introduced, and the context of the study was provided in detail, as Lincoln and Guba (1986) indicated. Each step of the four lesson study cycles was presented in detail, and the data collection process was given explicitly in the main study section of the methodology. Secondly, I studied with more than one preservice teacher to increase the transferability of this study.

3.7. The Role of the Researcher

The role of the researcher may vary in the studies, and Gold (1958) proposed four stances ranging from complete participant to complete observer. I was in the role of the observer as a participant in the planning and reflecting phases and a complete observer in the observation of the teaching phase of the study. The observer-as-participant role is defined as "observe and interact closely enough with members to establish an insider's identity without participating in those activities constituting the core of group membership" (Merriam, 2009, p. 124). I participated in the meetings as a researcher; however, observation was my main concern during this participation. In other words, I was in the "peripheral membership role" (p. 124) in the lesson study group. On the other hand, I did not participate in any activity conducted in the classroom environment and I was a complete observer. The details are given below.

With respect to the "observer as participant" role, I presented the PCK for STEM and its components in the initial meetings of the study. Then, I talked about the elements of lesson study and described each step in a detailed way. I set the schedule for meetings for designing STEM lesson plans in the planning phase. I attended all the meetings and observed, took field notes, and video-recorded the meetings. I did not present my ideas while preservice science teachers were preparing STEM lesson plans. Instead, I was involved in the discussion by asking questions like "Which objective do you want to choose from the science curriculum? Why do you think we should continue with … objective?". I tried to include all participants in the group discussions without making evaluations. Moreover, I ensured that participants answered the prompts in CoRe while planning the collaborative STEM lesson and developed and integrated the engineering notebook appropriately.

In the reflecting phase, I was in the facilitator role and encouraged participants to share their observations and suggestions for improving the STEM lesson plan. Firstly, I benefited from observation protocols and post-interviews to create a discussion environment in the reflection meetings. Then, I started with the experiences of the teacher of the lesson first and then continued with the observation of other preservice science teachers. I guided the group in terms of talking about the prompts in the CoRe in these meetings.

For the teaching phase, I was in the role of a complete observer. I was present in the classroom but did not interfere with the lesson. I sat behind the classroom and completed the observation protocol. Sometimes, I walked around the students' groups and monitored the dialogues among students' groups and student-teacher. I recorded them in the related part of the observation protocol. The students were familiar with the presence of the researcher in the classroom because I was a research assistant of "Practice Teaching in Science-1" and I visited the classroom for two weeks before the main study started. I spent some time with these students.

3.8. Ethical Considerations

Prior to the study, ethical considerations were taken into account, and necessary permissions were granted. Firstly, I applied to the METU Ethics Committee to implement the research. Then, I applied to the Ege University Ethics Committee and Ministry of National Education since some data would be collected in a real classroom environment. The approvals taken are given in Appendix A, Appendix B, and Appendix C.

Before the study, participants were presented with the flow of the study, and the researcher's expectations were explained clearly. The present study was a part of the compulsory course. Participants were informed that they might quit the study at any time they wanted and follow the regular syllabus of the Practice in Science Teaching course. They all agreed to participate voluntarily and signed a consent form. Pseudonyms were used for all preservice science teachers and the science teacher involved in the study. They were informed about the data collection instruments. Nobody was harmed or deceived throughout the study (Frankel et al., 2012). Furthermore, the researcher ensured the confidentiality of the data and protected the video recordings, the recording and transcription of interviews, and other written materials.

3.9. Limitations

One of the main limitations of the present study might be not recording the teaching phases of the lesson study because of the school policy. Therefore, some important instances might be missed while observing the classroom. However, several observers were present during the teaching phases, and they used the observation protocol to minimize the effects of this limitation.

The other one might be related to the existence of the researcher in the planning, teaching, and reflecting phases. I frequently emphasized that the purpose of this study was not to criticize and evaluate the participants but to understand their PCK for STEM and how it changed throughout the study. I informed the participants about the process of the study at the introductory meeting and reminded them that they did not need to change anything while planning the lesson and teaching to decrease the limitation. Moreover, another limitation of the study might be associated with my approach to STEM education. Since there are different definitions of STEM education, I needed to clarify my perspective and conceptualize STEM education as a researcher at the beginning of the study. Then, my approach to STEM education might influence the participants' integration of STEM.

The last one might be related to the grouping of middle students during STEM lessons. Participants of the study desired to create heterogeneous groups in the design process (involving both girls and boys in the group, involving students with different academic levels in the same group, etc.). However, due to the Covid-19 restrictions, middle students had to be grouped with the students sitting near them. This might influence the results, especially with respect to the knowledge of learners and instructional strategies regarding design-centered teaching practices.

CHAPTER 4

FINDINGS

This section was divided into two main parts. In the first part, participants' PCK for STEM was presented under four components: knowledge of curriculum, knowledge of learners, knowledge of instructional strategies, and knowledge of assessment. The results for each case were presented in detail through four lesson study cycles. Then, summary tables for participants' PCK for STEM development were formed. The results from each case were compared and contrasted at the end of the first part. In the second part, which elements of the lesson study contributed to participants' PCK for STEM were described.

4.1. Results for Preservice Science Teachers' Development of PCK for STEM

4.1.1. Case 1: Ada

4.1.1.1. Knowledge of Curriculum

4.1.1.1.1. Lesson Study 1

Ada was the teacher of the revised version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation protocol, and planning and reflecting meetings were considered in this section.

Before the study, Ada set only science objectives in her pre-individual CoRe. She chose an objective related to designing projects for the efficient use of resources from the 8th grade in the science curriculum to prepare a STEM lesson plan. The researcher asked the reasons for her choice. She indicated that she experienced difficulty deciding the objectives to plan STEM lessons and changed the objectives twice while designing her lesson plan. She expressed that:

> The expression "designing a project" attracted my attention in the curriculum (science curriculum). I think it is suitable for STEM education because it

> includes a problem that we might encounter in daily life. This is the first thing that came into my mind while planning my lesson. There was no daily life problem in the plan that I changed before **(pre-interview-1).**

As seen from the excerpt above, she had little understanding of the reasons for choosing objectives for STEM lesson plans. She considered STEM education equal to doing a project. She did not establish objectives for the mathematics and engineering design process and did not mention any relation to other STEM disciplines before the study.

In planning meetings of lesson study 1, Ada was one of the active participants in choosing the objectives for the first STEM lesson plan. However, she stated that she had not analyzed the curriculum from a STEM education perspective before. She was unaware of the engineering practices provided on the front pages science curriculum at the beginning of the study **(researcher's field notes, planning meetings of lesson study 1).** She was involved in the discussions actively to choose objectives from the science curriculum:

> **Deniz:** We can choose the objectives regarding planets and make a design regarding planets. They can make a model of planets.
> **Ada:** Yes, maybe. We can choose the objectives related to the Solar eclipse. The students might have misconceptions about whether the Sun or the Earth is bigger. This misconception is not considered when forming Solar eclipse models **(video-recorded planning meetings, lesson study 1).**

She had a limited understanding of the engineering design process; therefore, it was reflected in her knowledge of the curriculum with respect to choosing science objectives for STEM lessons at the first meetings of lesson study 1. However, she began to look from a different point of view at the end of the second planning meeting:

> **R**: If you want students to prepare a model of a Solar eclipse in the STEM lesson plan, how could you plan an engineering notebook? For example, how can you arrange to propose more than one solution part?
> **Ada**: Actually, I have been thinking about this issue since the beginning of the meeting. I think there are no multiple solutions in the design process if we decide to continue with this objective. Students will create the same models to observe the Solar eclipse. There would be only one correct model **(video-recorded planning meetings, lesson study 1).**

Ada concentrated on that the objective of the science curriculum should be suitable for the engineering design process in STEM lesson plans in the planning meetings and gave up what she had suggested in the first meetings. Later, she came up with a totally different idea in the next planning meeting, which all-group members agreed on:

> **R:** Is there anything different you want to share about choosing objectives?
> **Ada**: I have an idea. We can make a Solar eclipse viewer by choosing the objective related to "predicting how the Solar eclipse happens. "While examining the textbook, I saw the warning, "do not look at the Sun with the naked eye. "This could be our problem, and we can apply to test and propose more than one solution part of the engineering notebook with this objective easily. We can create our own Solar Eclipse model, and students might test their design through this model. We can provide X-rays, CDs, and filters, and students might provide alternative solutions. We can say that there is a need for Solar eclipse viewers to observe the Solar eclipse that is cost-effective **(video-recorded planning meetings, lesson study 1).**

As seen in the excerpt above, she mentioned that the science objectives should be based on daily life problems and suitable for the engineering design process to plan a STEM lesson. The group participated in her opinion and continued with her suggestion. After deciding to set objectives for science, no more discussions were held about setting objectives for other STEM disciplines. They wrote only objectives from the science discipline in their first CoRe, and Ada agreed with her friends during the planning meeting. There was a minor change in the objective that was chosen. When asked the reasons for choosing a particular objective and modifying it, she stated that:

> We considered the engineering design process to choose an objective for our first STEM lesson plan. Students are going to design a Solar eclipse viewer. We chose an objective suitable for the engineering notebook. We just changed the verb of the objective. The science curriculum says students will predict how a Solar eclipse happens. We revised it and decided to use the verb "observe. "Students will observe the Solar eclipse through their viewers directly at the end of the engineering design process **(pre-interview, 1).**

She mentioned that the focus was on designing a product and engineering design process while writing and revising the science objectives. It showed an inconsistency between her knowledge of the curriculum and her knowledge of instructional strategies. She underlined the significance of the engineering design process while setting objectives but did not think about writing engineering-related objectives. Her knowledge of the curriculum with respect to setting goals was very limited at the end of the planning meetings.

In terms of relation to other science topics, she linked with the previous topic at the same grade, such as the motions of the Sun, Earth, and Moon relative to each other. She also associated the Solar eclipse topic with 5th-grade objectives which were related to shadow, penumbra, and umbra **(pre-interview, 1).** However, she did not link the topic with any objectives from other STEM disciplines. Similarly, she did not mention relation to other science topics and STEM disciplines in her observation form-1 while observing Deniz's lessons **(pre-observation form, 1).**

She started to criticize the objective that they wrote after implementing the first lesson plan. When she was asked whether she would offer changes in the objectives in the revision meeting, she expressed that:

> Actually, our lesson plan was more comprehensive than the objective we wrote. Maybe we could change it like this: students will observe the Solar eclipse through their designed viewers. I was thinking about how we can modify the objective in our planning meetings, but now I realize why we need to change. Students designed products, and we created an environment where students might develop some skills, such as creativity and critical thinking. They criticized their Solar eclipse viewers and determined the weakness of their designs at the end of the lesson. Making observations was a small part of our lesson; therefore, I think we need to modify the objective **(post-interview, 1).**

Based on observation of teaching, Ada also brought her ideas up for discussion in revision meetings.

> **R**: Do you want to make any changes to the lesson's objective?
> **Ada**: I have some thoughts about the objective. We do more than observe the solar eclipse in our lesson.
> **Ece**: I totally agree with you. I think we need to use the word "design" in our objective.
> **Ada**: Maybe.
> **Ece:** What about "observing Solar eclipse with the viewers they designed."
> **Ada**: If we say, "observe the solar eclipse in the solar eclipse model."
> **Ece**: I think we should directly write “design a viewer to observe Solar eclipse and test it”.
> **Ada**: yes, this is better **(video-recorded reflection meetings, lesson study 1).**

Ada did not make solid suggestions about revising the objectives; however, her knowledge of curriculum regarding setting objectives for other STEM disciplines began to develop through the reflection of lessons and discussions after the reflection meeting.

In the re-teaching part, she was the lead teacher of the revised version of the lesson plan. At the beginning of the lesson, she made links with the following topics at the same grade level and previous topics in the science curriculum. The part provided below was taken from Ada's observed instruction:

> **Ada:** Why should we use the Solar eclipse viewer?
> **S1:** To protect our eyes
> **S2:** Not to burn our eyes
> **Ada:** Yes, you are right. You had learned the sense organs in the previous years. But what we can do to keep our eyes healthy will be covered in the following units, so I will not go into the details right now **(researcher's post-observation form, 1).**

As seen above, she talked about horizontal and vertical relations in the science curriculum. As opposed to linking to other topics in science, no explicit relation to other STEM disciplines was observed in her lesson at the end of lesson study 1. No change was made in terms of the objectives at the end of lesson study 1.

Ada's PCK for STEM in relation to knowledge of curriculum belonged to the PCK-A category at the beginning of the study. She planned a CoRe to teach science lessons when asked to prepare a STEM lesson plan. She only set objectives for science by directly selecting the science curriculum, and no evidence of relating the topic to other science topics was found in her pre-individual CoRe. She moved to the PCK-B category after completing lesson study 1. Her PCK was transitional. Although she discussed integrating STEM disciplines, she did not suggest writing additional objectives for other STEM disciplines. She began to improve her knowledge regarding connecting relations to other science topics, but the relation to other STEM disciplines was not noticeable. These points in her teaching and explanations exhibited the features of the PCK-B category.

4.1.1.1.2. Lesson Study 2

Ada was the observer teacher in lesson study 2; therefore, the findings regarding knowledge of curriculum were from her pre and post-interviews, observation form, planning, and revision meetings.

With respect to setting goals, the group had different ideas in choosing science objectives from the science curriculum in planning meetings of lesson study 2. After intense discussions, the group agreed to continue with Ada's suggestion. She asserted choosing an objective regarding "speed" because she indicated that she had misconceptions about this topic. She thought students might have similar misconceptions, and they might eliminate misconceptions about speed by utilizing the engineering design process. Moreover, she pointed out the importance of writing a motivating problem for students for the engineering design challenge as follows:

> **Ada:** Recently, the F1 race was held in our country, and we watched the news about it. We could start with the problem of designing the fastest race car to win the race in the next year and ask students to solve the problem as engineers if we chose the objective regarding speed. They might learn the speed concepts and then design a race car. This objective and problem might be attractive to them. We can construct a racetrack for testing. The car that will come to the finish line earlier will win the race.
> **Deniz**: I like the idea. I am not sure whether the girls consider this activity engaging. However, if we choose the speed objective, it will fit with the engineering design process **(video-recorded planning meetings, lesson study 2).**

The discussions continued with writing objectives from different disciplines. Ada did not offer any objectives at this point. Defne suggested writing mathematics objectives from the mathematics curriculum focusing on drawing line charts with the data collected. Ece and Deniz put forward ideas for writing objectives regarding the engineering design process and product design. Ada joined her friends' ideas during these discussions **(researcher's field notes, planning meeting of lesson study 2).**

Although she did not offer to write objectives from other STEM disciplines, she contributed to the discussions. Moreover, she started to improve her knowledge of curriculum and talked about the importance of setting objectives from different disciplines in STEM lesson plans after planning meetings. The below conversation was from the interview conducted after the planning meetings:

> We had not written objectives regarding mathematics and engineering in the previous STEM lesson plan. On the other hand, one of the purposes of the STEM lesson plan was to provide students with the knowledge and skills from these disciplines. With the suggestion of my friends, we examined these curricula (mathematics and technology and design). Besides, I also realized that what we assessed in the previous plan and what we determined as an objective were not compatible **(pre-interview, 2).**

She underlined the significance of integrating the skills and knowledge from different disciplines through writing objectives about these disciplines in STEM lesson plans after group discussion. She also connected her knowledge of assessment and curriculum. The lack of harmony between the objectives and the type of assessment led her to consider writing objectives from other STEM disciplines during lesson study 2.

Moreover, she began to criticize the objectives of the science curriculum. She said there was a limitation in the objective that the concept of velocity should not be handled in the lesson. Though, she explained that:

> The curriculum says the concept of velocity should not be mentioned. But how can we clear up that misconception without mentioning velocity? I do not think it is possible at all. We have to teach the difference. We should say, this is speed, this is velocity, so the speed is not equal to velocity. Without mentioning velocity, I am unsure how we can avoid this (**pre-interview, 2).**

She considered that the science objective should be modified, and limitations in the science curriculum should be removed to eliminate students' misconceptions about speed. However, the first version of the STEM lesson plan included this limitation.

Ada had not provided a clear understanding of why she decided to choose particular science objectives in lesson study 1; however, she started to elaborate on her understanding concerning the reasons for selecting science objectives in planning meetings of lesson study 2. She had mentioned more general knowledge about the objectives in the previous cycles of lesson study; however, she reflected on the science and mathematics curriculum in the lesson study 2 as follows:

> We chose two objectives from the science curriculum about speed. We took an objective regarding drawing a graph from the mathematics curriculum. I believe that these two objectives from different disciplines complemented each other. Students will measure how many seconds their cars will complete the track, then calculate the speed by using this time and the length of the track. If we do not include the graphics that will show the speed of their car on the graphic, I think the testing phase would be left unfinished **(pre-interview, 2).**

With respect to other STEM disciplines, she touched upon the use of mathematics and technology and design curriculum while planning a STEM lesson plan for the first time in the present study, as seen above. She provided content-specific details, and the content of science was connected to the mathematics curriculum. She also added that she had never examined the mathematics curriculum before the study but remarked that it was necessary to plan this STEM lesson to collect and interpret data. She was aware of the objectives regarding the engineering design process that existed in the technology and design curriculum after planning meetings **(pre-interview, 2).**

Regarding links with other science topics, she said she did not know any science topics related to the concept of speed both in previous years and previous topics in the 6th grade **(pre-interview, 2).** She has limited knowledge of vertical and horizontal relationships in the science curriculum at the end of the planning meetings of lesson study 2.

After the planning phase, Ada observed Defne's lesson, and she thought that the teacher of the lesson did not link other science topics. On the other hand, she observed and noted that Defne explained how to draw line graphs by addressing the mathematics curriculum **(pre-observation form, 2).** It could be said that while her knowledge of relating to other STEM disciplines was improving, her knowledge of relating to other science topics remained undeveloped after the first implementation of the STEM lesson plan in lesson study 2.

When she was asked whether she had suggestions for the reflection meeting with respect to objectives, she stated:

> I think we should consider the concept of "velocity." We should not think of it as a limitation; we have to include it in our lessons to eliminate misconceptions. Moreover, the cooperating teacher suggested using the mathematical formula for the concept of speed which I also agreed with her. In this way, we can have a chance to overcome misconceptions about speed and velocity **(post-interview, 2).**

Using mathematical formulas in the concept of speed was a limitation of the science curriculum. Ada was aware of the scope of the curriculum, and she criticized this issue and discussed it with her friends. She used her subject matter knowledge to revise the objectives of the science curriculum. In the revised version of CoRe, objectives were modified, and these two limitations were removed. The science objectives were subjected to change after the reflection meeting, while the other STEM discipline objectives remained the same **(researcher's field notes, reflection meeting of lesson study 2).**

During the re-teaching part, she paid attention to the revised version of the science objectives. She noted that the teacher of the lesson used mathematical formulas and gave importance to the concept of velocity, as they discussed in the reflection meeting. She also noted that Ece related the speed of the car to the friction topic between the tire and surface from the previous grade **(post-observation form, 2).** This demonstrated that she was able to enhance her understanding with respect to relation to science topics from the previous year's science topics after observation of teaching.

In brief, Ada's knowledge of curriculum transitioned from the PCK-B to PCK-C category at the end of lesson study 2. She started to think about writing objectives for science, engineering, and mathematics with equal emphasis. Regarding science objectives, she provided a deeper understanding of the scope of science objectives, limitations in the curriculum, and the reasons for modifying science objectives. She explicitly connected science objectives and other STEM disciplines' objectives. Moreover, she could sufficiently relate the science topics with other science topics and other STEM disciplines, which displayed the features of the PCK-C category at the end of lesson study 2.

4.1.1.1.3. Lesson Study 3

Ada was the teacher of the first version of the STEM lesson plan in lesson study 3; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were presented in this section.

Ada suggested preparing a STEM lesson plan concentrating on the objective regarding thermal insulation in the science curriculum. All the group members participated in her idea **(researcher's field notes, planning meetings of lesson study, 2).** The original objective was "determining the selection criteria of thermal insulation materials used in buildings." The group modified this objective to prepare a STEM lesson plan. In the pre-interview, she was asked how they came up with revising science objectives; Ada responded that:

> In fact, we intended to plan a lesson by considering the principles of thermal insulation and designing a thermos based on these principles. We were concentrating on the buildings as the curriculum compelled us to write engineering design challenges. We needed to integrate different disciplines, and we thought the existing objective was inadequate. We used the thermal insulation of buildings concept in the elaboration part (of 5E) to apply the

> knowledge in different contexts. Students will go through a design process using their thermal insulation knowledge to solve the given problem **(pre-interview, 3).**

Ada criticized the science curriculum as narrow-scoped to preparing an integrated lesson plan. She elaborated on her understanding and proposed revisions to science objectives to make them suitable for the engineering design process in planning meetings of lesson study 3.

With respect to setting objectives for other STEM disciplines, she offered to write objectives in mathematics and engineering disciplines. However, in planning meetings, she argued to write objectives from the 2nd-grade mathematics curriculum and then changed her mind. She indicated that she did not focus on grade level when suggesting mathematics objectives. She thought that while calculating the budget as a limitation of the engineering design process, students would make some calculations, and she intended to include this part as a mathematics objective. When she examined the mathematics curriculum in detail, she decided that these objectives remained at the lower level **(video-recorded planning meetings, lesson study 3, pre-interview, 3).** Her knowledge of curriculum with respect to understanding the objectives and the scope of the mathematics curriculum was improved at the end of the planning meeting of lesson study 3.

In addition to objectives regarding the engineering design process, Ada suggested forming objectives focusing on the engineering career for the first time in the study (**video-recorded planning meetings, lesson study 3)**. She listed her reasons for her suggestion:

> First of all, one of our goals in the curriculum (science curriculum) is to develop career awareness. In parallel to this, I think we should write about increasing awareness of engineering-related careers as an objective in our STEM lesson plan. We have included the life stories of two male and female engineers in different engineering fields, unlike the other plans to serve our purpose. We aimed to show that if students, especially female students, have a perception that engineering is more of a male profession, we will have a chance to eliminate this misconception **(pre-interview, 3).**

As seen from the excerpt, it could be inferred that she offered objectives about developing career awareness in engineering that correspond to the goals of the science curriculum. Her knowledge of curriculum was enhanced at the end of the planning meetings of lesson study 3.

In terms of relating to other STEM disciplines, Ada was able to link the content of science with mathematics and engineering through the use of curricula from other disciplines. She stated the importance of relying on different curricula other than the science curriculum while planning STEM lessons:

> Although the technology and design curriculum is prepared for 7th and 8th grades, it involves objectives related to the engineering design process, finding solutions to problems, etc. I did not know anything about the curriculum of this course until I prepared the STEM lesson plan. I did not know that it (technology and design curriculum) was so relevant to our course (science course). I think these were necessary to prepare a lesson plan that included different disciplines…Likewise, for mathematics, yes, I was closer to mathematics curriculum than technology and design; however, I did not know so well what students learn in mathematics. What concepts are placed in which grade in the curriculum (mathematics curriculum) … This was one point I gained in this process **(pre-interview, 3).**

From the above statements, it could be stated that the amount of connection between the objectives and science and other disciplines was enhanced at the end of the planning meetings of lesson study 3. Moreover, she began to grasp the content of curricula of other STEM disciplines and developed her knowledge about which objective was located in which grade.

Additionally, she mentioned that students would know the difference between heat and temperature from the 5th grade while designing their thermos, which showed she made links to the topic in the previous grade. On the other hand, she did not talk about the particulate nature of matter which was a relevant topic before thermal insulation in the 6th grade. She could not make links to the topics at the same grade level.

During the teaching of the first version of the STEM lesson, Ada started the lesson by linking the topic to the previous grade, as she indicated in the pre-interview:

> **Ada:** What is heat?
> **S1**: It is energy.
> **Ada:** Yes, please remember that from the 5th grade, heat and temperature are not the same **(researcher's pre-observation form, 3).**

At the beginning of the lesson, she took students' ideas and stated that they would design a thermos to solve a problem and moved on to the engineering design challenge.

She connected science and engineering in some parts of the lesson explicitly. For instance, she said: "One goal of science education is to increase your career awareness. We put some activities to do this. Now, I will share the life stories of two engineers" **(researcher’s pre-observation form, 3).**

Figure 4. 1 Scene from Ada’s lesson in Lesson Study 3

She related the goal of the science curriculum with the content of engineering through career awareness, as seen in Figure 4.1. After implementing the first version of the lesson plan, she did not propose any changes to the objectives. She thought the objectives were adequate and suitable for the student's level **(post-interview, 3).** The other participants agreed with Ada's suggestions, and no modifications were made to the objectives after first teaching **(researcher’s field notes, revision meeting of lesson study 3).**

During observation of the re-teaching phase, she noted that Deniz made a connection between other science topics in her observation form. She indicated that one of the students in the classroom asked questions about why the aluminium foil did not burn; he answered that the melting point was too high and that he would learn about this issue in high school **(post-observation form, 3).**

In summary, Ada was able to establish objectives for science and other STEM disciplines at the end of lesson study 3. She emphasized the different objectives equally and had a comprehensive understanding of the scope and the reasons for writing these objectives. Moreover, she did not only relate the thermal insulation topic with other science topics but also connected the topic with mathematics and engineering disciplines sufficiently. These points revelated that her knowledge of curriculum met the features of the PCK-C category after completing the steps of lesson study 3.

4.1.1.1.4. Lesson Study 4

Ada was the observer teacher in lesson study 4; therefore, the findings regarding knowledge of curriculum were from her pre and post-interviews, observation forms, planning, and revision meetings.

Among the group members, Ada put forward the idea of designing a sound-proof music room as an engineering design challenge. The group chose the science objectives based on the engineering design challenge. They preferred to continue with the "explain the importance of sound insulation and design sound-proof environment" objectives from the science curriculum with Ada's suggestion **(researcher's field notes, planning meetings of lesson study 4).** When she was asked about the reasons for proposing objectives regarding the sound insulation, she stated that students got familiar with the insulation concept from the previous STEM lesson plan, and the sound insulation concept was suitable for the engineering design process. It was based on a daily-life problem students might confront **(pre-interview, 4).** The group also decided to establish objectives for other STEM disciplines. When asked about the reasons for writing engineering objectives, Ada pointed out that the science curriculum lacked engineering-related objectives and added that:

> We want to teach some concepts and skills from the engineering discipline, such as constructing a prototype and deciding the best solution. However, there is no curriculum for engineering, and also there are no corresponding objectives in the science curriculum. There should be a resource for teachers to pick their engineering objectives. We wrote them by considering engineering design practices and technology and design curriculum. We wrote them to guide us through the lesson **(pre-interview, 4).**

At the end of the planning meetings of lesson study, she directed criticism about the lack of resources to set engineering objectives and explained why there was a need for engineering objectives in STEM lesson plans at the end of the planning meetings of lesson study 4.

Her knowledge of curriculum improved concerning setting objectives for other STEM disciplines. Another example of her enhanced understanding of the curriculum was related to setting goals for mathematics. She stated that:

> In the mathematics curriculum, drawing a bar graph was placed in the 5th grade. Students might have difficulty drawing graphs; however, we had to remind them in our lesson. Students will decide the effectiveness of their sound-proof music room by interpreting the graphs. For instance, every group will decide easily by looking at their first measure of decibels in a music room without sound insulation and their last measure of decibels after completing their designs. In this way, we visualize the process and make it concrete by writing this objective. So, it plays a critical role in the decision-making process, even for re-designing. Because groups will compare their design with other groups and understand their weakness, we will provide them with an example first (example of bar charts), and we should guide them as a teacher **(pre-interview, 4).**

As seen above, Ada was able to reflect on the mathematics curriculum and made a critique of the sequence of the objectives at the end of the planning meetings of Lesson study 4. Her explanations became specific to the content and included many details compared to her explanations at the beginning of the study. Additionally, it could be stated that her knowledge of curriculum with respect to the related topic to other STEM disciplines through the use of mathematics and technology and design curricula was improved. For instance, she was able to connect engineering and mathematics by drawing graphs to compare groups' design solutions to reach a conclusion about their effectiveness.

Regarding relating the topic to another science topic, she mentioned that sound insulation was related to sense organs and noise pollution in previous grades. On the other hand, she did not connect the topic to the previous topics in the same grade level, such as how sound travels. Her knowledge of relating to other science topics did not noticeably change at the end of planning meetings for lesson study 4.

However, while observing Ece's lesson, Ada wrote in her observation form that Ece touched on how sound travels, sound absorption, and reflection concepts in the same unit during the implementation of the lesson plan **(pre-observation form, 4).** This demonstrated that she developed her knowledge of relating to other science topics in the teaching phase in lesson study 4. During revision meetings and post-interviews, she did not recommend any modifications to the lesson's objectives and advocated that those objectives were adequate and suitable **(researcher's field notes, reflection meetings of lesson study 4, post-interview, 4).**

In her post-individual CoRe, Ada was able to set objectives for more than one STEM discipline with equal emphasis. She benefited from science objectives directly from the curriculum and wrote new ones related to engineering including engineering design process, working in a team and career awareness. She also established mathematics objectives appropriate to students' grade levels. In summary, the findings revealed that Ada was able to focus equally on science and other STEM disciplines, which was one of the types of evidence of developed PCK regarding knowledge of curriculum. She showed remarkable development in setting objectives, modifying them, and explaining their preferences by considering the basic features of STEM education. Furthermore, she enlarged her view with respect to relating the topic with other science topics and STEM disciplines through the observation of the lesson and reflection meetings. It could be inferred that Ada was in the PCK-C category regarding knowledge of curriculum after completing four lesson study cycles.

4.1.1.2. Knowledge of Learners

4.1.1.2.1. Lesson Study 1

Ada was the teacher of the revised version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

To begin with, Ada submitted pre-individual CoRe before beginning the lesson study cycles. She chose the topic of designing projects to efficiently use resources from the 8th-grade science curriculum for preparing a STEM lesson plan. She wrote only one science-related misconception "students might have confusion in distinguishing between renewable and non-renewable energy sources." She did not provide any further details regarding misconceptions that students might have. Similarly, she wrote about one science-related difficulty: "students might have difficulty distinguishing between recyclable and non-recyclable materials" regarding the big idea of the lesson. She did not mention any engineering or mathematics-related misconceptions and difficulties. It could be said that her knowledge of science-related misconceptions and difficulties was limited prior to the present study.

In the planning meetings, the group experienced difficulties in determining the possible misconceptions and difficulties that they might confront as a teacher. Their focus was on the science content in these planning meetings **(researcher's field notes, planning meetings of lesson study 1).**

After the planning phase, Ada stated misconceptions only in science content. However, she mentioned various alternative science-related misconceptions compared to her pre-individual CoRe. For example, she stated:

> Students might think the Solar eclipse can be seen in anywhere in the World, and it could happen once a month regularly. Furthermore, they might think that it will also happen during the full moon phase. One might think that the Moon is halfway between the Sun and the Earth in a solar eclipse, but the Moon is closer to Earth during the eclipse **(pre-interview, 1).**

When she was asked why students might have these misconceptions, she shared her classroom experiences while observing the cooperating teacher. For example, she attended another 6^{th}-grade science class as a part of the Practice Teaching in Science course and realized that the student chose the wrong option in the multiple-choice test and had an alternative conception that the Solar eclipse could be observed worldwide at the same time while observing the cooperating teacher. She indicated that as a teacher, she had some misconceptions as well regarding the topic before the study. In terms of detecting and eliminating these misconceptions, she explained that they did not discuss any method during the planning phase and did not include anything on the CoRe. However, if she was the teacher of the first lesson, she explained that she could draw a Solar eclipse diagram on the board and use animation to address students' misconceptions **(pre-interview, 1).** However, she had not suggested these ideas in the planning meetings **(researcher's field notes, planning meetings of lesson study 1).** She identified several possible sources of such alternative conceptions that students might have about the Solar eclipse based on her experiences and observations but detecting and eliminating these misconceptions was missing in her explanations after planning meetings of lesson study 1.

In terms of students' difficulties, Ada was aware of some of the students' possible difficulties that students might face both in science and engineering disciplines after planning meetings **(pre-interview, 1).** She thought that since the Solar eclipse was an abstract concept, students could not observe the motion of the Sun and the Earth directly with the naked eye; therefore, they might have difficulty understanding their motions and positions during the eclipse. She provided the reasons why learners might experience difficulty with science concepts. Moreover, she talked about engineering-related difficulties that students might confront. She said:

> Students might have difficulty choosing the best solution. More than one solution might solve the engineering problem and meet the criteria, but these solutions might have a different budget which is a limitation in our situation. The student might have difficulty analyzing more than one solution and choosing the best one. This is the reason why we gave the (decision) table. To make their work easier. Moreover, students might have difficulties in the engineering design process. Choosing the appropriate filter that meets the criteria for designing a solar eclipse viewer might be compelling. Which filter is more suitable for their designs? They will definitely experience difficulty in this situation for me. They are used to the question-answer technique in their science lessons. However, we ask them to propose ideas, justify them and look critically. They are not very accustomed to this. It will be the first time they experience STEM lessons so they might have difficulties **(pre-interview, 1).**

She gave elaborated explanations about the reasons for students' difficulties. She also mentioned the way of handling difficulties. She stated the specific difficulties (using the appropriate filter for the solar eclipse viewer) regarding the engineering design process. Ada proposed using the decision table in choosing the best solution part of the engineering notebook during planning **(researcher's field notes, planning meetings lesson study 1).**

During the implementation of the first version of the STEM lesson plan, Ada could not able to identify any misconceptions that emerged during Deniz's lessons **(pre-observation form, 1)**. However, some misconceptions that emerged during the lesson were noted by the researcher both in the science and engineering disciplines **(researchers' pre-observation form, 1).** To illustrate, the student explained that the Solar eclipse could be watched directly through telescopes or binoculars. Moreover, the teacher of the lesson asked, "Who is an engineer" and a few students responded that "engineers build something, they construct buildings". Ada missed these misconceptions during STEM lessons. She was asked whether she had observed any misconceptions, and she expressed that although they had written some misconceptions in the CoRe in the planning meetings, none of them was seen during instruction **(post-interview, 1).** Then, the researcher shared some of her observations regarding the above-mentioned misconceptions. Then, she remembered some of the instances and explained that:

> The misconception regarding watching the Solar eclipse through binoculars could not be handled during the lesson; it came to my mind when you asked. Deniz did not comment on the student's question as true or false; he just said we could put a filter on binoculars. I think that was not enough. We had not talked about this misconception before the lesson **(post-interview, 1).**

On the other hand, Ada observed more difficulties than was written in the CoRe during STEM lessons **(pre-observation form, 1).** She recognized that learners experienced difficulty in the concepts of criteria and limitations in an engineering design challenge and wrote in her observation form. Her observation was reflected in the post-interview:

> Students did not experience difficulty in determining the problem, but when it came to the criteria and limitations, they had difficulties. We also experienced similar things in our planning meetings. I plan to support my instruction with daily-life examples (in the revised lesson) about criteria and limitations. We should also add it in the CoRe **(post-interview, 1).**

She did not mention this difficulty before the implementation of the lesson; therefore, it could be said that her knowledge of learners with respect to students' difficulties began to improve after observation of teaching.

In the revision meeting, this point was discussed in the group with Ada and Defne's suggestions, and decided to be included in the CoRe. Moreover, Deniz indicated they might present the work of engineers from different fields, such as genetic engineering, to handle students' misconceptions that emerged in his lesson. Ada participated in his idea and indicated she would use these examples in her instruction in the revised lesson. The group did not revise the CoRe in terms of science-related misconceptions and difficulties **(researcher's field notes, reflection meetings of lesson study 1).**

Ada implemented the revised lesson in the re-teaching part, and she did not make any attempt to detect students' misconceptions about science. The big idea of the STEM lesson was the Solar eclipse, and as a group, they had written students might have some misconceptions regarding the Solar eclipse. She only asked, "What is a Solar eclipse" and took one student's response, who provided the correct explanation. She stated that she might draw the Solar eclipse model on the board to deal with students' misconceptions in post-interview 1. However, she did not include this drawing in her lesson **(researcher post-observation form, 1)**. She did not do something specific to catch students' misconceptions in science, rather, she concentrated on misconceptions in engineering. Her knowledge of students concerning science-related misconceptions remained unchanged after lesson study 1.

The participants had discussed that students had some misconceptions in terms of the types of work engineers do in reflection meetings. From this viewpoint, Ada concentrated on engineering-related misconceptions in her lesson. An example dialogue from her lesson is provided below:

> **Ada:** (showing the brochure in Figure 4.2) there is something in the brochure that has attracted my attention. Who is an engineer?
> **S1:** To be an engineer, we need to be a designer.
> **S2:** Engineers measure the houses.
> **S3:** Civil engineers.
> **S4:** They build houses.
> **Ada:** Is engineering only related to civil engineering? What about aerospace engineering? Genetic engineering? Actually, engineers propose solutions to problems. Where do engineers work? What do you think?
> **S5:** In construction sites.
> **S6:** In factories.
> **Ada:** Engineers do not only work on construction sites, but they also work in offices, laboratories etc. Today you will work as a team of engineers **(researcher's post-observation form, 1).**

Figure 4. 2 The Brochure used in Lesson Study 1

Ada hadn't realized engineering-related misconceptions in the first version of the lesson plan which she was in the role of observer. Participants discussed these misconceptions in reflection meetings, and Ada gained awareness after the reflection part. She was able to identify students' alternative conceptions about "civil engineering is the only type of engineering" and "engineers only work on construction sites". She tried to eliminate these misconceptions through brief and correct explanations and asking questions. It could be said that Ada started to improve her engineering-related misconceptions to some degree in the observation of instruction and reflection phases of lesson study 1.

Regarding difficulties, she paid specific attention to what she had observed in the first version of the plan. Firstly, she asked one student in the classroom to read the engineering design challenge. Then, she wrote the words "criteria and limitation" on the board to attract students' attention and asked:

> **Ada:** Can you describe the criteria for the engineering design challenge?
> **S1**: The viewer should protect our eyes from the sunlight.
> **S2:** Must have a creative name.
> **Ada:** What about limitations? What do you think about the limitations of the challenge?
> **S:** (no response).
> **Ada**: Limitation is something that hinders us in the design process. For example, I want to buy a cell phone; I want it black. Is it a criterion or limitation?
> **S1:** Criteria.
> **Ada:** I want it to have 64 GB of memory. Is it a criterion or limitation?
> **S2:** Criterion.
> **S3:** No, it is a limitation.
> **Ada:** But 64 Gb memory is a feature that I want on my cell phone. It is a must for me. Therefore, it is a criterion. On the other hand, I have 5.000 TL to buy a cell phone. But this budget limits me. Although I want to buy a cell phone with 64 GB memory, I have to buy 32 GB. I have to compromise on the feature I want. Therefore, the budget in this example is a limitation. Let's have a look at our challenge now and try to determine criteria and limitations based on this example **(researchers post-observation form, 1).**

Ada also mentioned that students wanted to use the whole budget in the first version of the lesson, which showed students could not be able to understand the concept of limitation. She emphasized that this contradicted what they wanted to do with limitation **(post-interview, 1).**

Since Ada considered students' possible difficulties regarding the engineering design process, she introduced the phases of the engineering notebook step by step **(researcher's post-observation form, 1).** Moreover, she noticed that one group had difficulty in proposing alternative solutions to the problem and tried to handle it by asking questions and explanations as follows:

> **S1:** We have decided on our design (right after determining the problem)

> **Ada:** But we are in the proposing alternative solution part of the engineering notebook. We should follow the steps written here. As I indicated before, we need more than one solution. You may write this one as the first solution and think about any other possible solutions, please **(researcher's post-observation form, 3).**

Ada was able to identify students' difficulties mostly in engineering. She extended her knowledge of difficulties with respect to students' difficulties to some extent and was able to adjust her teaching to overcome students' difficulties at the end of lesson study 1. She enriched her teaching with daily life examples based on her observation of teaching the first version of the lesson. On the other hand, her understanding related to science-related difficulties did not considerably change in lesson study 1.

To conclude, Ada's PCK for STEM regarding the knowledge of learners represented the features of the PCK-A category at the beginning of the study. She considered one science-related misconception and wrote one science-related difficulty in her pre-individual CoRe. She did not plan anything to detect or overcome the misconception and difficulty. On the other hand, Ada's knowledge reflected the characteristics of the PCK-B category at the end of lesson study 1. Concerning difficulties, her focus was on the engineering discipline, and she superficially mentioned students' difficulties in science. She attempted to detect engineering-related misconceptions superficially and did not delve into the possible science-related misconceptions written in CoRe. Therefore, she switched from PCK-A to PCK-B with respect to the knowledge of learners at the end of lesson study 1.

4.1.1.2.2. Lesson Study 2

Ada was in the role of observer teacher during lesson study 2. She observed the first and revised versions of the STEM lesson plans on "Designing a Race Car". The following presentations are mainly based on interviews, an observation form, and planning and reflecting meetings.

In the planning meetings, collaboratively prepared CoRe included misconceptions in science and mathematics disciplines. The science-related misconceptions were centered on the difference between speed and velocity. Defne and Deniz suggested adding this misconception in the CoRe, and Ada agreed with them and added that she also had misconceptions about this topic **(researcher's field notes, planning**

meetings of lesson study 2). Different from the previous lesson study, a mathematics-related misconception which was "there is only one type of graph for each data set" was written in the first version of the CoRe. Defne opened this issue up for discussion. She advocated that students might tend to draw line graphs with ascending slopes under every circumstance. However, for instance, this was not the case for the speed-time graph for constant speed. Ada indicated that she had never thought of this misconception but participated in Defne's idea **(researcher's field notes, planning meetings of lesson study 2).** Moreover, Ada suggested writing engineering-related difficulties as follows:

> I think students will experience difficulty in choosing the appropriate body of the car and tires. In the previous lesson plan, they struggled in generating alternative solutions. We should add these points into CoRe…They might experience difficulty in designing a solution according to the criteria and considering the budget **(video-recorded planning meetings, lesson study 2).**

After planning meetings, Ada talked about both science and mathematics-related misconceptions. She extended her understanding of how to eliminate science-related misconceptions through the engineering design process as follows:

> This plan was mostly concentrated on eliminating the speed and velocity misconception. I think the engineering design process would help students to grasp the concept of speed. They will design a race car and calculate the speed by using the distance travelled and time for completing the track. The speed concept will be more concrete in this way **(pre-interview, 2).**

Contrary to the first lesson study cycle, she was aware of students' misconceptions in science and elaborated her understanding in terms of possible sources of misconceptions. She mentioned that the mismatch between everyday language and scientific explanations was the major source of this misconception. She used an example that "in cars, we have speed indicator, not velocity indicator. It shows our speed, but we say it shows our velocity in our everyday language" **(pre-interview, 2).**

Additionally, Ada began to consider how to detect and address science-related misconceptions in the planning meetings. When she was asked to justify her thoughts, she stated:

> We will use the word association test about the speed at the beginning of the lesson. We will have a chance to learn what the students have in mind about speed. They might say velocity. Maybe it is a good opportunity for us to compare

> how much they have learned after the STEM lesson. We planned to use a concept cartoon at the end of the engineering design process. We wrote the items of the concept cartoon by considering the possible points that students might have misconceptions regarding the concept of speed. If students choose alternative conceptions, it means that they still hold their misconceptions. If so, we should go back to the relevant point of the lesson, explain, and ask additional questions to address the misconception **(pre-interview, 2).**

After planning meetings of lesson study 2, Ada started to talk about the methods of detecting and eliminating students' misconceptions in science. However, she adopted a simplistic approach to eliminating them by providing the correct explanation. Moreover, she thought that the possible sources of the mathematics-related misconception might be due to a lack of prior knowledge because line graphs were placed in the 7th-grade in the mathematics curriculum **(pre-interview, 2).**

With respect to difficulties, Ada addressed difficulties associated with engineering and mathematics. She stated that students might experience difficulty in choosing the wheel and the body of the car while designing their cars. There should be minimum friction between the ground and wheels for the car to be at high speed, which was one of the criteria, and she considered that this point might be compelling for students **(pre-interview, 2).** It was seen that she mentioned difficulties specific to the car that students would design. Moreover, she thought that students might have difficulties related to organizing the data and how transforming these data into graphs. She referred to how they planned to handle this difficulty as follows:

> Defne (the teacher of the lesson) will explain how to create a line graph in the activity sheet. She would use example data sets to show how to draw a line graph. Later, students will collect data on their designed car and create a graph with this data. We try to avoid difficulties in this way **(pre-interview, 2).**

As seen from the excerpt above, Ada was able to determine the points that students might experience difficulty with mathematics and suggested ways to address the difficulties after planning meetings for lesson study 2. No science-related difficulties were observed in her explanations.

During the implementation of the lesson plan, Ada noted that most of the students still held misconceptions about speed after the lesson. She did not write any other misconceptions. Regarding students' difficulties, she recognized that the teacher of the lesson provided additional examples of organizing and plotting data to overcome difficulties related to mathematics. She also noted science-related difficulties, such as students having difficulty in expressing the unit of speed. She noticed that students could not be able to determine the unit of speed both in the activity sheets and in their car designs **(pre-observation form, 2).**

After observation of teaching, she mentioned that there should be more emphasis on the misconception regarding speed. She expressed that:

> When we walked around the groups, they were talking about how their car had higher velocity than the others. We need to give more importance to the testing phase (of the engineering design process). We should ask "Why did your car finish the race earlier, What was your calculated speed, and could you define the concept of speed through your car design." We should emphasize the distance travelled by car and how this was related to the speed of the car. This process should be more effective for me **(post-interview, 2).**

She suggested addressing misconceptions through the engineering design process. It demonstrated that she expanded her understanding of the strategies for eliminating misconceptions after observation of teaching. Furthermore, she added that the word association test was very effective in detecting misconceptions, but she offered to apply it in the earlier parts of the lesson. She also referred to mathematics-related misconceptions in the post-interview:

> While we were writing the misconception part (in the planning meetings), Defne advocated that students might have a tendency to create a line graph with ascending slope for constant speed, and it really happened in our lesson. She realized this misconception during teaching and provided the correct explanation in a detailed way **(post-interview, 2).**

Her main suggestions for the revised lesson focused on dealing with science-related misconceptions in a more detailed way. Moreover, Ada with Defne's contributions suggested using concept cartoons earlier in the lesson. She believed that the concept cartoon would be more effective in addressing this misconception in this way **(researcher's field notes, reflection meeting of lesson study 2).**

In the observation of re-teaching, she realized that students experienced difficulty in determining the unit of speed and drawing graphs as in the previous observation form. She noted that science-related misconceptions were partially eliminated in the revised lesson **(post-observation form, 2).**

In summary, Ada's knowledge of learners displayed the features of the PCK-C category at the end of lesson study 2. She was able to touch on misconceptions and difficulties in science and other STEM disciplines in a balanced way. For instance, she did not pay too much attention to science-related difficulties in the planning meetings. However, she started to consider them after the teaching phase, along with the engineering and mathematics-related difficulties. Moreover, she began to talk about the possible sources of these misconceptions and difficulties in parallel with the literature and provided ways to overcome them and scaffold students' learning which met the PCK-C category.

4.1.1.2.3. Lesson Study 3

The big idea of the third lesson study was thermal insulation. Ada implemented the first version of the STEM lesson. The following presentations are mainly based on interviews, observation of teaching, observation form, and planning and reflection meetings.

The number of science-related misconceptions that Ada mentioned increased during lesson study 3 along with the possible resources for these misconceptions. Furthermore, she started to talk about engineering-related misconceptions in line with the literature as provided in the dialogue below:

> **R:** Do you think any misconceptions in other STEM fields?
> **Ada**: One thing might be related to the engineering design process. I am not sure but students might think there is only one correct design, the one with the most successful design. They might think their solution is wrong. I realized this situation in the previous lesson plan.
> **Ece**: I agree with you. In the previous lesson plan, we picked up one car design as the most successful. Other groups might think our designs are not correct **(video-recorded planning meetings, lesson study 3).**

Moreover, she extended her point of view regarding science and engineering-related misconceptions after the planning meetings. She stressed that:

> I read some articles regarding temperature and heat before coming to the planning meeting. I realized that students had confusion regarding heat and temperature. I suppose one of the main reasons for the misconceptions on this topic was the concepts we use in our daily life. We use heat and temperature interchangeably in our daily life. I did not have any idea how to detect or

> eliminate them before the study, and I thought that we could use the diagnostic tree in our lesson plan… Students might consider heat insulators as the source of heat. For instance, they might think that blankets and sweaters keep us warm; therefore, they are the source of heat… They might have a misconception that there is only one correct design as a result of the engineering design process. Because they discussed that "our car design was not successful, it could not complete the racetrack, the group that won the race had the most successful design" in the previous STEM lesson plan **(pre-interview, 3).**

As seen in the excerpt above, she read the relevant literature and combined her knowledge with her experiences and observations while talking about misconceptions. She was able to notice a misconception about the engineering design process emerged during the observation of re-teaching in lesson study 2. Then, she reflected on her understanding in lesson study 3 and suggested writing it as a misconception in the CoRe.

In terms of difficulties, Ada touched on engineering and science disciplines. When asked in pre-interview 3 before teaching, she stated that using and reading thermometers in testing the prototype part of the engineering notebook might be challenging for students. She attributed this difficulty to the lack of experience since students were generally subjected to demonstration experiments in their science classes. Second, she mentioned that another difficulty might be related to choosing the best solution part of the engineering notebook based on her observations from the previous STEM lessons. Lastly, she talked about her observations that students generally had difficulty in identifying the units, and she was expecting the same difficulty in terms of temperature in this lesson **(pre-interview, 3).**

During the teaching of the first version of the lesson plan, Ada noticed some misconceptions in science and engineering disciplines that were written in CoRe. She realized the misconception that there is only one successful design to solve the engineering design problem that she mentioned in the planning phase. An instance occurred when one of the students presented their design:

> **S2:** We were the group with the highest temperature change (in our thermos design). Why did our design fail?
> **Ada:** There is no single successful design to deliver a solution to the engineering problem. You may not have chosen the appropriate combination of heat insulator materials. Let's listen to other groups' solutions. I will write down every group's combination of heat insulators next to the table (data collection table that shows groups' temperature changes). Then, we might discuss the points that might be

> improved in your thermos design in the re-design part of the engineering notebook **(researcher's pre-observation form, 3).**

It could be said that Ada was able to detect and eliminate the students' prementioned misconception. Moreover, she also detected and provided explanations for science-related misconceptions, such as a few students expressing that "we will measure the heat in our thermos designs through thermometer". She addressed this misconception by giving the correct explanation.

However, although Ada was aware of a misconception that students might think of blankets, sweaters etc. as a source of heat before teaching, she could not able to detect and eliminate it during her teaching. An example dialogue is presented below:

> **Ada**: (showing the picture of the sleeping bag from her presentation during the Elaboration part of 5E) Is there heat insulation in sleeping bags?
> **S:** Yes, it keeps us warm because it is the source of heat (**researcher's pre-observation form, 3).**

Ada did not realize this misconception and continued to lesson by giving other daily-life examples. When this moment was reminded in post-interview 3, Ada explained that:

> I should directly say the sleeping-bag is not a source of heat. But I could not. I should add that it keeps things warm because it traps heat. I actually detected it but could not address it. Maybe I was in a hurry to complete the lesson on time. I could benefit from the information cards and asking additional questions, and I should be clearer at this point (**post-interview, 3).**

As seen from the excerpt, she was aware of the misconception that emerged in the lesson but could not handle it due to time limitations. Her strategy to deal with the misconception was an activity and providing the correct explanation.

Concerning difficulties, several students experienced difficulty in terms of defining criteria and limitations in the engineering design challenge. The following excerpt was from her lesson:

> **Ada:** What are the limitations of our engineering design problem?
> **S1:** The thermos design should be durable.
> **Ada:** The limitation is something that limits us. Remember the example that I provided at the beginning of the lesson. 64 GB memory and black are the features that I want to buy a telephone. If we think about our problem, is it a criterion or a limitation to want it to be durable?

S1: Then, it is the criteria **(researcher's pre-observation form, 3).**

Ada was able to catch students' difficulties with criteria and limitations and eliminate them by providing explanations and addressing the previous STEM lesson. Another point regarding students' difficulties, Ada explained how to use and read the thermometer to eliminate the possibility of difficulties before emerging. Then, she moved to test the prototype part. Moreover, she wrote the units of temperature and heat onto the board to attract students' attention. She emphasized this issue during the lesson. One of the dialogues from the classroom was:

> **Ada:** What was the last temperature you measured on the thermometer?
> **S:** 56.
> **Ada:** Just 56? Does 56 have a unit? Let's have a look at what we have written here (Showing the unit of temperature on the board).
> **S:** 56 °C.

Regarding difficulties with the engineering design process, she walked around the groups and stressed the importance of filling out the table in the "choosing the best solution" part of the engineering notebook for deciding on their solutions **(researcher's pre-observation form, 3).** The group discussed in planning meetings and wrote on the CoRe that "students might have difficulty in proposing more than one solution to keep the soup hot". Ada was aware of this difficulty in her lessons and took precautions. One group did not offer the second solution; she noticed and asked "what other heat insulator combinations would be effective, how other solutions might meet the criteria" types of questions to handle the difficulty she faced **(researcher's pre-observation form, 3, post-interview, 3).**

Lastly, Ada realized another difficulty that was not written in CoRe after teaching. Exemplifying excerpt from her teaching:

> Students experienced difficulty in understanding why we took more than one measurement to assess their design solutions. We took the first measurement of the hot water in their thermoses, and one group said that "our design is the best one; the least temperature change was in our design." I think they were not accustomed to collecting and interpreting data. I explained that we need to take multiple measurements to ensure reliability. Students considered that taking the first measurement would be enough for the testing part. From this point of view, I explained the testing process in detail later. I explained that we would take a measurement every five minutes and see how much the temperature would change. I drew a data collection table on the board to make things easier for them. **(post-interview, 3).**

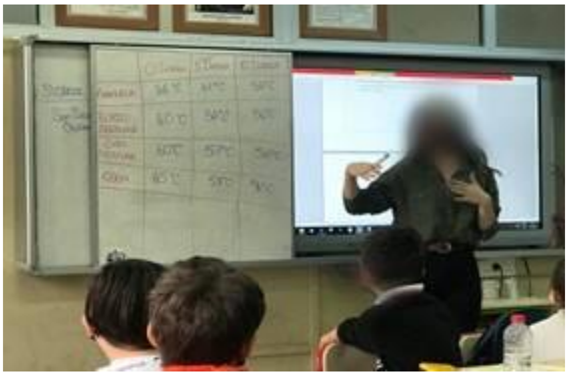


Figure 4. 3 Scene from Ada’s Classroom in Lesson Study 3

Figure 4.3 shows some parts of the data collection table that Ada formed during her teaching. She expressed the possible reasons for the prementioned difficulty and tried to handle it at the end of lesson study 3. Ada was able to provide more meaningful explanations for students’ difficulties both in the science and engineering disciplines. Moreover, she developed her PCK and dealt with the difficulties before emerging, and adjusted her teaching according to pre-determined difficulties during teaching. When confronted, she was able to detect and try to eliminate these points.

In the reflection meeting, Ada offered to prepare a concept cartoon to detect students’ misconceptions in science; however, other participants did not accept her idea because of time limitations. Defne suggested adding science-related misconceptions based on her observation of teaching, which was “heat can be measured directly”. Everyone in the group agreed with her. No changes were made in terms of difficulties in the revised CoRe **(researcher’s field notes, reflection meeting of lesson study 3).**

In brief, Ada’s knowledge of learners showed the features of the PCK-C category at the end of lesson study 3 as in the previous lesson study cycle. She was able to provide detailed explanations of learners’ misconceptions and difficulties in science and other STEM disciplines. She developed a comprehensive understanding of identifying and eliminating these difficulties and misconceptions. For instance, she recognized difficulties were not present in CoRe during teaching. She partially detected a science-related misconception, and she suggested ways to correct it in the reflection part of the lesson study. These points pointed out her advanced knowledge with respect to learners.

4.1.1.2.4. Lesson Study 4

Ada was in the role of observer teacher during lesson study 4. She observed that the first and revised versions of the STEM lesson plan concentered on "designing sound-proof music room." The following presentations are mainly based on interviews, observation forms, and the planning and reflecting meetings.

The number of science-related misconceptions that Ada mentioned was enhanced at the end of the planning meetings. Moreover, she indicated that her confidence in determining the points in which students had misconceptions and difficulties increased after the planning phase. She provided the possible source of misconceptions more easily. For instance, she stated that:

> Our previous lesson was related to thermal insulation. Students might tend to overgeneralize that the materials we use in thermal insulation could also be used in sound insulation. They might be confused, such as insulation is always the same and made with the same materials, whether thermal or sound insulation. **(pre-interview, 4).**

Moreover, Ada focused on engineering-related misconceptions based on her observations and experiences from previous STEM lessons. She was able to catch the misconceptions in previous STEM lessons. She made suggestions to write these misconceptions in the last CoRe and consider them during planning **(video-recorded planning meetings, lesson study 4).** For instance, she said:

> One of the students said that "scientists and engineers are doing the same thing" (in implementing the revised lesson plan in lesson study 3). We discussed this point in the planning phase, and the teacher of the lesson will emphasize this issue and explain the differences between them in the final lesson plan. We prepared an activity, "What the World would be like if engineering did not exist?" to understand whether students still hold engineering-related misconceptions at the end of our last STEM lesson" **(pre-interview, 4).**

She also added one more misconception regarding engineers:

> (Participants had implemented a "Draw an Engineer Test" in a previous STEM lesson, and Ada referring the results of it): Students drew engineers as working alone. Actually, we always stress during our STEM lessons that "you are a team of engineers working together." Therefore, we created an animation that involves engineers from different fields working as a group to solve the problem to overcome this misconception" **(pre-interview, 4).**

As seen in her explanations above, Ada was able to identify engineering-related misconceptions and suggest different methods to remediate them instead of giving correct explanations.

Concerning difficulties, Ada indicated science, engineering, and mathematics-related difficulties. She elaborated on the sources of these difficulties more at the end of lesson study 4. Rather than addressing her own experiences as a student, she focused on her observations and experiences in the classroom and made suggestions to overcome the difficulties during planning meetings. For instance, she knew that students might have difficulty drawing bar charts since they had difficulty forming line charts in previous STEM lessons **(pre-interview, 4).**

As an observer teacher, Ada noted that the misconceptions that emerged in the lesson were handled by asking questions and using explanations. Moreover, she observed that students experienced difficulty deciding whether sound absorption or reflection principles would be used to design a sound-proof music room. Ece handled this difficulty by directing students to the science magazine and activity **(pre-observation form, 4).** She mentioned difficulties highly specific to the engineering design process after observation of teaching.

When asked about her suggestions for the revision meeting regarding students' misconceptions and difficulties based on observation, she suggested enriching the content of the science magazine. She believed that students needed to investigate further information about sound absorption and reflection before generating alternative solutions **(post-interview, 4).** She opened her opinion to the discussion, and they revised the science magazine **(researcher's field notes, reflection meeting of lesson study 4).**

After completing the four lesson study cycles, Ada wrote misconceptions in science and engineering disciplines in her post-individual CoRe. She planned to identify these misconceptions by asking questions and using the concept cartoon. She did not utilize any specific method to overcome them; she preferred question-answer and providing the correct explanations. Regarding difficulties, she included both science and engineering-related difficulties in her CoRe. She paid attention to these difficulties while planning her lesson plan **(post-individual CoRe).**

To conclude, Ada’s knowledge of learners met the features of the highest PCK category at the end of lesson study 4. The number of misconceptions she mentioned was extended in number. She was talking about her self-experiences at the beginning of the study; however, she drew upon her teaching experiences and related literature in terms of misconceptions in science and other STEM fields. Moreover, she developed her understanding of how to handle difficulties in all STEM disciplines in a balanced way. It could be inferred that the lesson study cycles caused the extension of PCK for STEM regarding the knowledge of learners and displayed the properties of the PCK-C category.

4.1.1.3. Knowledge of Instructional Strategies

Knowledge of instructional strategies was examined under these dimensions: teaching strategies compatible with STEM, design-centered teaching practices, and strategies for engagement with engineering concepts and representations, and activities. Teaching strategies used in each cycle are shown in Table 4.1.

Table 4. 1

Teaching Strategies used in Lesson Study Cycles

Lesson Study Cycles	**Teaching Strategy**
Lesson Study 1	5E Learning Cycle
Lesson Study 2	REACT
Lesson Study 3	5E Learning Cycle
Lesson Study 4	Problem-based learning

4.1.1.3.1. Lesson Study 1

Ada was the teacher of the revised version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were presented in this section.

Before participating in the study, Ada prepared an individual CoRe, and she did not use particular teaching strategies compatible with STEM education. Moreover, she did not include any design-centered practices in her pre-CoRe. She only focused on teaching science concepts and did not include the characteristics of STEM education. No engineering design process was observed in her pre-CoRe. Moreover, she had a limited understanding of representations and activities specific to science **(pre-individual CoRe).**

In the planning meetings of lesson study 1, Ece suggested using the 5E learning cycle for their first collaborative CoRe, and Ada supported this idea. She also made some suggestions about how they could use 5E, such as using animation or newspaper in Engage part of 5E. She discussed that the animation they were going to use should attract students' attention and should not include any knowledge regarding the lesson's objectives. She offered to prepare their animation through Vyond by saying, "we can give the scenario over Vyond in determining the problem part. An engineer would say we need a Solar eclipse viewer at the end of the animation". The group members shared their idea and prepared an animation **(video-recorded planning meetings of lesson study 1).**

When asked in an interview how STEM education and the 5E learning cycle were compatible with each other, she said:

> I have always used the 5E learning cycle in my lesson plans. It is very easy to use and convenient for the teacher. I have recently read one book chapter that asserted 5E is very appropriate for STEM education. I also agree that the 1engage, explore and explain” parts (of 5E) are very suitable for the engineering design process. We are in the role of mentors, and students explore the knowledge on their own in 5E **(pre-interview, 1).**

As seen from the excerpt, Ada did not give detailed explanations about the reasons to use the 5E learning cycle in a STEM lesson. Her explanation included no content-specific features. She only mentioned the usefulness of 5E learning cycles in general at the end of the planning meetings of lesson study 1.

In terms of design-centered teaching practices, Ada guided the discussions in the group in planning meetings. For example, Deniz offered that each student group should propose just one solution to solve the problem, and Ada objected to this idea. She advocated that each group should provide at least two different solutions by using different materials based on the nature of STEM education. She also suggested how to manage and balance group work during STEM lessons. Every student in the group should offer one individual solution. Then, the group members should discuss each solution to choose the best one among them **(video recording planning meetings,**

lesson study 1). With these suggestions, she aimed to balance the roles in students' groups during the design process. Another example of dialogues between the participants and Ada regarding design-centered practices:

> **Deniz:** In my opinion, we should provide a ready-made frame of Solar viewers to the groups. They would put filters on these frames.
> **Defne**: Then, how do we develop their creativity skills?
> **Ece**: We could not develop as Deniz suggested.
> **Ada**: For example, if they put wires, straws, and ready-made frames for designing eclipse viewers in front of me, I would choose the ready-made frame directly. But this is not what we want to do; students need to develop a product. If we do what you have suggested, we will do the same things in the textbooks that we criticized. I will give you a frame; you will put a filter on it. I think this does not fit with the understanding of STEM education. We even have a criterion to design viewers suitable for the structure of the eye. Students need to think about these criteria while designing prototypes. For instance, students will discuss whether should I make a frame from a straw or should I use the wire **(video recording planning meetings, lesson study 1).**

As seen from the excerpt, she was able to discuss some features of design-centered instruction to some extent at the end of the planning meetings of lesson study 1.

Regarding engagement with engineering concepts, the scenario suggested by Ada included contrived problems which were not authentic. On the other hand, Ada proposed the use of "the client" terminology to engaging students in engineering concepts in the planning meetings.

Concerning representations and activities in science and engineering disciplines, no representations specific to science were discussed in the planning meetings. On the other hand, she offered to use representation specific to engineering, such as using a decision diagram in re-designing part of the engineering notebook, as seen in Figure 4.4. **(researcher’s field notes, planning meeting of lesson study 1).** When asked in the interview, she indicated that:

> Students might think that their solution is the best one. However, they should be aware that different filters might create a more effective design to solve the problem (given at the beginning of the engineering notebook). We want to make this point concrete through the table; we ask students what could be done to improve their designs and criticize them. In this way, they would determine the positive and negative parts (of their design) **(pre-interview, 1).**

8. Yeniden Tasarlama:

Çözümüzünüz test etme ve sunma aşamalarını düşününüz. Yeniden tasarlanması gereken en az bir şey önerin.

Tasarımın Güçlü Yönleri	**Tasarımın Zayıf Yönleri**	**Tasarımın Geliştirilebilir Yönleri**

Figure 4. 4 Decision Diagram used in the Re-design Part of the Engineering Notebook

Ada offered to use role-play for the activities specific to engineering and indicated that after introducing the engineering design challenge, the students would work as a group of engineers during the lesson. Moreover, she suggested preparing a brochure and distributing it to the students to prepare them for role-play, as seen in Figure 4.5. For the activities specific to science, the group prepared information cards about the Solar System to investigate the problem with the suggestion of Ece.

Figure 4. 5 Example of Brochure used in Lesson Study 1

Deniz implemented the first version of the lesson plan in the teaching phase, and Ada was one of the observer teachers. She noted that Deniz carried out the lesson properly according to the 5E learning cycle; however, she wrote that the time devoted to the evaluation phase should be increased. Based on her observations, no representations specific to science were used in the lesson. Moreover, she also jotted down that Deniz applied the engineering design process steps correctly **(pre-observation form, 1).**

On the other hand, with respect to design-centered teaching practices, Deniz limited providing alternative solutions in just two in his instruction **(researcher's pre-observation form, 1).** Although Ada was involved in a discussion about the issue in the planning meetings, she ignored this instance while observing the teaching. Another point that Ada realized was that Deniz did not emphasize engineering terminology in his lessons. For instance, she indicated that he did not use the expression of "prototype" throughout the STEM lessons. Lastly, she partially agreed that Deniz provided scientific explanations in the engineering design process. **(pre-observation form, 1).**

After observing Deniz's STEM lessons, Ada did not recommend any other teaching strategy compatible with STEM education. However, she complained about strategies for engagement with engineering concepts:

> Students had not known what the prototype meant. Deniz used this concept in the last 5 minutes of the 3-hour class. He should have asked, "what is a prototype" and then explained it at the beginning of the engineering design process because the "prototype" was in the engineering notebook. The students filled out this part without knowing what it was **(post-interview, 1).**

Although Ada did not note in her observation form, she thought Deniz's expression of "just two alternative solutions were enough; there was no need for the third solution during" was inappropriate **(post-interview, 1).** The last point that she talked about regarding design-centered practices was the lesson's lack of taking criteria and limitations into account to solve the given problem **(post-interview-1).** Her knowledge of instructional strategies with respect to design-centered teaching practices began to improve after observation of teaching.

During the reflection meeting, the teaching strategy remained the same. In terms of activities specific to science, the group discussed that information cards used to investigate the problem should be discarded, and Ada agreed with her friends. Moreover, she recommended drawing a Solar eclipse diagram on the board to make the concept concrete in the revised lesson **(researcher's field notes, reflection meeting of lesson study 1).** In this way, she was able to offer representations specific to science after reflection meetings.

As discussed in the group, Ada carried out the revised lesson version by using the steps properly by utilizing the 5E learning cycle. She did not prefer to use representations specific to science, such as the Solar eclipse diagram, although she suggested using it in the reflection meetings (**researcher's post-observation form, 1).**

In terms of design-centered teaching practices, she integrated features of STEM education to some extent. For instance, she paid attention to taking criteria and limitations into account to solve the problem and encouraged teams to choose the best solution among alternatives. She walked around the students' groups and tried to manage and balance group work. **(researcher's post-observation form, 1).** Figure 4.6. showed how Ada handled teamwork in the engineering design process in her first teaching of the STEM lesson plan.

Figure 4. 6 Scene from Ada's Classroom

On the other hand, she could not implement some elements of design-centered practices in her instruction. For example, she did not attempt to provide a scientific rationale for students' design solutions. She asked general questions about students' designs in communicating the solution part and skipped that part quickly. An exemplifying instance was:

> **Ada:** Why don't you look at the Sun with the naked eye? Why did you design Solar eclipse viewers?
> **S1**: To keep our eyes healthy.
> **S2**: Not to be blind **(researcher's post-observation form, 1).**

After asking the question, she moved on to the next activity. She did not delve into the details about why specific filters were used in students' designs which were one of the main components of this lesson. The connection of engineering content to science was not explicit. She spent little time communicating the solution part, and she did not devote time to the re-designing part. Therefore, a full iteration of the engineering design process could not be completed **(researcher’s post-observation form, 1).**

Regarding strategies for engagement with engineering concepts, Ada included more engineering talk, such as prototypes, marketing, and client, in her lessons compared to Deniz's lesson. On the other hand, students found the real-world problem contrived. Example dialogue from the classroom was:

> **S1**: There are Solar viewers, which are sold for 5 TL and do the same job. Why are we making it?
> **S2:** We have chosen an X-ray for the filter. I can directly look at the Sun with this. Why do we need viewers?
> **Ada:** But today, we have worked as engineers; we understand how they work, how they design things **(researcher’s post-observation form, 1).**

As seen from the excerpt above, the engineering design challenge was not engaging for some students. Therefore, it could be inferred that Ada's knowledge of engagement with engineering concepts was developed to some extent at the end of lesson study 1.

To conclude, Ada did not use any particular teaching strategy, and no design-centered teaching practices were observed in her pre-individual CoRe, which referred PCK-A category at the beginning of the study with respect to knowledge of instructional strategies. Then, she moved to the PCK-B category after completing lesson study 1. Her PCK was transitional in some respects. For instance, she could not match the features of teaching strategy and STEM education explicitly. She mentioned and applied some design-centered teaching practices, but many of them were still missing in her explanations and teaching. Her focus was on engineering disciplines in terms of representation and activities. She developed a partial understanding of the strategies for engagement with engineering concepts. These features met the characteristics of the PCK-B category at the end of lesson study 1.

4.1.1.3.2. Lesson Study 2

Ada was the observer teacher in lesson study 2; therefore, the findings regarding knowledge of instructional strategies were from her pre and post-interviews, observation form, planning, and revision meetings.

In the first planning meeting, the group discussed using different teaching strategies compatible with STEM education; however, Ada tended to use the 5E learning cycle again. After discussions, she agreed with the group and made suggestions about how to use REACT **(researcher's field notes, planning meeting of lesson study 2).** After completion of the planning process, she explained her thoughts about using REACT:

> I think REACT and STEM education are compatible with each other. One step of REACT was collaboration, and we use collaboration in our STEM lessons frequently. It is one of the points that makes them suitable for each other. Actually, I find 5E and REACT very similar. The steps (of REACT) help us to organize the plan easily. I am not sure whether there is too much difference between them (REACT and 5E); I do not have enough knowledge about REACT. … I am still considering the transfer phase (of REACT). I have a question mark regarding whether we managed to transfer the knowledge to different situations or not. We generally tend to use 5E in our lesson plans but trying to implement another strategy positively impacted our development **(pre-interview, 2).**

Before implementing the first version of the lesson plan, Ada mentioned general points about why they decided to use this strategy. Her knowledge of teaching strategies was limited since she did not provide specific points regarding STEM education.

Regarding design-centered teaching practices, she talked about some characteristics of STEM lessons. For example, she emphasized the importance of managing group work and the process of choosing the best solution:

> As I observed, students are egocentric while working collaboratively. Each student in the group insists that his/her idea is the best one and defends that his/her solution will solve the problem. In my previous STEM lesson plan, I usually warned that the important thing is to find out which solution meets the criteria and limitations better. I guide them to consider the decision table while choosing the best solution. Completing the table (decision table) is really helpful for teachers to handle the problems in group work. Moreover, students easily understand how many criteria their solution meets and then make their decisions. Using a table at this point plays a critical role **(pre-interview, 2).**

As seen above, she also talked about representations specific to engineering. She mentioned how a decision diagram specific to the engineering design process helped her balance the group work in a STEM lesson. She demonstrated a notable elaboration in her knowledge of instructional strategies in terms of using representations specific to engineering after planning meetings of lesson study 2. On the other hand, there were some missing elements of design-centered practices in her explanations, such as conducting research to solve the problem, and re-designing parts at this point.

While observing the first version of the lesson plan, she noted that Defne implemented the phases of REACT correctly but advised that time devoted to the transfer phase should be increased in her observation form. Moreover, she observed and wrote some characteristics of design-centered instruction. For instance, she thought that girls were active in completing the engineering notebook; however, boys in the group were dominant while testing the solutions. She recommended that the teacher should be careful about balancing the roles in the teamwork **(pre-observation form, 2; post-interview, 2).** Moreover, she was able to notice that although some groups managed to discuss the concept of speed in the context of the engineering design process in teamwork, the teacher could not be able to do it with the whole classroom. Some groups were not aware of the speed concept at the end of the lesson. She provided an example dialogue from one group that featured science concepts in the engineering design process:

> One student in the group said that they needed to consider the friction between the wheel and the surface. To complete the racetrack, firstly, they discussed choosing a plastic cover instead of foam as wheels. Moreover, they used wire on the back side of the car to stabilize the motion, and the process worked well in this group **(post-interview, 2).**

As seen above, she was attentive to discussing science concepts in the context of the engineering design process, to which she did not pay attention before the teaching phase. It could be inferred that her understanding of design-centered practices was augmented, and she mentioned many of them after observation of teaching.

Moreover, she found the use of representations such as video, graphs, and activities sufficient. Regarding engagement with engineering concepts, she realized the use of engineering talk during instruction and how the different types of engineering were introduced for promoting STEM careers in the lesson **(pre-observation form, 2).** The above statements showed that Ada became more knowledgeable about instructional strategies based on her observations of teaching.

After implementation, she thought using REACT was appropriate in STEM lesson plans. She did not specify any content-related reasons. However, she talked about some difficulties in utilizing REACT:

> We had some time management problems because using REACT required preparing student-centered activities for each step. I think choosing REACT as a strategy causes time management problems. On the other hand, students were really active for four hours, and they enjoyed the lesson a lot **(post-interview, 2).**

Regarding design-centered teaching practices, she touched upon what she noted on her observation form. In the reflection meeting, firstly, she offered to involve girls in the testing phase of the race cars based on her observations. The group members accepted her suggestion **(researcher's field notes, reflection meetings of lesson study 2).** Ece, who taught the revised version of the lesson plan, paid specific attention to involving girls in the testing part to balance the group roles in teamwork, as seen in Figure 4.7 **(researcher's post-observation form, 2).** Another point that she pointed out in the reflection meeting was discussing which car had the most speed and its reason after the testing process **(researcher's field notes, reflection meeting of lesson study 2).**

Figure 4. 7 Scene from Classroom in Lesson Study 2

During the observation of re-teaching, she noticed that the discussions about the concept of speed in the engineering design process were better in the revised lesson plan. However, she criticized some points regarding design-centered practices, such as the positive and negative sides of the car designs and re-designing parts were skipped.

Regarding engagement with engineering concepts, she noted that the concepts of prototype and trade-off were not mentioned enough. On the other hand, she found the emphasis on STEM careers (engineering and data analysts) adequate. She realized the engineering design challenge motivated the learners as opposed to lesson study 1 **(post-observation form, 2).** Her knowledge of instructional strategies in terms of design-centered practices and engagement with engineering concepts was improved to some extent after observation of re-teaching.

Ada's knowledge of instructional strategies moved from the PCK-B category to PCK-C category at the end of lesson study 2. She elaborated understanding about using REACT in STEM lesson plans. Although she could not able to talk about some design-centered teaching practices at the beginning of the cycle, observation of teaching and reflection parts helped increase her knowledge. Moreover, she was able to mention representations in science, engineering, and mathematics in a balanced way. Therefore, these features met the PCK-C category regarding knowledge of instructional strategies.

4.1.1.3.3. Lesson Study 3

Ada was the teacher of the revised version of the lesson plan in lesson study 3; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were provided in this section.

Ada is one of the participants that suggested using 5E for the third lesson study cycle. She also offered to use problem-based learning (PBL) in the planning meetings; however, other participants disagreed with her. They said they had never used problem-based learning before, and it could be challenging to plan a STEM lesson with PBL **(researchers' field notes, lesson study 3).**

After the planning meetings, Ada provided a more comprehensive understanding of why they preferred to use 5E in their STEM lesson plan as opposed to lesson study 1:

> I think 5E is very suitable for STEM education. We discussed different situations in which we could apply science and engineering practices in the Elaboration part. For instance, we put an example of a spacesuit and asked students to discuss the science and engineering practices. Similarly, we put an ice-cream truck example and aim to force them to think about how the truck is designed by using

> the principles of thermal insulation and how engineers propose a solution to keep the ice-creams cold. We want to emphasize that thermal insulation is not only applicable to buildings and apply their knowledge in different situations. We expected students to talk about thermal insulation and look from an engineering perspective. Moreover, we have an engineering problem in the Engage part that probably attracts students' attention. Searching the problem part of the engineering notebook as a group provides the opportunity to gain scientific knowledge about their design this time (**pre-interview, 3).**

As seen from the excerpt, Ada provided content-specific details and mentioned fundamental features of STEM education while choosing the instructional strategy in the planning phase in lesson study 3. She elaborated on her understanding of the reasons for choosing an instructional strategy and its characteristics compared to the first time they used the 5E learning cycle in the first lesson plan.

With respect to design-centered teaching practices, she deepened her understanding compared to her first implementation of the STEM lesson plan. She touched upon providing a scientific rationale for the design solution and provided more content-specific explanations. For instance, she said:

> Students will learn about the characteristics of thermal insulation materials such as fibreglass wool in researching the problem part through material cards. They need some scientific information to design the thermos. They will recognize the reasons for using fibreglass wool as a thermal insulator and then make their designs by considering what they find in their research **(pre-interview, 3).**

As seen from the excerpt above, she emphasized conducting the research part of the engineering design process. She was aware of using scientific concepts to explain students' decisions about their designs. Moreover, regarding engagement with engineering concepts, she actively participated in discussions and emphasized promoting engineering careers, using real-world problems, and coaching the students during the engineering design process before teaching the lesson **(researcher's field notes, planning meetings of lesson study 3).**

Additionally, Defne suggested using visuals specific to engineering, and Ada favored integrating and using these visuals in her lesson **(researcher's field notes, planning meeting of lesson study 3).** She thought that the visuals would help students to understand what our lives would be like without engineers **(pre-interview, 3).** In terms of representations specific to science, she agreed to use a data collection table to foster students' science process skills **(pre-interview, 3).** She indicated that:

> We want students to record their data, take multiple measurements, interpret data in their groups, and make inferences about their designs. As I observed, they are generally subjected to demonstration experiments in their science classes, and using a data collection table will be helpful for them to develop these skills **(pre-observation form, 3).**

She taught the STEM lesson plan for the second time in lesson study 3. She used the phases of 5E correctly. Moreover, she was able to modify the flow of the lesson. She changed the order of the activities. She preferred to use the "The world without engineers" activity at the end of the Elaboration phase instead of using it in the introduction part of the engineering notebook as written in CoRe **(researcher's pre-observation form, 3).** When she asked for the reason, she indicated that:

> I changed the place of the activity as opposed to our lesson plan. It seemed reasonable to me because I said that "today, we have worked as engineers, and let's have a look at what if the world without engineers." In this way, I believe visuals and questions supported the engineering design process **(post-interview, 3).**

She used representations and activities in science and engineering disciplines and enriched her instruction compared to her first teaching. Specific to science, she used material cards effectively to investigate the problem given at the beginning of the engineering design process. Moreover, she utilized more daily-life examples than her implementation of the first STEM lesson plan. An example dialogue between Ada and the students is given below:

> **Ada:** Have you ever made coffee before?
> **S1**: Yes.
> **Ada**: What did you use as a spoon?
> **S2**: Wooden spoon.
> **Ada**: Did you burn your hand?
> **S2**: Little.
> **Ada**: What if we used a steel spoon?
> **S2**: It burned more.
> **Ada**: Definitely **(researcher's pre-observation form, 3).**

She drew a data collection table onto the board and picked one student from each group, and asked them to collect data through their design and record them on the board **(researcher's pre-observation form, 3).**

Additionally, in terms of representations specific to engineering, she used visuals, as seen in Figure 4.8, and supported them with daily life examples. For instance, she demonstrated the visual given in Figure 4.8 and asked that:

Figure 4. 8 Scene from Classroom Using Representations Specific to Engineering

Ada: What do you see in this visual?
S1: Calculator.
S2: Some people are doing calculations.
Ada: Yes, in case you have noticed, a group of people come together and seem to be struggling. They are making the things we do in our daily life easier now. If the engineers did not exist, we would have worked like this. Most probably, there would be no computers or calculators. Thanks to them, we continue our lives much easier **(researcher's pre-observation form, 3).**

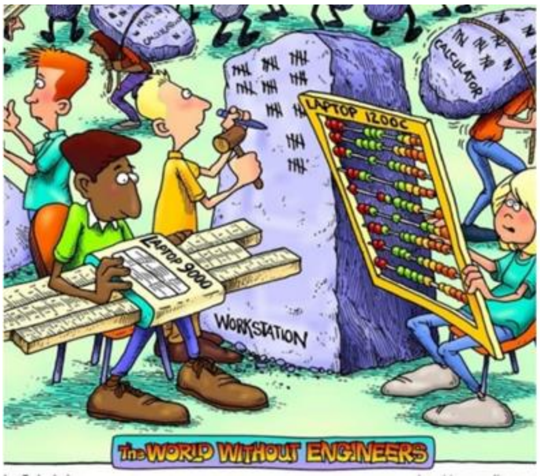


Figure 4. 9 The World Without Engineers Visuals-1

Another characteristic of her second teaching of the STEM lesson plan was the increased number of daily-life examples in engineering disciplines. She highlighted how engineers propose solutions to the problems in her teaching. An instance from the Elaboration phase of the lesson:

Ada: Is there thermal insulation in organ transplantation bags?

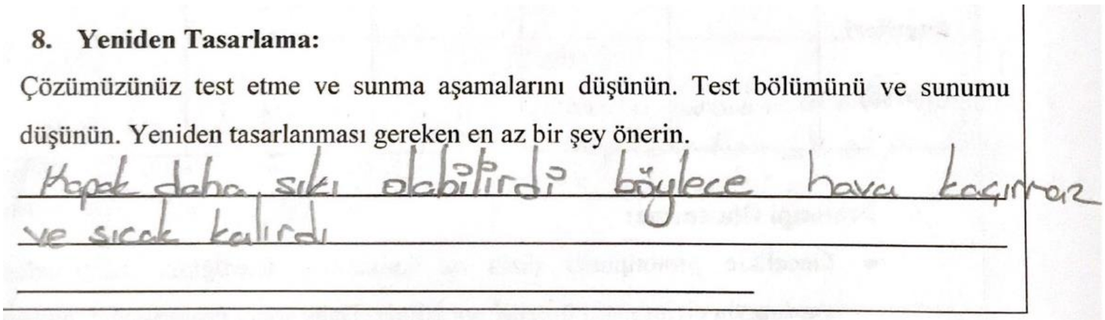
S1: yes, the organs should be kept cold.
S2: It must be kept cold to be transferred to other people.
Ada: Definitely. Let's say there will be intestine transplantation. We cannot just simply put ice in a plastic bag to carry the organ. We have to supply the right environment. Engineers find a solution to this problem like we just did. We have proposed solutions to keep the hot soup challenge in the previous lesson **(researcher's pre-observation form, 3).**

As seen from the explanations above, her knowledge of instructional strategies with respect to representations and activities progressed after the teaching phase of lesson study 3.

Furthermore, her instruction exhibited many features of design-based teaching practices. She integrated the engineering design process explicitly compared to her first implementation of the STEM lesson plan. For instance, she started by presenting an open-ended engineering design challenge. Then, students acquired knowledge regarding the problem and took criteria and limitations into account to solve the problem. Students also utilized budget sheets. They sketched their designs and built and tested them, as seen in Figure 4.10. Students were provided with opportunities to communicate their solutions, and Ada asked them to justify their design solutions **(researcher's pre-observation form, 3).**

Figure 4. 10 Students Testing their Design Solutions in Lesson Study 3

The missing part in Ada's instruction concerning design-centered teaching practices was "learning from failure." She did not attempt to determine the strengths and weaknesses of students' designs. No time to discuss the points that could be improved in students' designs was allocated in her lesson. Three student groups out of four did not write anything in the re-designing part of the engineering notebook **(researcher’s pre-observation form-3).** Figure 4.11 demonstrates one example of how the re-designing part was written superficially from the engineering notebook.


8. Yeniden Tasarlama:

Çözümüzünüz test etme ve sunma aşamalarını düşünün. Test bölümünü ve sunumu düşünün. Yeniden tasarlanması gereken en az bir şey önerin.

Kapak daha sıkı olabilirdi böylece hava kaçırmaz ve sıcak kalırdı

Figure 4. 11 Example from the Re-design phase of Engineering Notebook

Another feature of her instructional strategy regarding engagement with engineering concepts was using engineering talk frequently. She stressed the terms such as criteria, prototype, and testing during the lesson **(researcher’s pre-observation form-3).** The number of dialogues between students regarding engineering terminology raised compared to her first teaching of the STEM lesson plan. Engineering talks were the parts of a lesson's content. Moreover, Ada's lesson was connected to STEM careers explicitly.

When she was asked to assess the implementation of the lesson plan after teaching, she gave 9 points out of 10. She indicated that:

> All groups completed and tested their designs. Thermal insulators that were used in their design were discussed in a classroom. The data collection table would help us to compare the success of thermos designs at this point. We compared the most temperature change designs and the groups with the least temperature change. Each group shared which materials they used and their budget. We can use additional questions to communicate the solution part to make students discuss science concepts in their designs more in the revised lesson. We provided an opportunity to develop an interest in engineering careers as well. Using the life stories of engineers was really helpful, and we stressed that women could be engineers too **(post-interview, 3).**

As seen above, she mentioned how she utilized most of the design-centered teaching practices in her lesson.

After teaching, no revisions were made to teaching strategies. The group continued with the 5E learning cycle. Ada suggested some improvements in the CoRe for the revised lesson. One of her suggestions was using visuals to support how to prevent heat loss in buildings because she thought that students experienced difficulties at this point. In other words, she offered to utilize representations specific to science after the teaching phase. She also realized that the re-designing part was not effective in her lesson, and as a group, they needed to think about alternative ways to make this part useful **(researcher's field notes, revision meeting of lesson study 3).**

While observing the revised version of the lesson plan, she took some notes on her observation form regarding instructional strategies. For example, she wrote that the evaluation phase of the 5E could not be implemented due to the time limitation. She realized how Deniz benefited from drawings to explain the question from one student "why do we get cold in the rain." This shows she could detect representations that were not written in CoRe. Lastly, she found featuring science concepts in the engineering design process inadequate **(post-observation form, 3).**

In brief, Ada's knowledge of instructional strategies met the features of the PCK-C category at the end of lesson study 3. For instance, she enhanced her understanding of choosing and using appropriate strategies in STEM lessons by considering the basic features of STEM education. Her explanations were topic-specific rather than discipline-specific when choosing the teaching strategies. She used representations in science and other STEM disciplines in a balanced way and supported her instruction with daily-life examples compared to previous lesson study cycles. Moreover, she was able to use engineering terminology as a part of the lesson and progressed her understanding of promoting STEM careers. Therefore, she had coherent PCK, labelled as PCK for STEM, regarding knowledge of instructional strategies at the end of lesson study 3.

4.1.1.3.4. Lesson Study 4

Ada was the observer teacher in the final lesson study cycle. The following presentations are mainly based on interviews, an observation form, planning, and reflection meetings.

There were discussions about the effective strategies to integrate STEM education in the planning meetings of lesson study 4. Ece was in favour of using problem-based learning, while Deniz insisted on using the 5E learning cycle. Ada supported the idea of using problem-based learning in the last STEM lesson plan **(researcher's field notes, planning meetings of lesson study 4).** When asked why she preferred to utilize problem-based learning, Ada responded like this:

> I think the steps of the engineering design process and problem-based learning are really compatible with each other. Students will define the problem and conduct research to solve the problem of designing a sound-proof music room on their own. These steps in the engineering design process intertwined with the steps of problem-based learning. I also suggested using the KWL chart at this point and I think it is one of the best ways to understand what students know before the lesson and how they develop after the lesson. Students will write what they already know about sound, what they want to learn about sound insulation to solve the engineering problem and what they learned after researching. We assisted this point with a science magazine that we prepared. Students will infer they need rough, porous and soft materials to design a sound-proof music room. Problem-based learning made our planning process easier. The defining problem, generating and finding the best solution parts are really suitable for STEM education **(pre-interview, 4).**

The above statements showed that Ada lacked the knowledge to use problem-based learning before participating in the study and this situation prevented her to implement the strategy in STEM lesson plans. However, she was able to list the reasons for using problem-based learning and its characteristics after the planning phase. Enhanced knowledge of Ada in using problem-based learning affected on her choices of teaching strategies to plan a STEM lesson in lesson study 4.

Moreover, her knowledge of representations and activities improved at the end of the planning meetings of lesson study 4. For instance, she was aware of activities specific to engineering. Among the group members, she proposed using the poster in communicating the solution part of the engineering design process and convinced her friends with detailed explanations **(researcher's field notes, planning meetings of lesson study 4).** She indicated that using posters would help to attract attention and summarize the lesson. She stated that:

> Students should explain which sound insulators they used in their designs with justification in the communication part. The teacher should ask which sound-proof music room designs have the least decibel measure and I believe the poster will make this process more effective. That part (communicating the solutions)

> was a bit abstract in previous lesson plans. We can also integrate the re-design part into the poster **(pre-interview, 4).**

She had not implemented the re-design part in her teaching in lesson study 3; however, she suggested integrating the re-teaching phase in a more useful way at the end of lesson study 4. Additionally, she talked about the reason why they prepared a video using Vyond about the work of engineers. She indicated that:

> In the previous lesson, there were discussions regarding the differences between scientists and engineers. We prepared the content of video the considering these points and aimed at how engineers work in teams, in what fields they are working, their working areas etc. The video will attract students' attention **(pre-interview, 4).**

Ada developed varying representations in terms of engineering after participating in the study. Regarding design-centered teaching practices, she emphasized the importance of grasping scientific knowledge about sound concepts in the engineering process to generate alternative solutions that reflected her improved knowledge of design-centered teaching practices at the end of lesson study 4. The above explanations were also reflected in her pre-observation form 4.

She observed what had been written in the CoRe and extra points that emerged during the lesson. She noted that the steps of problem-based learning were carried out properly. She realized how the teacher of the lesson created a data collection table to make students understand the concept easier and discussed the characteristics of sound insulator materials that groups had chosen for designing a sound-proof music room. Regarding representations, Ada found it useful to discuss the effectiveness of designs through bar graphs. Ece, who was the teacher of the lesson, utilized improvisation during the lesson to make the intensity of the sound concept clearer. Ada noticed this point and wrote in observation form **(pre-observation form, 4).**

After observing the lesson, Ada focused on some points regarding the lesson in her post-interview:

> I observed that using the KWL chart was very effective. Students investigate through the sound magazine (that we prepared). They investigated sound reflection and absorption concepts and reached conclusions about the characteristics of sound insulation materials. They organized their knowledge through KWL, which then used this knowledge in generating solutions to the problem. Ece guided students very well at this stage and asked questions while

> walking around the groups. For example, one group had difficulty in whether the principles of sound reflection or absorption would be used in the design process. Ece did not provide the information directly, and she made students read the magazine carefully and infer the necessary information from there **(post-interview, 4).**

As seen from the excerpt, Ada mentioned some features of design-centered teaching practices and representations by correlating them to the topic after observation of the lesson. Moreover, she attracted attention to the importance of researching the problem part:

> I always make students discuss the science concepts from the beginning of this study, and I think we achieved this in this lesson plan. Students gained the necessary scientific knowledge for solving an engineering problem. The discussions in the groups were intense. I understood the importance of making investigation and reaching scientific knowledge in STEM lesson plans **(post-interview, 4).**

For the reflection meeting, Ada did not offer any changes in terms of teaching strategies. On the contrary, she wished that they had used problem-based learning in the previous lesson plans. She had one suggestion regarding design-centered teaching practices. She offered to enrich the content of science magazine in terms of sound reflection and absorption. This opinion was supported by the group members and they added new content to the magazine **(researcher's field notes, reflection meeting of lesson study 4).**

After completion of four lesson study cycles, she prepared individual post-CoRe and utilized problem-based learning. This situation demonstrated that she became more knowledgeable about the teaching strategies compatible with STEM at the end of the study. In terms of design-centered instruction, she employed the engineering design process as opposed to her first individual STEM lesson plan. She provided an open-ended challenge at the beginning of the lesson. She wrote a scenario that the Municipality of Izmir was looking for a solution to the drinking clean water problem by including criteria and limitations. Her real-world problem was based on authentic context which showed her engagement with engineering concepts was increased. She prepared an "Environment Magazine" in which students would investigate necessary information for their designs. She also prepared a budget sheet and a decision table in which students weighed their solutions. She drew a table to determine the most successful design and prepared a poster for communicating the solution **(post-**

individual CoRe). These points demonstrated that she was able to utilize design-centered teaching practices and use representations and activities specific to science and engineering at the end of four lesson study cycles. Apart from these, Ada emphasized engineering careers in her post-CoRe and utilized engineering talks such as criteria, limitations, prototypes and trade-offs in her CoRe. In summary, Ada became more knowledgeable about the teaching strategies compatible with STEM education at the end of lesson study 4. She elaborated on her understanding of the preferences for choosing strategy in a STEM lesson. Similar to the previous lesson study cycle, she had comprehensive knowledge regarding the use of representations and activities in more than two STEM disciplines in a balanced way and sufficiently mentioned strategies for engagement with engineering concepts. These characteristics in her explanations met the PCK-C category at the end of the study.

4.1.1.4. Knowledge of Assessment

4.1.1.4.1. Lesson Study 1

Ada was the teacher of the revised version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

Firstly, the analysis of Ada's pre-individual CoRe showed that she concentrated on assessing only science content outcomes through presentations and posters. She intended to use the rubric to assess students' projects about using the resources efficiently. She did not explain why she preferred to choose this type of assessment, and no content-specific examples were given. She did not write anything regarding how to assess students' prior knowledge before the study.

In the planning phases of lesson study 1, Deniz put forward the idea of assessing the engineering design process steps using the analytical rubric, and Ada participated in this opinion **(researcher’s field notes, planning meetings of lesson study 1).** The discussions in the group did not include how to assess students’ prior knowledge, science content outcomes, and students' products.

Ada used general statements regardless of the topic about why they preferred to choose a rubric to assess the lesson's objective. She only highlighted that they wanted to assess how students' would present their products and how they would defend their ideas through an analytical rubric **(pre-interview, 1).** These points were the small parts of the engineering design process, and she only focused on engineering content for assessment. However, there was no engineering objective stated at the beginning of the lesson. The reasons why they preferred to use a particular assessment type were not apparent in her responses after the planning meetings. It could be stated that her knowledge of assessment concerning what to assess and how to assess was in STEM lessons limited. Furthermore, she did not mention the importance of assessing students' prior knowledge and the product of the engineering design process at the end of the planning meetings of lesson study 1.

On the other hand, she had concerns about the harmony between the objective and assessment at the end of the planning meetings. She explained that:

> Actually, it seems that the objective and assessment are not very compatible with each other. Students need Solar eclipse viewers to observe the phenomenon. They want to design the best viewer, and we will assess this process. However, it does not seem to fully meet the objective we wrote in my opinion... We should talk about it after the implementation **(pre-interview, 1).**

As seen above, she talked about the mismatch between the dimensions of learning that is worth assessing and the lesson's objective. She had thoughts about revising the objectives based on the assessment at the end of the planning meetings.

Deniz implemented the first version of the STEM lesson plan, and Ada took some notes on her observation form regarding assessment. Firstly, she noted that students' prior knowledge about the topic was assessed by asking questions at the beginning of the lesson, such as, "why don't we look at the Sun directly." Secondly, she wrote that Deniz guided the discussions through the lesson by walking around the groups and providing feedback to the groups emphasizing the use of formative assessment **(pre-observation form, 1)**.

When she was asked whether she would propose changes in the reflection meeting, she again stressed the inconsistency between the objective and assessment:

> I think the rubric assesses the engineering design process completely. Our objective was related to observing the Solar eclipse on the model. We did not

> assess this. I think we should discuss changing objectives or assessment methods **(post-interview, 1).**

She was confused about what part of the lesson should be assessed after teaching the first version of the lesson plan in lesson study 1. It showed that not having clear lesson objectives misled Ada in terms of what to assess.

During the revision meeting, the group assessed the engineering notebook of students' groups by using the rubric, they prepared. Defne and Ece suggested changes in the items of the rubric and Ada participated in their ideas **(researcher's field notes, reflecting meetings, 1).**

After completing the reflecting phase, Ada implemented the revised version of the STEM lesson plan. She was able to reflect on their revisions based on the assessment. Example dialogue between Ada and students:

> **Ada:** What is the meaning of the criteria?
> **S:** It is the feature of something.
> **Ada:** What is a prototype?
> **S:** It means draft.
> **S:** something uncompleted.
> **Ada:** we can understand the weakness and strengths of a design by testing the prototype; it allows us to improve our product **(researcher's post-observation form, 1).**

Ada attempted to elicit students' prior knowledge in engineering in addition to science through the use of informal questions. The abovementioned questions did not exist in Deniz's first version of the lesson plan, and the group discussed these points in the reflection meeting **(researcher's field notes, reflection meeting of lesson study 1).** Therefore, instruction was revised based on the assessment results of the first version of the lesson plan since the group realized students did not know engineering terminology. Ada used informal questioning for diagnostic purposes at the beginning of the lesson. In light of the information acquired from the answers from students, she explained what the criteria and limitations were. She was able to reflect her observation of teaching into her instruction.

Another example of revision in the instruction based on the assessment was related to the engineering outcomes of the lesson. Some groups took lower grades in the rubric for proposing more than one solution to the problem part and choosing the best solution part in the reflection meeting when analyzed with the rubric. Ada considered these points and arranged her instruction based on the results of the assessment. After introducing the engineering design challenge, students were expected to generate solutions and create prototypes. At this point, Ada walked around the groups, observed them, attracted students' attention to the points they ignored, and gave them feedback **(researcher's post-observation form, 1).** Providing feedback was more obvious in the revised version of the lesson plan.

Concerning what to assess, although Ada's knowledge of assessing students' pre-knowledge in science and engineering began to develop, however, she did not assess learners' product at the end of the lesson. The groups observed their Solar viewers through the model; however, little time was devoted to assessing students' designs. No criteria for determining the success of students' designs were specified for students at the beginning of the lesson. Furthermore, science content outcomes were not assessed; the focus of the assessment was on the engineering design process at the end of lesson study 1.

In brief, the analysis of pre-individual CoRe showed that Ada concentrated on only assessing science content which met the features of topic-specific PCK, i.e. PCK-A category. Then, she moved to the PCK-B category at the end of lesson study 1. She focused on only assessing the engineering outcomes of the lesson while ignoring the other parts of the lesson worth assessing. Moreover, she could not able to use a variety of assessment methods regarding how to assess. She began to consider assessment results for making modifications in the instruction in the group discussions; however, this part of her knowledge is still open to development.

4.1.1.4.2. Lesson Study 2

Ada was not responsible for teaching the first and second versions of the STEM lesson plan in lesson study 2; therefore, the findings regarding knowledge of assessment were from her pre and post-interviews, observation form, planning, and revision meetings.

In terms of what part of students' learning should be assessed, Ada focused on students' prior knowledge and misconceptions in science. She also talked about other STEM discipline outcomes (i.e., mathematics and engineering design process) with respect to what to assess sub-component. Moreover, she mentioned assessing learners' product as a result of the engineering design process. Her knowledge of assessment with respect to what to assess became varied after the planning meetings of lesson study 2 when compared to the previous lesson study **(researcher's field notes, planning meetings of lesson study 2).** For instance, she emphasized the assessment of students' products as follows:

> Students will get points based on some criteria, such as how far the car will go and whether the tires will turn correctly. It would be helpful for the teacher of the lesson; I would understand how well the students' design fits the criteria. Moreover, based on these points, the successful designs will get their certificate. We thought this would motivate the students and be a part of our assessment. In the previous plan, we did not assess the students' designs, but I think we should do it from now on. We could not establish the objectives properly in the first lesson plan, but in this one, we have an objective regarding designing a product, and we should assess it **(pre-interview, 2).**

Concerning to how to assess, she suggested using conceptual change text to assess students' prior knowledge of the concept of speed in planning meetings; however, she changed her mind because it might take too long to implement it, and they had time management problems. Instead, they decided to use the word association test with Deniz's suggestion, and Ada agreed with the group members at this point **(video-recorded planning meetings, lesson study 2).** She thought utilizing a word association test would help assess students' pre-knowledge in terms of speed and would be helpful to elicit their misconceptions about speed and velocity at the beginning of the lesson. She thought that based on information gained from students' answers, the teacher of the lesson could shape the lesson and decide whether to mention velocity or not **(pre-interview, 2)**. The group prepared different assessment methods for revealing students' prior knowledge in science compared to lesson study 1.

Ada was asked about her thoughts on assessment methods in the interview, and she stated:

> Towards the end of the lesson, we will use a concept cartoon to assess the science objectives. We will apply it individually. Moreover, we prepared an activity sheet and there were short-answered questions and multiple test questions, especially to assess the concept of speed and drawing graphs. We also have an engineering notebook and a rubric to assess every part of it. We also prepared a budget sheet as an assessment method. We wanted to assess everything in the

lesson. We will also have an assessment of the students' products **(pre-interview, 2).**

Ada mentioned using alternative and traditional assessment methods, as seen in the excerpt above. She mentioned they prepared a concept carton about speed, a criteria list for students' products, a rubric for the engineering design process and a budget sheet. Some of the sources used for assessment were given in Figure 4.12. Ada also talked about the summative assessment that was going to be applied at the end of the lesson. She explained that there were short-answered questions to assess drawing a graph for mathematic objectives and multiple-choice and short-answered questions for the concept of speed **(pre-interview, 2).** On the other hand, she presented a general understanding of the purposes of using particular assessments. She did not delve into how the type of assessment would assess particular objectives by giving topic-specific examples.

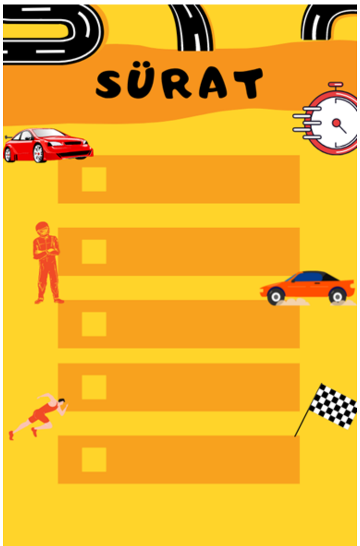


Figure 4. 12 Examples of Word Association Tests Used for Assessment

The first version of the lesson plan was implemented by Defne, and Ada noted on her observation form that the criteria list to assess the students' products was not implemented in the lesson. She also wrote that some activity sheets that involved short-answered questions were given as homework due to the time limitation **(pre-observation form, 2).**

Ada did not offer to make changes regarding the type of assessment; however, she tied assessment and objectives, and she had some suggestions for the way of using assessment methods in the post-interview:

> We prepared a criteria list to grade the students' car designs. Nevertheless, this was not used by Defne. Whether students' designs solve the problem at the beginning or not, this point was not handled during the lesson. We need to assess students' designs and be clear about what counts as a successful design. We can easily say your design gets 90 points because you have finished your design and completed the racetrack, but the time of completion was longer than the other group at the end of the lesson. We should make explanations to the students according to which criteria their cars will be assessed right after presenting the engineering design challenge because we have stated objectives regarding these two points. We did not give zero points to any group. If the group created their design, they would get at least 30 points. We tried to give a message that designing the car with the highest speed is not our priority, the process that they will go through is important (**post-interview, 2).**

Ada provided content-specific explanations in terms of assessing the students' products after observation of teaching in lesson study 2. She talked about the assessment should not be concentrated on the final product; the process was also worth to assess. She realized that students did not utilize the budget sheet efficiently and this point should be considered in the reflection meeting **(pre-observation form, 2).**

In the reflection meeting, she triggered discussions about these points and advocated that a word association test should be used earlier in the lesson to elicit students' prior knowledge about the topic. She added that when it was used after the introduction of the topic, it hadn't served its purposes. She meant that if they aimed to use a word association test for diagnostic purposes, the time of using it should be changed in the flow of the lesson. The group member accepted her idea and changed the time of implementation **(researcher's field notes, reflection meeting of lesson study 2).**

She wrote down her observations about the assessment in the observation form during the revised version of the lesson and indicated that the teacher of the lesson paid attention to when to use the word association test as discussed in the group meeting. She also noted that the criteria list was not presented to students at the beginning of the lesson **(post-observation form, 3).** She was able to understand the reason for presenting the rubric while assessing students' products at the end of lesson study 2. Lastly, she shared her ideas that Ece did not spare enough time to give feedback about students’ designs and did not use the criteria list to assess students’ car designs effectively **(researcher’s field notes, reflection meeting of lesson study 2).**

Ada’s PCK for STEM regarding knowledge of assessment switched from PCK-B to PCK-C category at the end of lesson study 2. She benefited from each phase of lesson study and developed her knowledge. She concentrated on different parts of the lesson to assess. She emphasized assessing students’ products and mathematics content for the first time in the study. She was able to establish connections between objectives and assessment and provided suggestions for when to implement particular assessment methods during the lesson. Regarding how to assess, her understanding became diversified.

4.1.1.4.3. Lesson Study 3

Ada was the teacher of the first version of the STEM lesson plan in lesson study 3. Therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were given in this section.

Ada focused on students' prior knowledge in science, science content outcomes, engineering design process, and students' product in the planning meetings in terms of what to assess components. She mentioned the significance of assessing students' misconceptions in science:

> The diagnostic tree directly measures students' content knowledge in heat and thermal insulation in our lesson. We added items regarding daily-life examples. Students will probably have misconceptions about this topic, and we added possible misconceptions regarding heat and insulation in the branches of the diagnostic tree. For instance, we thought that students might think wool sweaters are a source of heat, and we put it on the diagnostic tree to assess their misconceptions **(pre-interview, 3).**

Ada indicated that she could obtain information about students' misconceptions about thermal insulation and their understanding of applications of thermal insulation in daily life through an assessment which demonstrated her enhanced knowledge of what to assess at the end of the planning meetings of lesson study 3. She was able to provide topic-specific examples and additional explanations about how the diagnostic tree was created.

Concerning how to assess, she was able to extend her understanding and suggested using different types of assessment that the group had not used in previous lesson study cycles. For instance, she talked about using the "Draw-an-Engineer Test" in the planning meetings to assess the engineering objective related to developing an interest in an engineering career **(researcher's field notes, planning meetings of lesson study 3).** She stated that:

> I found this test (Draw and Engineer Test) while researching STEM education the other day. I liked it very much. Students draw engineers at work. We should definitely use it because career awareness is one of our objectives, and drawings would give us a clue about what students think about engineers or whether they would reflect what we have been doing since the beginning of the semester with STEM lessons **(pre-interview, 3).**

As seen above, she suggested applying assessments focusing on engineering and engineering careers in the planning meetings. The team participated in her idea and decided to integrate it into the lesson. Moreover, she offered to use a diagnostic tree to assess the science content outcomes of the lesson on thermal insulation. She added that if students chose the wrong branches in a diagnostic tree, the teacher would provide feedback to make them choose the right branch. The group participated in her idea. In this way, she touched upon employing formative assessment and using the information from the assessment for additional explanations to eliminate learners' difficulties.

Moreover, Deniz suggested employing self-assessment for students' products, and Ada liked the idea. She offered to integrate it at the end of the engineering notebook. In this way, students would assess themselves at the end of the engineering design process **(researcher's field notes, planning meetings of lesson study 3).** She pointed out the importance of assessing students' products through self-assessment in the interview:

> In fact, students start the engineering design process without knowing the criteria for success (of their designs). We will distribute the assessment paper and will say we are assessing our thermal designs at the end of the lesson. Students will tick whether "yes or no" to the questions. We can introduce these self-assessment forms at the beginning of the lesson **(pre-interview, 3).**

In addition to assessing students' products, she touched upon the time of introducing the criteria used for deciding the successful design as in the previous lesson study cycle.

With respect to revision based on assessment, she talked about how the flow of the lesson could be organized by using the assessment results. For instance:

> When we assessed engineering notebooks with an analytic rubric in the previous lesson plan, some groups received lower grades, especially in proposing more than one solution, selecting the best solution, and re-designing parts. It shows that we should put more weight into these parts. For example, I will be careful whether the groups pay attention to discussing each criterion when choosing the best thermos design alternatively, whether they appropriately fill out the table in the re-design part. I can use the poster of the engineering design process effectively if students would have difficulties with these points **(pre-interview, 3).**

Before she implemented the lesson, she was ready to make revisions to her instruction based on the assessment results in the previous cycle.

Ada started the lesson by assessing students' prior knowledge of science content by asking informal questions such as "What is heat? What is the difference between heat and temperature" from the 5^{th} grade. She walked around the groups throughout the lesson and gave feedback about their designs, as seen in Figure 4.13. For instance, she was aware that students took lower grades in proposing more than one solution in the group, and she decided to ask additional questions to help learners in the group. Example dialogue in this process was given below:

> **Ada:** Why do you write only one solution?
> **S1**: We do not have an alternative idea. Our solution will solve the problem.
> **S2:** We cannot find another solution.
> **Ada:** Let's look at the budget list and the possible materials. Let's discuss this again. What if we use foam instead of glass in the body of the thermos? What other combination could we do?
> **S1**: Our budget will decrease if we use foam.
> **Ada**: Very good. We should think about these alternative points while writing the second solution **(researcher's pre-observation form, 3).**

Figure 4. 13 Scene from a Classroom while Ada Providing Feedback to Groups

She employed the diagnostic tree by providing feedback. Even if students gave a correct explanation and found the correct exit in a diagnostic tree, she also focused on the wrong items and provided feedback. For instance:

> **Ada:** Let's look at this statement (showing from the smart board). It says the thermal conductivity of heat insulators should be higher. What do you think about this statement?
> **S1:** I think it is correct
> **Ada**: Why do you think so?
> **S: (**no response).
> **Ada:** Remember the thermos you have created; the most successful design was the one with the least temperature difference. We can say that the thermal conductivity of heat insulators should be lower **(researcher's pre-observation form, 3).**

Ada gave feedback about the wrong answer, and she addressed the engineering design process to help the learner. She provided additional explanations and reminded the activity that the students had done earlier in the lesson. On the other hand, although she indicated the significance of presenting the criteria for successful design at the beginning of the lesson, she did not mention it during her teaching. Moreover, she skipped the self-assessment form that students were required to assess themselves at the end of the engineering design process. She only expressed verbally that they were looking for thermos designs with the least temperature change at the end of the testing phase of the engineering design process **(researcher's pre-observation form, 3).**

As a teacher of the lesson, she did not recommend any revisions to the type of assessment they used. The teaching phase of the lesson study did not increase her knowledge of assessment with respect to how to assess. She thought the types of assessment they used were appropriate.

The only thing that she remarked on was the re-designing part. After assessing engineering notebooks with the rubric, they saw that two groups out of four got lower grades in this part. She triggered discussions in the group about what could be done to make the re-designing phase more effective **(researcher's field notes, revision meeting of lesson study 3).** It demonstrated that she was able to make decisions for the re-teaching phase based on assessing students' artefacts after teaching. Moreover, when she was asked the reason for skipping the use of students' product assessment after the lesson, she stated that:

> The content of the plan was intense; I was in a hurry to complete all the activities on time. I realized later that I had skipped it. Nevertheless, I still think that the discussions we had to determine a successful thermos design during the testing process were enough **(post-observation, 3).**

Deniz implemented the revised version of the lesson plan, and he followed the same steps in assessing students' products. He explained the criteria for successful design after students completed their design solutions. Ada paid attention to this point and wrote in her observation form that the criteria for successful design were not given at the beginning of the engineering design process **(post-observation form, 3).**

To sum up, her knowledge of assessment put equal emphasis on the science content outcomes and other STEM discipline outcomes at the end of lesson study 3. She was able to reflect the points discussed in the group into her instruction regarding assessment. She suggested new assessment methods to assess the objectives of the lesson. Lastly, she could make revisions to the instruction by considering the result of the assessment, such as putting more weight on the re-design part in the following lesson. It could be inferred that her knowledge of assessment met the criteria of the PCK-C category at the end of lesson study 3.

4.1.1.4.4. Lesson Study 4

Ada was the observer teacher in the first and second versions of the STEM lesson plan in lesson study 4; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

Concerning what to assess, Ada mentioned prior knowledge in science, students' products, science content outcomes, and other STEM discipline outcomes (mathematics and engineering) at the end of planning meetings in lesson study 4 **(researcher's field notes, planning meetings of lesson study 4).** Her assessment knowledge of what to assess was consistent with the prior lesson study cycle. She focused on misconceptions in science when using assessment in the previous lesson study, and this time she also considered eliciting students' misconceptions in engineering **(pre-interview, 4).**

In terms of how to assess the objectives of the STEM lesson, firstly she offered to use a diagnostic tree. Then, she gave up and suggested a new type of assessment for measuring prior knowledge. She advocated using the KWL chart to research the problem partly to elicit students' prior knowledge of sound and sound insulation **(researcher's field notes, planning meetings of lesson study 4).** She advocated her opinion by saying:

> We aimed to bring out students' prior knowledge about sound and sound insulation through question-answer at the beginning of the lesson and also by applying the KWL chart. K part was related to what is known about the topic. The teacher of the lesson might quickly understand students' prerequisite knowledge while walking around the groups and might organize her lesson, especially the knowledge required to design a sound-proof music room **(pre-interview, 4).**

She emphasized the importance of shaping the engineering design process part of the lesson by considering students' prerequisite knowledge in science, as seen in the excerpt above.

Furthermore, the participants used a similar rubric to assess the engineering objectives throughout the study; however, Ada's understanding progressed in providing detailed explanations of the reasons for using it at the end of the four lesson study cycles. She indicated the importance of using the rubric in the assessment part like this:

> In fact, the rubric will allow us to assess the design process that we used to solve the problem of a sound-insulated music room. We analyzed how students filled out the engineering notebook. We put every step of the engineering design process into the rubric and assessed the items as very good, adequate, and poor. For instance, if the bar graph shows how the decibel value changes in a sound-proof and uninsulated environment drawn correctly, the group will get three points. If the groups do not draw the graph correctly or do not fill out the data collection table, they will get two points **(pre-interview, 4).**

She mentioned topic-specific details and how to use the rubric to assess students' understanding of the engineering design process. Moreover, Ada discussed the use of word association tests to detect engineering-related misconceptions as follows:

> We prepared a word association test about engineering careers and will use it toward the end of the lesson... We will ask students to express their ideas about what engineers do. If they still have misconceptions about engineers' work, such as engineers build or fix things, we have a chance to improve their understanding after the implementation of the word association test **(pre-interview, 4).**

She mentioned unveiling engineering-related misconceptions in the assessment and planned to provide feedback if students still had engineering-related misconceptions. She was able to make revisions to the instruction based on students' misconceptions after the assessment. Moreover, Ada connected the third and fourth lesson study cycles to make revisions to the instruction. She explained that:

> We used the Draw an Engineer Test in the previous lesson study. We used these drawings while forming the content of Vyond (which is an animation related to an engineering career). Students drew engineers as a woman in many papers (in Draw-an-Engineer Test), which I liked. On the other hand, engineers were generally working alone on the drawings. We used this information and emphasized that engineers work as a group in Vyond (animation was prepared in this program) in this lesson plan **(pre-interview, 4).**

As seen from the excerpt above, she mentioned using the results of the assessment from the previous lesson study cycle to prepare an activity in the last lesson study. While assessing students' drawings, the group realized that students had difficulty understanding how the engineers worked. Ada mentioned how they used the assessment results to revise their following lesson plan.

The final lesson plan also included a multiple-choice assessment at the end of the lesson. Ada indicated that they intended to measure science content outcomes through multiple choice at the end of the lesson using Kahoot **(pre-interview, 4).** The group used it for summative purposes and graded student groups' answers.

While observing Ece's lesson, Ada noted that the teacher used all types of assessments they prepared at the planned time of the lesson. She wrote that using a word association test regarding engineering would be used more effectively in the revised lesson plan **(pre-observation form, 4).** When asked in the interview about the reasons why she thought like this:

> Students had written something irrelevant to the question "what if engineers do not exist." The teacher of the lesson might provide more solid feedback to students' answers. The teacher might address the previous STEM lesson in which we used visuals about engineering careers to provide feedback **(post-interview, 4).**

Furthermore, Ada realized how Ece gave feedback during the implementation of Kahoot at the end of the lesson. She stated that:

> When groups gave the wrong answer, Ece asked them why they thought like this. This was one of the most powerful parts of the lesson. She did not skip the next question, made the correct explanation, and moved to the next question **(post-interview, 4).**

In general, she did not offer any changes in the type of assessment they used. She underlined the importance of giving feedback to students in the assessment part. She also added that assessing all parts of the engineering design process through an analytic rubric, not just the students' products, was very suitable for the nature of STEM education **(researcher's field notes, revision meeting of lesson study 4).**

In her post-individual CoRe, she planned to assess students' science content outcomes and engineering outcomes through two different rubrics. Moreover, Ada used a similar rubric that they prepared in the lesson study cycles to assess the parts of the engineering design process. Lastly, she prepared a self-assessment sheet in which groups assessed their performance in designing water purification systems and teamwork. She assessed students' prior knowledge of science content through question-answer at the beginning of the lesson. Compared to her first individual CoRe, her assessment knowledge in terms of what to assess and how to assess was enhanced after participating in lesson study cycles. She was able to use different types of assessment, and she was able to determine the parts of students' learning that were worth assessing at the end of the study.

In conclusion, Ada's knowledge of assessment was coherent, and she assessed science content outcomes and other STEM disciplines sufficiently. Her explanations were aligned with the objectives of the lesson and consisted of different ways to assess students' learning which were the main features of the PCK-C category with respect to knowledge of assessment.

4.1.1.5. Summary of the Findings for Case 1

Ada showed noticeable progress in all components of PCK for STEM at the end of the study. When asked to design a STEM lesson plan, she planned her CoRe to teach a specific science concept at the beginning of the study. In other words, her PCK was topic-specific before the study. On the other hand, her PCK for STEM was more coherent and balanced at the end of the four lesson study cycles. Table 4.2. displays how components of PCK changed after attending each lesson study cycle for Ada.

Table 4. 2

Ada's Development of PCK for STEM in Four Lesson Study Cycles

	Before the Study	**Lesson Study 1**	**Lesson Study 2**	**Lesson Study 3**	**Lesson Study 4**
Curriculum	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**
Learners	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**
Instructional Strategies	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**
Assessment	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**

Firstly, her PCK with respect to all components moved from PCK-A to PCK-B simultaneously after completing lesson study 1. For instance, she only considered science-related misconceptions and had difficulty in identifying and eliminating them at the beginning of the study. On the other hand, she gave more importance to engineering-related difficulties in her explanations and instruction in lesson study 1. In the same manner, she concentrated on assessing the engineering design process, although no engineering-related objectives were stated in CoRe. Her emphasis was on one STEM discipline after completing lesson study 1.

Secondly, her knowledge of curriculum, learners, instructional strategies, and assessment shifted from the PCK-B to PCK-C category simultaneously at the end of lesson study 2. The coherence between STEM disciplines was stronger compared to the previous lesson study cycle. For instance, while talking about the assessment, Ada offered to use different assessment methods with diagnostic, summative, and formative purposes and focused on science and other STEM disciplines in an equal way. She was able to mention many design-centered teaching and talked about representations specific to science, mathematics and engineering in a detailed way at the end of lesson study 2, which was evidence of more coherent PCK for STEM.

Lastly, Ada's PCK for STEM for all components was enhanced and met the criteria of the PCK-C category at the end of lesson study 3 and lesson study 4, as seen in Table 4.2. For example, she elaborated on her understanding of the possible origins of misconceptions in parallel with the literature in science and other STEM disciplines. She was able to recognize students' difficulties in STEM disciplines equally and considered them while planning CoRe. Another evidence of her strong PCK for STEM could be related to the balance between STEM disciplines in terms of assessment. Ada adopted various methods to assess students' knowledge and performance during the design process at the end of the study. These features indicated the features of the typical PCK-C category for Ada.

4.1.2. Case 2: Defne

4.1.2.1. Knowledge of Curriculum

4.1.2.1.1. Lesson Study 1

Defne was in the role of observer teacher during lesson study 1. She observed the first and revised versions of the STEM lesson plans on "Designing Solar Eclipse Viewer." The following presentations are mainly based on interviews, observation forms, and planning and reflection meetings.

Before the study, Defne chose objectives regarding genetic engineering and biotechnology from the science curriculum in the 8th grade. Her pre-individual CoRe did not include any objectives from other STEM disciplines. When she was asked the reasons for choosing this particular objective and made a comparison between the individual and first collaborative STEM lesson plans, she indicated that:

> I have difficulty understanding genetic and biotechnology concepts personally. I thought it would be better if I went over the things to prepare a STEM lesson plan. Moreover, the word "genetic engineering" attracted my attention since STEM includes engineering as a discipline. I had not known if it was suitable for STEM or not. However, with my current knowledge, I could say that those objectives did not fit the STEM lesson plan. It did not include the engineering design process as in the STEM lesson plan we designed as a group. Integrating engineering does not mean choosing objectives, including “engineering” terms **(pre-interview, 1).**

As seen from the excerpt, Defne preferred to choose objectives from the science curriculum by considering her subject matter knowledge in her pre-individual CoRe. She thought her knowledge of genetics and biotechnology was insufficient and that she could improve her subject matter knowledge by designing a STEM lesson plan. She had shallow knowledge regarding setting objectives for STEM lesson plans because she picked up an objective that involved an "engineering" statement before starting the study.

In planning meetings of lesson study 1, Defne was not actively involved in discussions regarding choosing objectives. She suggested selecting the "comparing the planets in the solar system with each other" objective and added that they could determine one planet, and students might design rockets to be sent by considering the characteristics of this planet, such as its temperature and atmosphere, etc. However, the group discussed that testing part of the engineering design process would be difficult if they continued with this objective. As a result, she participated in Ada’s ideas and did not bring up any discussions regarding setting objectives for other STEM disciplines **(video-recorded planning meetings, lesson study-1).** She mentioned why she changed her mind regarding setting objectives in the pre-interview as follows:

> We concentrated on designing a product while choosing an objective. For example, I suggested sending rockets to the planets (in the planning meetings), and the rocket should be designed according to the weather, temperature, and amount of oxygen on the planet. However, designing and testing it in the

> classroom environment would be difficult for us; I could not find ways how we can test the designed rockets. Therefore, Ada's idea made sense to me; students could easily test their Solar eclipse viewers **(pre-interview, 1).**

Furthermore, she made links with other science topics and explained that they might think about telescopes in the Elaboration phase of 5E, which was an objective from the 7^{th} grade in the science curriculum. However, Ada was not in favour of addressing the objective from the following year in the Elaboration phase and convinced Defne The following dialogue was taken from the planning meetings:

> **Defne:** There are some objectives regarding the Solar system in the 7^{th} grade. Satellites and telescopes are included. Maybe we can discuss whether their (students') way of thinking while designing Solar eclipse viewers could be utilized in designing telescopes, we can discuss it in the Elaborate phase.
> **Ada:** But we want to attract student's attention to the Solar eclipse at this point. What you have suggested is a totally new concept for students. Therefore, I am not in favour of using telescopes in the Elaboration part.
> **Defne:** Actually, you are right… Maybe we can discuss how they use the principles of Solar eclipse viewers in daily life, for instance, how welders work **(video-recorded planning meetings, lesson study 1).**

This situation demonstrated that Defne's understanding of the 5E learning cycle was limited and had an influence on her knowledge of curriculum because she proposed covering a new concept from the following year's objectives in the Elaboration phase. When she was asked to provide detailed explanations of why to utilize objectives in the 7^{th} grade based; she explained that:

> The topics of the first unit in the 7^{th}-grade science curriculum were space and space junk. Students will learn about how new technologies might cause space junk problems. There is also an objective related to the telescope, and I thought we could use it in the Elaboration part at first. I gave up this idea during discussions because it was not related to the Sun and Moon motions. I realized that this concept was not the main part of our lesson, and if we used to design a telescope, there would be disconnection. Designing a telescope was more about optics **(pre-interview, 1).**

As seen from the excerpt, the discussions among the group members in planning meetings were effective in improving Defne's knowledge of curriculum concerning relation to other science topics.

Regarding setting objectives for science, the original objective in the science curriculum was "predict how a solar eclipse occurs." When she was asked why they modified the objective, Defne stated:

> We changed the verb of the objective to "observe" instead of "predict." We actually considered the engineering design process while doing this modification. The previous version was at the understanding level, but we wanted students to create a product and then make observations through their products **(pre-interview, 1).**

Defne’s main idea while setting objectives for science was to make objectives compatible with the engineering design process. Although she started to talk about infusing the engineering design process when compared to her pre-CoRe, she was not aware of setting objectives for engineering after the planning meetings of lesson study 1. Regarding setting objectives in mathematics, she explained that she was not familiar with the mathematics curriculum and had not examined it before **(pre-interview, 1).** With respect to relation to other science topics, she linked the topic to the previous topics at the same grade. She mentioned that students should know about the motions and positions of the Sun, Earth, and Moon and their properties to learn about the Solar eclipse.

She was the observer teacher in the implementation of the first version of the lesson plan, and she noted in her observation form that Deniz did not link the topic with other science topics, and he partially connected the Solar Eclipse topic to other STEM disciplines **(pre-observation form, 1).**

Although Defne was aware that the teacher of the lesson could not be able to relate the topic to other science topics, she could not provide specific examples in the post-interview. For instance, she said that she did not know the place of eye health topic in the science curriculum and in which grade level this topic was covered **(post-interview, 1),** which was related to the content of their lesson plan based on designing Solar eclipse viewers.

Moreover, when she was asked whether she would offer changes in the objectives in reflection meetings, she explained that:

> I think there are much more things in our lesson than making observations as we wrote (in CoRe). We can specify the objective more directly; we have handled it somewhat indirectly in our lesson. I am not sure how we can revise it **(post-interview, 1).**

She had concerns about the objective that they wrote was not covering the content of the lesson; however, she could not make further suggestions both in individual interviews and reflection meetings. She participated in Ada's and Ece's ideas in terms of revising the objective **(researcher's field notes, reflection meetings of lesson study 1).** Moreover, she did not write anything in her observation form about the revised objectives **(post-observation form, 1).** Her knowledge of curriculum with respect to setting objectives for other STEM disciplines did not significantly change after completing lesson study 1.

To summarize, before the study, Defne's knowledge of curriculum represents the features of the PCK-A category. She only considered setting objectives for science in her pre-individual CoRe. On the other hand, she moved to the PCK-B category at the end of lesson study 1. She started to consider the integration of other STEM disciplines, but not in an explicit way. She was in favour of setting objectives only for science. The engineering design process and mathematics were integrated into the lesson, although no objectives were established for these disciplines. She connected science topics to other science topics to some degree, but no obvious relation between other STEM disciplines was observed.

4.1.2.1.2. Lesson Study 2

Defne was the teacher of the first version of the lesson plan in lesson study 2; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

Participants were asked to choose an objective from Force and Motion unit in the science curriculum in lesson study 2. Everyone in the group had different ideas about the science objectives. Defne suggested continuing with balanced and unbalanced forces and writing an engineering problem related to designing a seesaw at the beginning of the planning meetings. However, after she listened to Ada's idea for proceeding with the speed topic, she gave up her initial suggestion and participated in her idea. She stated that if they continued with the speed topic, they could integrate mathematics concepts more efficiently by creating line graphs in STEM lessons. She added:

> **Defne**: If we continue with the engineering design challenge regarding seesaw, we cannot develop their creativity skills. The final product for all groups would be the same. Only the materials might show differences; for example, one group

> might use cardboard while the others might use a paper board. Our aim is not to design a material **(video-recorded planning meetings, lesson study 2).**

Moreover, she triggered discussions in the group about writing mathematics-related objectives:

> **Defne:** I think reading and creating a graph are essential parts of our lesson; they should be in our objectives. I have noticed that the fourth unit of 7th-grade mathematics curriculum involves related objectives. But is it okay to write objectives from the 7th grade?
> **Ada**: But we have a science objective about the distance-time graph. We should extend it and write mathematics objectives about this point as well.
> **Defne**: Can we change it like this: "shows the collected data to the line chart and interprets the graph"?
> **Ada**: I think it is okay, more simplistic, and matches our purpose **(video-recorded planning meetings, lesson study 2).**

After the planning meeting, Defne began to improve her knowledge with respect to understanding objectives in the science curriculum and provided topic-specific details about the reasons for choosing particular objectives in STEM lessons in lesson study 2. She explained that:

> Firstly, I suggested choosing objectives regarding balanced and unbalanced forces. I thought of writing an engineering design-based scenario about designing a seesaw. However, we could not contribute to the student's development of creativity and critical thinking skills with this objective. There is already a classical seesaw design; students might only change the center of gravity and balancing point. It did not allow them to generate alternative solutions. On the other hand, we chose the speed topic with Ada's suggestions and created a daily-life scenario for designing a race car. I am happy with choosing this objective because it allows the development of students' creativity skills, and there are different ways of designing race cars **(pre-interview, 2).**

As seen above, Defne highlighted that science objectives should be suitable for the engineering design process, be based on daily-life problems, and promote developing 21st-century skills in STEM lessons. She began considering the essential elements of STEM education while choosing science objectives from the curriculum. She also started to talk about the limitations of the science curriculum. It could be stated that as her knowledge of instructional strategies concerning design-centered teaching practices developed, her knowledge of curriculum in relation to other STEM disciplines also improved. Moreover, she realized the limitations of the science curriculum for the first time and considered that they should touch on the concept of velocity; however, the science curriculum restricted them to this point **(pre-interview, 2).**

Contrary to lesson study 1, Defne examined the mathematics curriculum before coming to the planning meetings for lesson study 2. She guided the group in terms of writing mathematics objectives. For instance, she indicated that the objectives regarding drawing line graphs were in the 7th grade in the mathematics curriculum, and she triggered discussions in the group about how they could deal with this objective at the 6th-grade level **(video-recorded planning meetings, lesson study 2).** She started to develop her understanding of setting objectives for other STEM disciples after the discussions in the planning meetings of lesson study 2. She further explained her thoughts as indicated below:

> After the group discussions and assessment of the first STEM lesson, I realized that we needed explicitly write objectives for other (STEM) disciplines. We should be clear about our objectives. For example, we want students to develop a prototype using the engineering design process; this is one of the primary purposes of the lesson. Why had we not written it as an objective in the previous lesson study…I examined the mathematics curriculum after the first meeting (first planning meeting of lesson study 2) and tried to understand how we could cover drawing a graph and converting units. We also examined the technology and design course curriculum. Interestingly, we have never looked at it before. There were similar things to our STEM lesson's objectives (in this curriculum), for instance, designing a product using an engineering design process. We wrote the engineering objectives by thinking about the engineering design process steps we followed, such as students creating prototypes, presenting them, and so on **(pre-interview, 2).**

As seen from the excerpt above, she began to talk about the importance of setting objectives for other STEM disciplines and connected the science content to mathematics and engineering by using curricula from other STEM disciplines. She could mention specific details about the objectives of other STEM disciplines.

Concerning linking with other science topics, she made limited connections. Only horizontal relations to the topics previously taught in the same grade were found in her explanations. She indicated that students should know the force concept in the previous topic to learn about the concept of speed **(pre-interview, 2).** However, for instance, she could have addressed the friction force from the 5th grade because the friction force between the ground and the wheel should be minimum to design the race car with the highest speed.

During her teaching of the first version of the STEM lesson plan, Defne did not relate the topic to other science topics during her teaching **(researcher's pre-observation form, 2).** However, regarding relating to other STEM disciplines, she referred to the mathematics curriculum explicitly by saying:

> **Defne:** You will learn the details of drawing line charts in the 7th-grade mathematics class, but I want to show you some examples in this lesson. Now, I will create a data table showing the time and distance travelled… Let's say the vehicle takes 20 meters in one second, and then I connect these points on the two axes of the line graph **(researcher's pre-observation form, 2).**

Distance travelled	0	20	40	60
Time	0	1	2	3

After the implementation of the first version of the lesson plan, she proposed some changes to science objectives. She developed her understanding of the limitations after teaching and criticized them:

> I think we should definitely include mathematical formulas for speed. This issue was a limitation in the curriculum, but it is necessary to cover it for better student learning, especially for explaining the unit of speed. Additionally, another limitation was the concept of velocity in the science curriculum. The curriculum warned us not to mention the rate of change of the object's position with respect to the point of reference, but we should write them as objectives of the lesson **(post-interview, 2).**

Defne as a teacher of the lesson opened these issues up for discussion, and the group members participated in her ideas. The following excerpts were taken from the reflection meetings:

> **Defne:** We directly took objectives from the science curriculum with limitations. There are no displacement and velocity concepts. However, we are using concept cartoons and have items regarding velocity. I think we should remove this limitation.
> **Deniz:** The cooperating teacher said a similar thing.
> **Defne:** Moreover, mathematical formulas are not within the scope of the objective. We have a track; we measure the time for completing the track. We have a formula in the engineering notebook after the testing process. This limitation should also be removed, in my opinion.
> **Ada:** I totally agree with you. We should give the formula. But first, we should let them explore the connection between speed, time, and distance. Then, we should emphasize the mathematical formula **(video-recorded reflection meetings, lesson study 2)**.

The group agreed on adding two more science objectives in the post-CoRe. No more revisions were made to other objectives **(researcher's field notes, reflection meeting of lesson study 2).**

During the re-teaching part, Defne observed Ece's lesson and took some notes on her observation form. She noted that the new objectives they wrote in the reflection meetings worked well. Moreover, she wrote that Ece partially connected the science topics and added that more emphasis could be given to the relation of the topic to the friction force **(researcher's post-observation form, 2).** This shows that Defne's knowledge of curriculum with respect to linking between science topics started to develop after observation of teaching in lesson study 2.

Her explanations were consistent with the PCK-C category at the end of lesson study 2. Defne started to talk about setting objectives for science and other STEM disciplines in a balanced way and provided specific examples of the reasons for establishing objectives for mathematics and engineering. Moreover, she had difficulty relating the lesson's science concept to other science topics at the beginning; however, her understanding was improved after observation of teaching. Accordingly, it could be said that Defne transitioned from the PCK-B category to "PCK for STEM" concerning knowledge of curriculum at the end of lesson study 2.

4.1.2.1.3. Lesson Study 3

Defne was in the role of observer teacher during lesson study 3. The following presentations are mainly based on interviews, observation forms, and planning and reflection meetings.

In terms of setting objectives, Ada first suggested using an objective about thermal insulation, and Defne supported this idea. However, participants had different ideas for writing engineering design challenges with this objective. They discussed designing a thermally insulated animal house, storage box, thermos, and space clothes. Defne was in favour of designing a thermos with a thermal insulation objective **(researcher's field notes, planning meetings of lesson study 3).** Defne explained the reasons for choosing this science objective as follows:

> One of the objectives of this unit was to develop alternative thermal insulation materials. There was an activity in the student book that provided students with step-by-step directions on how to develop these materials. However, we did not ask students to follow the steps and develop the materials in a structured way in our CoRe; it did not fit with the understanding of STEM education. We want them to solve a problem through the use of the engineering design process. Therefore, the thermal insulation objective was more appropriate for the engineering design process. It also contains a daily-life problem. I believe the problem will attract students' attention and motivate them to learn the characteristics of thermal insulation materials to make their thermos designs **(pre-interview, 3).**

Similar to her understanding in the previous lesson study cycle, she preferred to choose science objectives by considering the engineering design process and being familiar with daily life issues. She provided topic-specific examples in her explanations. Moreover, the group did not directly use the original science objectives in this unit and modified them. Defne elaborated on her understanding of the science curriculum and reflected on it as follows:

> We revised the science objectives, and I believe they should be changed in the science curriculum too. Because there is a perception that thermal insulation is done only in buildings in the curriculum, it may lead to a misconception that thermal insulation is done only in buildings. However, there are many places in our daily life where principles of thermal insulation are applied. We did not focus only on buildings in our STEM lesson; we asked students to develop a thermos using thermal insulation principles. We will have another daily-life example, too **(pre-interview, 3).**

Defne talked about the reasons for making changes in science objectives and criticized the curriculum, which demonstrated her improved knowledge concerning setting objectives for science.

Regarding setting objectives for other STEM disciplines, she provided a comprehensive understanding of the engineering objectives:

> We wrote the engineering objectives by using the explanations on the front pages of the science curriculum. There is no curriculum that we can benefit from while writing engineering objectives. The Science curriculum involves the engineering design process, and we have been inspired by them and wrote engineering objectives in our own words. But technology and design curriculum also helped us at this point. Although it was developed for the 7th and 8th grades, the objectives were appropriate for our purposes. This curriculum also consists of the steps of the engineering design process (**pre-interview, 3).**

Additionally, she increased her knowledge of setting objectives for career awareness after the discussions in the planning meetings. She indicated that:

> In fact, we should develop students' career awareness as science teachers, which is one of the aims of the science curriculum. With Ada's suggestion, I also increased my awareness about this point. We had not written it as an objective in our previous STEM lesson plans. For the first time, we added career awareness as an objective and created activities in parallel with this objective. For instance, we designed the "What if the engineers do not exist" activity and included the life stories of two engineers. In our STEM lesson plan, we made career awareness explicit in this way **(pre-interview, 3).**

In terms of understanding the scope of the mathematics curriculum, Defne explained that she had the most difficulty writing mathematics objectives according to students' levels. Mathematics objectives were more of a question mark for her, but she expressed that it became apparent with the help of discussions in the group at the last planning meeting **(pre-interview, 3).** As seen above, the number of connections between science and other STEM disciplines was increased at the end of the planning meetings of lesson study 3. She developed her understanding of the scope of science, mathematics, technology, and design curricula. She suggested writing new objectives, such as considering themselves as team member to emphasize the collaborative work in our plan **(video-recorded planning meetings, lesson study 3).**

Regarding the relation to other science topics, she was able to establish vertical relations and emphasize that students should know about heat, temperature, and differences between them from the 5^{th}-grade objectives. However, horizontal connections were not observed in her explanations **(pre-interview, 3).** She did not mention the particulate nature of matter which was the previous topic that needed to be linked to thermal insulation.

During observation of teaching, she realized that the teacher of the lesson connected the thermal insulation topic with heat and temperature in the previous grade level **(pre-observation form, 3).** It demonstrated that she could identify the instances she mentioned in the pre-interview. She found the connections between science and other STEM disciplines adequate. She did not include detailed explanations about this item; she just added that mathematics was related to science by using a budget sheet and engineering was related to the engineering design process and career awareness **(pre-observation form, 3).**

Defne did not propose any changes in terms of setting objectives after the implementation of the lesson. She thought they touched on each objective equally **(post-interview, 3, researcher's field notes, reflection meeting of lesson study 3).**

During observation of re-teaching, Defne detected that the teacher of the lesson connected the thermal insulation topic to the previous topic at the same grade. She noted that Deniz talked about how heat was transferred in solids, liquids, and gases and asked questions about the particulate nature of matter **(post-observation form, 3).** It could be said that her knowledge of curriculum for establishing a vertical relationship in the science curriculum improved after observation of teaching.

These features in her PCK met the PCK-C category totally, which is PCK for STEM. Defne was able to set objectives for STEM disciplines in addition to giving detailed and topic-specific explanations about the reasons to choose and modify them. Her use of science, mathematics, technology and design curriculum was enhanced. Moreover, she established vertical and horizontal relations in the science curriculum, and her relation to other STEM topics was evident in her explanations.

4.1.2.1.4. Lesson Study 4

Defne was the teacher of the revised version of the STEM lesson plan in lesson study 4; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

The participants were required to choose an objective from "the Sound" unit for the last STEM lesson plan. The group discussed continuing with the sound insulation concept with Ada's suggestion, and Defne supported this idea as follows:

> **Ada:** The curriculum has an objective, such as designing an environment for sound insulation and acoustic applications. I have something in mind to design the music room environment. We can also use materials such as egg cartons and styrofoam; we can plan the engineering design process effectively.
> **Defne:** There is an activity in the textbook developed for this purpose. Students are asked to create sound insulated music room. Of course, it is a structured activity; everyone had to follow the same steps. But I think we can choose this objective and turn it into an open-ended problem.
> **…**

> **Deniz:** Students will measure the decibel values; they might compare their data through graphs. We can write an objective about this point.
> **R:** Do you have any ideas about the possible mathematics objective based on Deniz's suggestion?
> **Defne:** Maybe we can write collect data from the decimeter...Or create a graph.
> **R:** What kind of graphs might be used in this situation?
> **Defne:** Line graph…I am not sure, but we have groups' names and decibel values. The group names are not continuous data. Can a bar chart be appropriate?
> **Ada:** I agree with you. We can write "create bar charts from the data collected and interpret".
> **Deniz:** Then, forming bar charts for their groups is meaningless. There should be every group's bar chart in the engineering notebook to make comparisons among them **(video-recorded planning meetings, lesson study 4).**

As seen from the dialogues, Defne considered the key elements of STEM education, such as proposing open-ended design challenges and integrating the design process while arguing over the science objectives. Moreover, she was aware of setting related objectives for the mathematics discipline and made recommendations that showed her developed understanding of the scope of the mathematics curriculum at the end of the planning meetings.

Defne was asked to compare her pre-individual CoRe and the last STEM lesson plan concerning setting objectives for STEM lessons; she explained that:

> I realized that I did know anything about STEM education when I examined my first individual lesson plan. I considered STEM education as teaching science in a more detailed way... I had insufficient knowledge in terms of genetics and biotechnology, so I chose this objective in the science curriculum. There was no integration of other STEM disciplines, engineering design process, and daily life problems. Accordingly, I just wrote science objectives. Now I can set objectives from other disciplines as well and plan activities in the STEM lesson plan to reach these objectives **(pre-interview, 4).**

As seen from her explanations, she improved her knowledge of the basic features of STEM education. This understanding was reflected in her knowledge of curriculum concerning setting objectives for other STEM disciplines. Moreover, her knowledge of curriculum and knowledge of assessment interacted because she realized the importance of writing objectives for other STEM disciplines after using the rubric and elaborated on her understanding of writing engineering-related objectives **(pre-interview, 4).** She suggested adding engineering-related objectives to the science curriculum after the planning meetings of lesson study 4. She stated that:

> There are some explanations about the steps of the engineering design process in the science curriculum; however, I think they are insufficient. Some science objectives might be enriched with engineering objectives. For instance, the "design an environment related to thermal insulation" objective in the curriculum might be supported with engineering objectives as we did in our CoRe. In this way, STEM education might be prioritized in the science curriculum, and it could be a guide for teachers **(pre-interview, 4).**

Apart from engineering objectives, she developed a critical perspective on the mathematics curriculum and objectives. She indicated that:

> We are having minor problems in writing mathematics objectives. I will criticize the science curriculum again. When we were choosing science objectives for the STEM lesson plan and searching for possible objectives from the mathematics curriculum, I realized that both curricula did not progress in parallel. For example, we wanted students to collect data and transform this data and graphs to assess the effectiveness of their designs, but I noticed that the related mathematics objectives were placed in the upper grade in the previous lesson plan. If we could not find the fully related objective from the mathematics curriculum, we had to write new objectives for other disciplines. In this lesson, we want them to draw bar charts from the data collected using a decimeter, which they had already learned in previous grades. The objectives of these two courses may be a little more parallel **(pre-interview, 4).**

Defne was unaware of the mathematics and engineering objectives at the beginning of the study; however, she developed her knowledge of understanding of the curriculum in different STEM disciplines and provided suggestions for planning an integrated lesson plan at the end of lesson study 4. She enhanced her knowledge of connecting the content of other STEM disciplines to science objectives.

Concerning establishing connections with other science topics, she had limited knowledge about this topic because she did not mention the concepts of sound and its properties and sound technologies that students were expected to learn in previous grades. On the other hand, she had enough knowledge to link the topics to previous science topics **(pre-interview, 4).**

Defne observed Ece's lessons, and she noted that Ece was able to link the sound insulation topic with the previous topics, such as how sound travels in different mediums, as stated in pre-interviews. This situation was missing in her explanations and developed with the observation of teaching. She also considered that the connection with other STEM disciplines during the lesson was adequate **(pre-**

observation form, 4). She did not attempt to change the objectives of the STEM lesson after the first implementation of the STEM lesson **(post-interview, 4).**

Defne was responsible for teaching the lesson in the re-teaching part. She accomplished covering all objectives written in CoRe. She started the lesson by asking questions as follows:

> **Defne**: Have you remembered how sound travels in solids from the last week's classroom?
> **S1**: Through the waves.
> **S2**: It first vibrates and then travels.
> **S3**: Interacts with matter **(researcher's post-observation form, 4).**

As seen from the dialogues, she established horizontal relations by reminding the previous science topic at the same grade. Moreover, mathematics content was connected to the content of science and engineering in the lesson. The following dialogue was taken from her teaching:

> **Defne:** In our previous STEM lesson, we learned to create line graphs. Do you remember?
> **S1:** Yes, we drew it after testing our race cars.
> **Defne:** Yes, today we will form another type of graph, which is a bar graph. You have already learned the details of bar graphs in the 5th grade, but I will help you remember today. We will measure the decibel value and create a bar chart for each group. We will also have a bar chart for the empty music room. Then, we will compare the effectiveness of your design by examining bar charts. Are we okay? **(researcher's post-observation form, 4).**

Defne was aware of the scope of the mathematics curriculum and used her knowledge to relate the topic to other STEM disciplines after the re-teaching phase of lesson study 4. Her knowledge of curriculum was consistent with the PCK-C category at the end of lesson study 4. Her understanding of the science and mathematics curriculum was improved, and she was able to direct criticism regarding the objectives and make recommendations for the curriculum. Similarly, she established objectives for science and other STEM disciplines in her post-individual CoRe. She chose a science objective directly from the science curriculum: "design a mechanism that will provide ease of work in daily life by utilizing simple machines". She wrote mathematics objectives following students' levels, and engineering objectives included the design process, collaborative work, and career awareness. She connected the science topic to the force concept and pulley, lever, inclined plane so on, and the other STEM disciplines **(post-individual CoRe).**

4.1.2.2. Knowledge of Learners

4.1.2.2.1. Lesson Study 1

Defne was an observer teacher during lesson study 1. The following presentations are mainly based on interviews, observation forms, and planning and reflection meetings.

In her pre-individual CoRe, Defne did not specify any misconceptions in science and in other STEM disciplines. With respect to difficulties, she wrote, "students might have difficulty in understanding the genetic and biotechnology concepts". She approached learners' difficulties from a general point of view, and no more details were found in her first individual CoRe.

The discussions in the planning meetings were concentrated on science-related misconceptions **(researcher's field notes, planning meetings of lesson study 1).** After planning meetings, Defne started to talk about science-related misconceptions along with the possible resources for these misconceptions. For instance:

> We observed that students considered all planets lined up in one direction. Actually, I was not aware of it; however, Deniz shared his observation (in our planning meetings), and my awareness increased. There were some students' drawings regarding the Solar system in the classroom; almost all planets were the same size, and the distance between them was equal. These misconceptions should be handled. This is an abstract concept, and students cannot do experiments. I think this is why they have misconceptions about these topics. Let's consider the friction force concept. Experiments might be designed easily to overcome this misconception, but astronomy topics are abstract, and more misconceptions emerge more easily. I also had similar misconceptions before the study **(pre-interview, 1).**

Defne touched on the possible sources of science-related misconceptions, and she relied on her observations in the classroom, her own experiences, and discussions in the planning meetings to explain these reasons. Her knowledge of learners started to evolve concerning science-related misconceptions. However, she stated that they did not specifically plan anything for dealing with Solar eclipse misconceptions **(pre-interview, 1)**. No misconceptions regarding other STEM disciplines were encountered in her explanations after the planning meetings.

Concerning difficulties, Defne described both science and engineering-related difficulties. However, her explanations regarding difficulties were superficial. For instance, she only mentioned that the students might have difficulties understanding the positions of the Sun, Earth, and Moon during the eclipse because of the abstract nature of the topic. Regarding engineering-related difficulties, she stated that:

> Students might have difficulty choosing the best solution. They might also experience difficulties in working as a team. They are not used to these types of activities; therefore, I have some questions about the points that they might have difficulty with **(pre-interview, 1).**

As seen above, Defne addressed that lack of experience in terms of the engineering design process might be challenging for students. She did not mention any content-specific details about the difficulties, and her explanations were too broad. Besides, her explanations of how to handle students' difficulties in science and engineering were missing after the planning meetings of lesson study 1.

While observing the first STEM lesson, Defne noted that no misconceptions were encountered in Deniz's lesson. However, she realized and wrote down that students had difficulty understanding the difference between criteria and limitations, which was not written in CoRe during the planning meetings. She also added that the teacher of the lesson provided daily-life examples to handle engineering-related difficulties **(pre-observation form, 1).** This situation shows that Defne started to develop her knowledge of learners concerning difficulties after observation of teaching.

Before the reflection meeting, she was asked whether she identified any misconceptions that emerged in the lesson; she said that there were no misconceptions emerged in the lesson. Then, the researcher reminded her of some instances from the lesson, and Defne started to talk about science-related misconceptions:

> Two students said that a Solar eclipse could be watched directly through binoculars. Deniz briefly explained that the filters of the binoculars should be changed, but there should be more emphasis. I am not sure whether the misconception was eliminated or not **(post-interview, 1).**

Moreover, the researcher reminded Defne that when Deniz asked the question "who is an engineer?", the students responded that engineers built something. She remembered the dialogues and began to talk about engineering-related misconceptions as follows:

> Yes, I remember. The student from the back of the classroom said that engineers built. We could have been clearer about the work of engineers. It seems that there was a misconception regarding the work engineers did. More time should be devoted to this issue, and the teacher of the lesson should explain that engineering design and create projects for buildings; they do not build. We did not discuss it in the meeting, so I think Deniz skipped this part quickly **(post-interview, 1).**

As seen above, Defne could not detect misconceptions during teaching; however, she started to improve her knowledge in the reflection part and suggested that the teacher should handle engineering-related misconceptions through correct explanation.

In terms of difficulties, she realized that students had difficulty determining the criteria and limitations of the engineering design challenge. She paid attention to how the teacher of the lesson handled this particular difficulty and said:

> I think one of the missing parts of our lesson plan was that we ignored the possible points that students might experience in determining the criteria and limitations. These were the key concepts of the lesson, and we also struggled (in planning meetings). We should have explained the concepts of criteria and limitations at the beginning of the lesson. Deniz provided examples to explain these concepts, and I believe it was really helpful. We should definitely add explanations and examples of criteria and limitations to our lesson plan **(post-interview, 1).**

She also added that students still had difficulty understanding the concept of the limitations in the engineering design challenge after Deniz's explanations. She pointed out that students did not consider budget, and they spent all their money while designing their products. She said that most groups took many materials and did not consider designing effective Solar eclipse viewers with the lowest budget, demonstrating they did not fully grasp the idea of limitation **(post-interview, 1).**

Additionally, Defne mentioned that since students lacked experience in STEM lessons, they had difficulty generating more than one solution to the engineering problem and evaluating whether each solution met the criteria and limitations **(post-interview, 1).** Although she realized difficulties that were not written in CoRe during the observation of teaching, her explanations were not content-specific, and the way of overcoming difficulties was limited to explanations.

In the reflection meetings, Defne favored adding some engineering-related difficulties in CoRe, and the group revised this prompt in CoRe. With the suggestion of Deniz, the group agreed to add an engineering-related misconception as "the engineers' working area is limited to the construction sites". No more revisions were made regarding science-related misconceptions **(researcher's field notes, reflection meetings of lesson study 1).**

After revising the lesson plan, Defne observed the lesson in the re-teaching phase, and she was careful about the points they discussed and reflected on in the reflection meetings. For instance, she wrote that students had difficulty in identifying the limitations and criteria, and the teacher of the lesson provided daily life examples to handle this difficulty. Moreover, she realized that students also struggled in understanding the concept of prototypes, and the teacher of the lesson enriched her teaching with examples to overcome this difficulty. She noticed engineering-related misconceptions about the work of engineers **(post-observation form, 1).** It could be said that reflection and observation of the teaching phases of lesson study 1 had an influence on Defne's knowledge of learners with respect to misconceptions and difficulties. On the other hand, although the number of misconceptions and difficulties she mentioned increased in numbers, she had surface knowledge regarding identifying and eliminating them at the end of lesson study 1.

In summary, Defne's pre-CoRe showed the typical features of the PCK-A category at the beginning of the study. She did not indicate any misconceptions, and only science-related difficulty was written. While attending the lesson study phases, her knowledge of learners concerning misconceptions and difficulties started to develop. However, her focus was on one discipline of STEM when talking about difficulties and misconceptions. The way of identifying and clearing up misconceptions and the probable origins of most of these misconceptions were not addressed in her explanations. Therefore, it could be inferred that Defne made a transition from PCK-A to PCK-B after completing lesson study 1.

4.1.2.2.2. Lesson Study 2

Defne was the teacher of the first version of the STEM lesson plan in lesson study 2; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were presented in this section.

In the planning meetings of lesson study 2, Defne was one of the active participants who put forward ideas about students' misconceptions. Firstly, she participated in the discussions that students might not distinguish the concepts of speed and velocity. She was not sure how to deal with this misconception because of the limitation of the science curriculum. There were intense discussions about how to detect science-related misconceptions in the group, such as using concept cartoons, conceptual change text, word association tests, etc., and Defne was in favour of using word association tests for identifying science-related misconceptions and concept cartoons to understand whether the misconceptions was eliminated **(pre-interview, 1).** She began to provide ways other than question-answer for revealing misconceptions contrary to lesson study 1. Additionally, she mentioned that students might have been confused about creating the graphs **(researcher's field notes, planning meetings of lesson study 2).** This was the first time she pointed out a mathematics-related misconception: "there is only one type of graph for each data set". She indicated that students were required to form two different graphs; one for distance travelled/time and the other one for speed/time. She considered that students might have alternative conceptions about creating line graphs with ascending slopes in drawing constant speed-time graphs **(video-recorded planning meetings, lesson study 2).** Her idea was accepted by the group and was written in CoRe. It could be inferred that she started to think about misconceptions in other STEM disciplines after the planning meetings of lesson study 2. Moreover, she talked about students' difficulties in mathematics and engineering disciplines as follows:

> **Defne**: We discussed that our mathematic objectives are in the 7th grade; therefore, students might have difficulty in transforming the data into line graphs; we should add this on CoRe.
> **Ece**: I agree. Besides, they might have difficulty making the tires turn during the design process.
> **Defne**: Yes, it could also happen. Moreover, creating effective designs with the constraints of the budget might be difficult for students **(video-recorded planning meetings, lesson study 2).**

When asked in the interview after the planning meetings, Defne mentioned the importance of using strategies for detecting and eliminating science-related misconceptions. She said:

> We will use the word association test at the beginning of the lesson. We need to understand what students know about speed and determine their misconceptions

> to continue designing the race car with the highest speed. I believe word association is easy to use, time efficient, and will directly give us students' perspectives. At the same time, concept cartoon will be effective. We have three people talking about speed in the concept cartoon, and students will choose and support one idea from the concept carton; this will provide an opportunity to understand whether the misconception about speed is eliminated **(pre-interview, 2).**

As seen above, she elaborated on her understanding of detecting misconceptions and when to use particular techniques to detect and correct misconceptions. She pointed out that the primary sources of these misconceptions were her own experiences as a student. She also added that everyday language caused misconceptions about speed.

In terms of difficulties, she talked about engineering and mathematics-related difficulties. The significant difficulty that she emphasized was designing a race car by considering criteria. She had concerns that students might experience difficulty in applying their scientific knowledge in the design process, especially in terms of choosing the tires for the car. She planned to walk around the groups and guide them to minimize students' engineering-related difficulties **(pre-interview, 2).** Additionally, she was aware that creating line graphs might be challenging for students, and she provided ways to overcome this difficulty as follows:

> I will explain how to draw a line graph and how to insert the data in this graph through some examples. Later, I will ask them to calculate the speed of their designed cars and transform their data into graphs. If I had not been involved in this study, I would not have examined the mathematics curriculum. I could not consider that students might experience difficulty because drawing line graphs were in the following grade in the mathematics curriculum. Therefore, I will support them with different examples at the beginning of the lesson **(pre-interview, 2).**

Defne thought students' lack of knowledge might lead to mathematics-related difficulties, and she aimed to handle them through explanations and additional examples.

Defne applied the first version of the STEM lesson plan in lesson study 2. She used a word association test and asked students to work in a group of two. Then, she took answers from many groups. The answers included velocity, distance, traffic, running, displacement, and so on. However, she did not comment on the student’s responses to the word association test **(researcher’s pre-observation form, 2).** Unlike the original plan, she brought two students to the board and aimed to show the differences between distance travelled and displacement to address the misconception of speed and velocity. Both students started walking from the desk to the door, but one walked straight, and the other walked in a zigzag. Below is the conservation that occurred between Defne and the students:

> **Defne**: Where did student A start and finish?
> **S1**: started from the desk and finished next to the door.
> **Defne:** Alright then, where did the other student start and finish?
> **S2:** It is the same.
> **Defne:** Yes. Is the distance travelled the same for students A and B?
> **S3**: No. The one walking in a zigzag travelled more distance.
> **Defne:** Exactly. The distance that student B travelled is longer (wrote the term "distance travelled" on the board). But their displacement was the same (wrote the term "displacement" on the board). While talking about speed, we are interested in distance travelled, not displacement **(researcher's pre-observation form, 2).**

The misconceptions were usually emphasized during the teaching of the topic, and she utilized improvisation to refer to speed and velocity misconceptions. She did not have enough time to implement the concept cartoon to understand whether this particular misconception was eliminated; however, some students discussed the velocity concept rather than speed while presenting their designed race cars **(researcher's pre-observation form, 2).** This situation showed that the pre-determined science-related misconception in CoRe was not eliminated throughout the lesson by Defne. On the other hand, she addressed mathematics-related misconception through explanation. After students collected data using their race cars, they formed a speed-time graph. Although the group calculated the speed of their car and found it was a constant speed motion, they attempted to form a graph with ascending slope. Defne realized the misconceptions and warned students: "There are different types of line graphs, ascending slope and zero slopes. Our graph should be zero slopes" **(researcher's pre-observation form, 2).**

When these moments were reminded to Defne after teaching, she pointed out that using REACT as a teaching strategy was one of the reasons why she could not handle the misconception about speed. She mentioned they prepared many student-centered activities in every part of REACT, which resulted in time management problems, and she had to skip some parts of the lesson quickly without delving into details **(post-interview, 2).** When she was asked in the interview, she stated:

> I think using the word association test was very effective. We wanted to reveal misconceptions about speed, but time restricted me. I just read a few answers and could not provide feedback after the students' responses. I mean, I only identified their misconceptions but could not deal with them appropriately. We should discuss the way of using it in our group meeting. It was the same for the concept cartoon. I could not use it because of time limitations. I suggest that we should use it before starting the engineering design process. We want students to design the race car with the highest speed, and correcting their misconceptions about speed is essential before continuing the design process **(post-interview, 2).**

As seen above**,** she realized that most students still held their misconceptions about speed after the lesson. She had some suggestions about the way of using methods of identifying science-related misconceptions after teaching. She could detect them but had some problems eliminating them **(researcher's pre-observation form, 2).**

Concerning learner's difficulties, Defne realized more difficulties than was written in CoRe. For instance, she noticed students experienced difficulty in determining the unit of speed. She pointed out the testing and collecting data part of the engineering design process, and an instance was observed as follows:

> **Defne**: How many meters was our racetrack?
> **S1:** 2 meters.
> **Defne:** Yes, exactly. Then, how many seconds did it take for your race car to complete the racetrack?
> **S1**: 3 seconds.
> **Defne**: We have defined speed as "distance travelled per unit of time". So, your car completed a 2-meter racetrack in 3 seconds. The distance travelled is in meters, and we measured the time in seconds. So, what can we say?
> **S**: (No response).
> **Defne:** We can say that the unit of speed is meter/second; look at the formula in the sixth step of the engineering notebook **(researcher's pre-observation form, 2).**

She addressed the testing phase of the engineering design process and supported it with an explanation. She had different ideas for overcoming this difficulty after teaching:

> Students calculated the speed of their designed cars; however, they could not describe the unit of speed. I asked many times, and I could not get an answer which was unexpected for me. I asked about the distance travelled and the time to complete the racetrack, but it did not work for most of the students. I think we

> should use Distance-Speed-Time (DST) triangle. Students might visualize and easily describe the unit of speed as meter/second **(post-interview, 2).**

As seen above, the teaching phase of lesson study contributed to Defne's knowledge in terms of learners' difficulties. Additionally, she was aware of engineering and mathematics-related difficulties in her lessons. For example, students had difficulty in drawing graphs as written in CoRe, and she dealt with them through explanations and providing examples. She also noticed that students had difficulty in transforming distance travelled/time graphs into speed/time graphs **(researcher's pre-observation form, 2).** After teaching, she recommended using more examples regarding transforming graphs before implementing the engineering design process because of students' difficulties **(post-interview, 2).**

Defne mentioned engineering-related difficulties after the teaching of the lesson. She stated how she tried to handle these difficulties:

> One group experienced difficulty in creating prototypes. They could not choose the best solution as well. Two students insisted their idea was the best one and asked to continue with creating two prototypes in one group. I always directed them to the table (the decision table that participants prepared in choosing the best solution part) and told them to choose by considering the criteria and limitations in the engineering design process. These instructions were influential, and they chose one solution and created their prototypes to be tested. The other group had difficulty making tires work which was one of our criteria **(post-interview, 2).**

Defne detected engineering-related difficulties and utilized representations to deal with these difficulties after the teaching phase of the lesson study.

Defne suggested some points in the reflection meeting as a teacher of the lesson. She suggested using concept cartoon earlier in the lesson to deal with science-related misconceptions. Moreover, she explained that more time should be devoted to word association test, and the misconceptions identified in word association should be emphasized in testing and communicating parts of the engineering design process. The participants agreed to these suggestions and modified the flow of the lesson. She also added that the number of examples for creating and transforming graphs should be increased since students experienced difficulties and they prepared new examples. Lastly, she was in favour of using the DST triangle to address difficulties regarding unit of speed **(researcher's field notes, reflection meetings of lesson study 2).** This showed that her knowledge of curriculum and instructional strategies interacted with the knowledge of learners after teaching and reflection parts of lesson study 2. She suggested to modified limitations in the science curriculum to handle students' difficulties and utilize science-related representations.

In summary, Defne's knowledge of learners concerning misconceptions and difficulties expanded after completing lesson study 2. She was able to mention students' misconceptions in science and mathematics in a detailed way and provided ways for identifying and overcoming them. Although she could not eliminate science-related misconceptions during her lesson, she reflected on her teaching experience and suggested revisions in the CoRe about this point. Moreover, she was conscious of learners' difficulties in science, engineering, and mathematics and tried to handle them on purpose during instruction. These features met the highest level in PCK development, PCK for STEM, at the end of lesson study 2.

4.1.2.2.3. Lesson Study 3

Defne was an observer teacher during lesson study 3. The following presentations are mainly based on interviews, observation forms, and planning and reflection meetings.

The discussions in the planning meetings started with science-related misconceptions. Defne was the first one to put forward the idea of two science-related misconceptions about heat and thermal insulation as follows:

> **Defne:** I think students might have the misconception that heat and temperature are the same things.
> **Ada:** Yes, we should write it in CoRe. These two terms are used interchangeably in our everyday lives. It is very similar to the velocity-speed concept for me in this respect.
> …
> **Defne:** I have another suggestion. For example, we will have a sleeping-bag example; students might alternatively think that they are the sources of heat. While reading an article before the meeting, I encountered something like this. This might emerge in our lesson, too **(video-recorded planning meetings, lesson study 3).**

As seen in the dialogue above, Defne was able to talk about misconceptions in line with the literature. Moreover, Ada suggested that writing students might think there is only one successful design. Defne liked the idea and agreed to write it as an engineering-related misconception. When she was asked about her thoughts on engineering-related misconceptions in the pre-interview and engineering design process-related misconceptions. She stated that:

> We used "The World without Engineers" visuals because students think only of civil engineers and consider engineers as builders, according to my observations… Moreover, we also used the life stories of two engineers, one of them female. So, we attempted to emphasize that girls can be engineers, too, in our lesson. Moreover, I think the misconceptions that Ada mentioned were common among students. There should be alternative designs to solve the problem we gave at the beginning of the engineering design process. For example, we should tell our students that you used different thermal insulator materials to create the thermos that keeps the soup hot. You have used different combinations, and there are no single successful designs. After the first testing, you will have the chance to improve your designs. We should emphasize this point and make it clear to eliminate misconceptions about the engineering design process **(pre-interview, 3).**

Furthermore, the number of science-related misconceptions and topic-specific details of misconceptions increased in lesson study 3. She was able to mention misconceptions in line with the literature as follows:

> I believe everyday language has an impact on students' misconceptions about heat and thermal insulation. For instance, when we open the window in winter, we say, "Cold is transferred from outside". However, this is not the case. Heat moves from warmer to cooler; we should provide this understanding to our students. I think we should also deal with this misconception in our lesson. Moreover, students might think some objects like blankets are sources of heat. We put this misconception as an item in the diagnostic tree to check whether it will be eliminated or not **(pre-interview, 3).**

As seen above, Defne deepened her understanding of misconceptions. She benefited from her observations of teaching and discussions while talking about possible sources of misconceptions. She talked about how to minimize misconceptions before emerging. She considered ways of eliminating science and engineering-related misconceptions before they occurred and suggested ways to detect them, such as a diagnostic tree after the planning meetings of lesson study 3.

Concerning difficulties, Defne's explanations included science and engineering-related difficulties. Firstly, she talked about how using and reading a thermometer could be challenging for students since they were unfamiliar with it. Then, she mentioned that students might experience determining the unit of heat and temperature based on her observations and experiences in prior lesson study cycles. Lastly, she thought that deciding and choosing which thermal insulators would be more effective in the design process might be difficult for students. However, she added that they prepared material cards to overcome engineering-related difficulties **(pre-interview, 3).**

While observing the lesson, Defne realized some science-related misconceptions. For instance, she noted that the misconceptions of "cold is transferred" emerged during the lesson, and the teacher of the lesson skipped that part quickly. She also wrote that students had difficulty choosing the appropriate insulators and reading thermometers, as in CoRe. On the other hand, she did not catch the engineering design process-related misconception written in CoRe **(pre-observation form, 3).**

Although Defne did not write about engineering design process-related misconception in her observation form when it occurred, she talked about it after teaching:

> We wrote that students might think there is only one design that meets the criteria and limitations in our CoRe. It actually emerged, and Ada realized it. She explained that alternative combinations of thermal insulators could be considered in the re-designing part and discussed them **(post-interview, 3).**

Moreover, Defne explained that the teacher of the lesson realized the heat-temperature misconception and tried to eliminate it through explanation and by providing daily life examples **(post-interview, 3).** She talked about other science-related misconceptions as follows:

> Ada asked whether the sleeping bag had thermal insulation, and one of the students answered, "it keeps warm; something is warming inside". In planning meetings, we focused on blanket examples, and this was the same misconception as written in CoRe. I have seen this misconception in one article, so it was expected, but I do not think Ada corrected this misconception **(post-interview, 3).**

It could be seen that Defne was able to detect misconceptions and observed whether the teacher of the lesson handled them or not after observation of teaching in lesson study 3.

In terms of difficulties, Defne paid attention to what was written in CoRe. She emphasized how the material cards were helpful for students in choosing the appropriate thermal insulators:

> Students always had difficulty generating more than one solution. However, the discussion among the groups was intense this time, and they discussed which materials were better and which were more suitable for their budget. The decision table and material cards played a significant role in proposing solutions and choosing the best one for me. For instance, one group wanted to put fibreglass wool inside of the thermos, but then they decided that it was harmful to health and it could get wet when the soup was put into the thermos by looking at the material cards. These types of things helped dealing with students' difficulties **(post-interview, 3).**

In the reflection meeting, Defne suggested revising CoRe regarding students' misconceptions and difficulties. Regarding science-related misconceptions, she offered to add "the heat cannot be measured directly" into CoRe because she explained that one student explained that heat could not be measured, and Ada did not realize it. The group participated in her idea and revised the CoRe. She shared her observations about how students had difficulty using a thermometer, and the group decided to add an introduction part to using a thermometer (**researcher's field notes, reflection meeting of lesson study 3).**

In-reaching part, Defne noted that the science-related misconception regarding heat and temperature was eliminated in the lesson, and introducing the use of a thermometer was an effective way to deal with this difficulty **(post-observation form, 3).**

In brief, Defne was conscious of misconceptions and difficulties in science and other STEM disciplines with equal emphasis. She was able to mention the probable origins of misconceptions and their existence of them and provided content-specific details. She was able to put equal emphasis on STEM disciplines regarding misconceptions and difficulties. Therefore, it could be said that her PCK level met the criteria of PCK-C regarding the knowledge of learners after attending lesson study 3.

4.1.2.2.4. Lesson Study 4

Defne was the teacher of the revised version of the STEM lesson plan in lesson study 4; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were presented in this section.

In planning meetings, Ada proposed to write two new engineering-related misconceptions, and Defne participated in her idea. Moreover, she suggested writing science-related misconceptions, too **(researcher's field notes, planning meetings of lesson study 4).** When asked in the interview about these misconceptions, she stated:

> Actually, we discussed that students had misconceptions about the work of scientists and engineers in the previous plan (revised version of 3rd lesson plan). When Defne reminded this point in the planning meetings, it made sense to me, and I supported writing it as a misconception in CoRe. It was very spontaneous in the previous lesson, but Deniz had given appropriate answers. We used a word association test to detect students' misconceptions about engineering, and if their answers include scientists' work, we can easily explain the difference between science and engineers in this CoRe… We prepared Vyond to deal with misconceptions, especially "engineers work alone" misconception. We will also use daily life examples to overcome this misconception **(pre-interview, 4).**

Defne stated that they had difficulty in writing science-related misconceptions about sound. She emphasized that she had her misconception about this concept and drew upon her experiences as a teacher and observer while considering misconceptions. She found the KWL chart useful for detecting misconceptions about sound at the beginning of the lesson **(pre-interview, 4).** As seen above, the observation of teaching and reflection on the lesson was helpful for Defne in detecting science and engineering-related misconceptions. She drew upon her experiences to explain possible misconceptions and suggested ways to identify them rather than question and answer when compared to lesson study 1.

Regarding difficulties, Defne addressed science, engineering, and mathematics-related difficulties. She mentioned the possible sources of these difficulties based on her observations and said:

> Proposing more than one solution part was challenging for us throughout the study. We planned to make it as easy as possible by using a decision table, but generally, students have one solution in their minds. Our purpose is to make them propose more than one solution, compare these solutions, think critically and choose the best one. I think we will handle it in a better way in the last STEM lesson… Sometimes, they had difficulty creating the most suitable prototype for the budget. For this lesson plan, I think they might experience difficulty in creating bar charts. Creating graphs was complicated in the previous lesson plan. We want them to form bar charts by using the decibel values for each group and make their decision process easier in determining the best sound-insulated design. Since we know they might have difficulties, we first introduce the characteristics of bar charts and then ask them to create them using the data collected **(pre-interview, 4).**

As seen from her explanations, Defne paid attention to modifying the flow of the lesson by considering students’ possible difficulties based on her observations. This demonstrated her improved knowledge with respect to learners.

She was the observer teacher, and she noted that Ece gave importance to what students should know before covering the topic and asked appropriate questions, such as how the sound travelled in different mediums. Moreover, she found using the KWL chart and examining students' prior knowledge using the K parts effective. Regarding difficulties, she realized that students faced difficulties in understanding the sound reflection and absorption principles of designing a sound-insulated music room. She also jotted down students who still had misconceptions about the work of engineers **(pre-observation form, 4).**

As a teacher of the revised version of the lesson plan, she had some suggestions after observing teaching. Firstly, she proposed to use example data to create a bar chart in addition to an explanation because some groups had difficulty in drawing them. She said:

> Ece drew the horizontal and vertical axis while forming graphs. She created the first bar chart herself by using the first group's data because no one could not draw. Instead, we can use other data here; the teacher of the lesson might demonstrate bar charts by using this data. Then, students might use their decibel values and draw their charts independently. But as a result, the groups compared their decibel values and figured out easily which group's solution was a more sound-insulated environment in Ece's lesson. We should definitely use bar charts **(post-interview, 4).**

In the reflection meeting, Defne triggered a discussion about the graphs and suggested adding new data and examples for the bar chart. However, the group had some concerns about time management, and they preferred not to add this example. Moreover, Defne found Ada's suggestions to expand the content of the science magazine appropriate because she also observed that students had difficulties in understanding sound absorption and reflection **(researcher’s field notes, reflection meeting of lesson study 4).**

Defne carried out the revised version of the lesson plan. She developed her knowledge of learners regarding the prerequisite knowledge required for learning sound insulation topics. Defne defined sound and mentioned how sound travels in different mediums. She also explained how students would use the KWL chart by saying:

> We have created a table for you. You are supposed to write what you know about sound insulation in the K part of the table. Please do not hesitate to write anything that comes to your mind. After you fill out this part, you will make an investigation by using a science magazine to get the necessary knowledge to solve engineering problems **(researcher's post-observation form, 4).**

Additionally, she emphasized the unit of sound intensity. She directed questions about why they took three measurements while testing their designs and took the mean value to address students' possible difficulties based on her prior experiences **(researcher's post-observation form, 4).**

Moreover, Defne was able to organize her lesson to overcome possible mathematics-related difficulties. After students' created their prototypes and collected their data, Defne guided the students in terms of creating bar charts. She explained that:

> We have collected our data, and let's create a bar chart. I will draw it for the music room without soundproofing. Then, each group's data analyst will come and draw a graph of their group by using their decibel values **(researcher's post-observation form, 4).**

As seen in Figure 4.14, Defne guided the students while creating bar charts using the data collected since students faced difficulties.

Figure 4. 14 Scene from Defne's Classroom in Lesson Study 4

Additionally, Defne focused on an engineering-related misconception, "engineers work alone," written in CoRe, and tried to eliminate it before it occurred. The following instance was taken from her teaching:

Defne: We have created a soundproof music room and tested them to solve our problem. How have we worked in this process? Individual? Or as a group?
S1: as a group.
Defne: Yes, today you are in the role of engineer, and you worked as a group of four or five people. Every student has a responsibility in the group, right?
S2: Yes, I drew the bar chart.
S3: I noted the decibel values.
S4: I drew our prototype in our notebook.
Defne: Definitely. Engineers also work as a group, just as you have done up to now. I will show you a video now (the animation that concentrates on a group of engineers working together).
…
Defne: (after showing the animation). What are the points that have attracted your attention in the video?
S5: Four engineers work together in the video. For example, one of them was an environmental engineer, but she collaborated with chemical engineers.
Defne: Exactly, environmental engineers do not work alone; engineers from different fields work as a group like you did today. They complement each other's work to find solutions to the problems **(researcher's post-observation form, 4).**

As seen from the excerpt above, Defne was aware of engineering-related misconceptions written in CoRe and attempted to eliminate the prementioned misconception before emerging by providing explanations and drawing upon animation.

Lastly, Defne prepared post-individual CoRe and concentrated on objectives regarding simple machines. Her CoRe included misconceptions specific to science and other STEM disciplines. She paid attention to the elimination of misconceptions. For instance, she wrote questions about "there is only one successful design" and utilized an engineering design poster to address this misconception. Similarly, she included difficulties in science and other STEM disciplines. For example, she considered that students might confront difficulties in determining the criteria and limitations of the engineering design challenge and added daily-life examples in her CoRe to handle it. It could be said that she considered misconceptions and difficulties while planning her lesson **(post-individual CoRe).**

It could be stated that throughout four lesson study cycles, Defne not only extended the number of science-related misconceptions with possible resources and ways of eliminating them, but she was also able to identify the misconceptions in other STEM disciplines. She provided topic-specific details and meaningful explanations for possible misconceptions and difficulties at the end of the four lesson study cycles. These features were consistent with the PCK-C category, and it could be said that she was in the highest category of PCK about the knowledge of learners at the end of lesson study 4.

4.1.2.3. Knowledge of Instructional Strategies

4.1.2.3.1. Lesson Study 1

Defne was an observer teacher during lesson study 1. The following presentations are mainly based on interviews, observation forms, and planning and reflection meetings.

Before the study, Defne prepared her pre-CoRe utilizing argumentation. She used a newspaper article to trigger discussions in the classroom regarding cloning. Then, she used concept cartoons to demonstrate different ideas on genetically modified foods and asked students to decide on whether genetically modified should be allowed or not. No features of STEM education were observed in her CoRe. There were no design-centered teaching practices or engagement with engineering concepts. The representations and activities specific to science were limited in number **(pre-individual CoRe).**

In planning meetings, Defne favoured using the 5E learning cycle because of her familiarity with strategy. She indicated that since STEM education was new to them, they should continue using the strategy they used frequently. She argued that using a strategy they did not have adequate knowledge of might be problematic for the first STEM lesson plan. The group thought similar things; therefore, they chose the 5E learning cycle **(video-recorded planning meetings, lesson study 1).**

Defne was asked why she agreed to use the 5E learning cycle as a teaching strategy; she stated that:

> In a typical lesson plan that we use 5E, we design experiments, students collect data, reach scientific knowledge, and are actively involved in Explore part. In a STEM lesson plan prepared by using 5E, we require students to create their prototypes concretely to solve a problem. Then, they will decide whether their prototypes solve the problem or not and present their solutions. We can integrate these features in Explore part of 5E. I think they fit with each other. But I still have a question mark in my mind, could there be a more suitable method for the

> STEM lesson plan? We should discuss it in our following lesson plans **(pre-interview, 1).**

As seen above, Defne suggested a teaching strategy compatible with STEM; however, she presented a general understanding of using 5E. She matched some features of STEM education with Explain part only, and no topic-specific details were provided.

Regarding design-centered teaching practices, she started to talk about some essential characteristics of STEM education in lesson study 1. She emphasized the importance of criteria and limitations to solve an engineering design problem. She indicated that:

> Students have to meet the criteria to solve the problem in our lesson. Moreover, we put a maximum budget because we did not want them to take all the available materials. The budget would limit them; they might compromise some criteria and think critically. We also prepared a brochure that involved the deadline for their solutions. We asked them to solve the problem within the specified date. It is also a limitation; students will learn to study with criteria and limitations **(pre-interview, 1).**

The excerpt above displayed that Defne took criteria and limitations to solve the problem, which were the features of design-centered teaching practices. She proposed to add some questions in researching the problem part of the engineering notebook, such as the role of viewers in the Solar eclipse to encourage students to investigate **(researcher's field notes, planning meetings of lesson study 1).** On the other hand, many features of design-centered practices were missing in her explanations after the planning meetings of lesson study 1.

In relation to representations, she mentioned using a table in choosing the best solution part of the engineering notebook given in Figure 4.15 as follows:

> We added this table to foster students' critical thinking skills. Every student in the group is expected to propose at least one solution, and then they are required to choose the best one. While doing this, students should consider which solution solves the problem in a better way and objectively. They need to discuss which solutions meet which criteria. At the same time, they will develop decision-making skills. If we did not put tables and ask open-ended questions such as "why did you choose this solution, " they probably would not consider arguing criteria and limitations **(pre-interview, 1).**

(Tabloda doldurulacak ölçütleri nedenleriyle belirtiniz.)

Çözüm Önerileri	Kriterlere Uygunluk	Sınırlılıklara Uygunluk	Avantaj	Dezavantaj	Neden en iyi çözüm önerisi olduğunu düşünüyorsunuz?
Çözüm Önerisi 1					
Çözüm Önerisi 2					
Çözüm Önerisi 3					
Çözüm Önerisi 4					

Figure 4. 15 Example of Decision Table in Engineering Notebook-1

Additionally, she was able to explain why they prepared a decision diagram in the re-design part. She thought that using this table to determine the weak parts of students' designs would be easier **(pre-interview, 1).** Defne began to explain the reasons for using engineering-related representations after the planning meetings of lesson study 1. On the other hand, no representations specific to science were found in her statements. Regarding activities, she mentioned science and engineering-related activities as discussed in the planning meetings.

Regarding engagement with engineering concepts, she started to use engineering terminology in her explanations, such as "criteria, limitations, and prototype". She also indicated that the engineering design challenge should be open-ended, and each group should develop unique solutions **(pre-interview, 1).**

Defne was the observer teacher and noted that the teacher of the lesson should spare more time to generate alternative solutions to the problem in the engineering design process. She noted that guiding the groups in the design process was sufficient and the use of representations and activities adequate. On the other hand, she partially agreed with the use of engineering terminology throughout the lesson **(pre-observation form, 1).**

After observing teaching, Defne started to talk about more design-based teaching practices and noticed how Deniz utilized some parts of these practices. For instance, she explained that:

> I think we should encourage every group to produce as many alternative solutions as possible; we should not restrict them just two alternatives as Deniz did. The teacher should say I expect you to have at least two different solutions. Then, the teacher should support students in discussions among the group. I think guiding student groups play a significant role in our STEM lesson **(post-interview, 1).**

On the other hand, she did not find the use of material cards effective **(post-interview, 1).** She could not link the researching the problem part and material cards. She did not mention scientific knowledge in researching the problem part, and her explanation was superficial. It could be stated that she began to improve her knowledge of instructional strategies with respect to design-centered practices to some extent after observing the lesson; however, she still did not consider many of them, such as discussing the rationale behind design solutions or re-designing.

Moreover, she found the 5E learning cycle suitable and did not offer to change it for the revised version of the lesson plan. She found representations specific to engineering sufficient and did not suggest any changes in activities **(post-interview, 1).**

Regarding engineering with engagement concepts, Defne proposed promoting STEM careers after observation of teaching. She indicated that:

> There was no career emphasis during the lesson. Deniz only asked the "who is an engineer" question. This part should be extended. How engineers work and what types of work they do should be taken into account. We had a client in our lesson, and the group engineers were expected to solve the client's problem and market it. I think this understanding should be prioritized in our lesson because it was missing **(post-interview, 1).**

Defne also mentioned the importance of using engineering terminology appropriately. She realized Deniz did not use the concept of the prototype until the end of the lesson and was able to criticize this issue after observation of teaching **(post-interview, 1).**

In the reflection meeting, no changes were made to teaching strategies. Defne opened the discussion that students should be encouraged to offer many solutions to the problem, and the participants agreed as follows:

> **Defne:** (while assessing students' engineering notebooks according to the rubric). I think we should emphasize that every group has to produce at least two different solutions. We should not restrict them as in Deniz's lesson.
> **Deniz:** Yes, I said there is no need for the third solution. But I was wrong. Besides, we should introduce them to the engineering notebook at the beginning of the lesson. If we do this, we can underline the importance of generating alternative solutions **(video-recorded reflection meetings, lesson study 2).**

Defne also argued her concerns about using the material cards more effectively and suggested providing more clear directions to the students while using them. However, the group decided to remove material cards, one of the activities specific to science **(researcher's field notes, reflection meetings of lesson study 1).**

In the revised version of the lesson plan, different from the previous observation form, she noted that 5E could be disadvantageous in terms of time management, and alternative strategies could be considered. Moreover, one of the students found the engineering design challenge unfamiliar, and Defne did not realize and note it **(post-observation form, 3).**

In summary, Defne's knowledge of instructional strategies showed the features of PCK-A at the beginning of the study. Although argumentation could be used in STEM education as a teaching strategy, she did not employ its fundamental characteristics while preparing her CoRe. No design-centered teaching practices were observed in her CoRe, and representations were used only for teaching a science topic. On the other hand, Defne began to talk about teaching strategies compatible with STEM education but with limited understanding. She had a general understanding and could not match the features of STEM education and the teaching strategy. Her knowledge of design-centered teaching practices was enhanced to some degree, and she started integrating strategies for engagement with engineering concepts. Lastly, her focus was on the engineering discipline in terms of representations and activities; the other STEM disciplines were not given too much weight. Therefore, these features reflected the properties of the PCK-B category about knowledge of instructional strategies at the end of lesson study 1.

4.1.2.3.2. Lesson Study 2

Defne was the teacher of the first version of the lesson plan in lesson study 2; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

Defne tended to use another strategy other than the 5E learning cycle in planning meetings of lesson study 2. She explained that she examined STEM lesson plans in the literature, most of which were prepared using the 5E learning cycle. However, she offered to utilize REACT as a teaching strategy in a STEM lesson. This was the first time Defne recommended alternative strategies in the study. The following excerpt was taken from the planning meetings:

> **Defne:** If we use REACT, we can connect to their daily-life experiences better than 5E. Moreover, the collaboration part is very suitable for the engineering design process. 5E is a good strategy but REACT can be a good alternative.
> **R:** What do you think about using REACT?
> **Deniz:** I do not want to use a specific strategy. We can just use an engineering notebook; a major part of the lesson is designing prototypes.
> **Ada:** We can use 5E again. We are knowledgeable about it, and it worked well in the previous STEM plan. I had only prepared one lesson plan using REACT.
> **Defne:** Yes, we did not use it very much, but we can learn together in the group.
> **Ece:** I think I am in favour of using REACT. It is very similar to 5E; we can use it easily. I wonder about the implementation of REACT strategy. We can choose a context that attracts students' attention to start, and the collaboration part seems very appropriate for STEM education.
> **Defne**: We expect misconceptions in our lesson, the science content of the lesson will be challenging. I think we can handle them using REACT. I know that we might have difficulty planning, but we should try **(video-recorded planning meetings, lesson study 2).**

As seen above, the group remained between the 5E learning cycle and REACT and preferred to employ REACT since they wanted to try something new and learn as a group. Defne further explained the reasons for using REACT in STEM lesson plans as follows:

> I think the STEM education approach and REACT fit with each other. I thought to use it in the first lesson plan, but I do not have enough background knowledge regarding REACT. I have not used it very much until this time; we are used to 5E in general. Then, I realized that REACT and 5E were similar to each other. I had difficulty in the Transfer phase because it did not match the Elaboration part of 5E. The other phases were very close to each other. I had concerns about REACT at the beginning of the planning phase because there were many

> misconceptions regarding the speed topic. I thought 5E might help us address misconceptions more effectively. But after completing the plan, I am happy with the result **(pre-interview, 2).**

Defne pointed out that she had surface knowledge regarding REACT. She did not delve into details about the connection between STEM education and REACT. Instead, she compared 5E and REACT with each other. The primary reasons for choosing REACT were its similarity with the 5E learning cycle and tackling science-related misconceptions, as stated by Defne. She could not provide a comprehensive understanding of the reasons for using REACT in STEM lesson plans.

In terms of design-centered practices, she touched on some features, such as proposing more than one solution to solve the problem and taking criteria and limitations into account to solve the problem, as in lesson study 1. Differently, she provided some details about the importance of researching the problem:

> We added two Formula-1 cars (one of them was from the 1950s and the other one was from the 2000s) and asked students to compare their similarities and differences in researching the problem part. They were going to generate solutions in the next step, so we wanted them to compare the height of the cars, the size of the wheels, and the structure and shape of the cars to get an idea **(pre-interview, 2).**

As seen above, students were not given opportunities to conduct research, and the questions asked to guide the learners were insufficient. The other point that Defne referred to regarding design-centered practices for the first time emphasizing the scientific rationale behind design solutions. She stated:

> We want students to complete the racetrack with their designed cars. In this way, we make the concept of "distance travelled" concrete. Then, they will measure the time and calculate the speed of their cars. They will collect data and draw graphs. Through the graphs, they will see the constant speed. We will also discuss in what ways their car goes with a higher speed **(pre-interview, 2).**

Defne started to discuss how students would grasp scientific knowledge in the design process by giving topic-specific details after the planning meetings of lesson study 2.

In relation to representations, she utilized representations in science and other STEM disciplines. She talked about the significance of drawing graphs in deciding the best solution, using videos to attract students' attention to the lesson, and using decision diagrams to support students' decision-making and critical thinking skills **(pre-**

interview, 2). With respect to engagement with engineering concepts, she paid attention to using authentic engineering design problems after the planning meetings of lesson study 2.

Defne was responsible for teaching the first version of the STEM lesson plan. While implementing REACT, she quickly skipped the Transfer phase because of time management issues. The group discussed that if there was not enough time, activities in the transfer phase could be given as homework, but Defne did not implement it either **(researcher's pre-observation form, 2).**

Concerning design-centered practices, she could not complete the full iteration of the engineering design process. Communicating solutions, re-design parts, and learning from failure were not emphasized in her teaching. Moreover, one group could not finish their car designs in a given time and could not calculate their car speed. She ignored this issue; therefore, that group could not discuss scientific knowledge in the engineering design process. On the other hand, she emphasized proposing more than one solution as follows: "Please be careful. You are required to propose at least two different solutions for the car with the highest speed. Fill in the decision table by discussing your ideas as a group of engineering team" **(researcher's pre-observation form, 2).** All groups completed the sketch of their designs, labelled the materials they would use, and calculated their budgets. Defne walked around the groups during teaching, as seen in Figure 4.16. An example dialogue was taken from her classroom while managing the group work and promoting collaborative working:

> **S1**: We should continue with my solution. I want to design the car in this way. I want to use a milk box as a body.
> **Defne:** Why do you think so?
> **S1:** The other ideas are not applicable. A foam plate could not be used.
> **Defne**: I want you, as a group, to fill out the decision table. You already have written three ideas. Please discuss each of them; which one meets more criteria? Remember, we are working as a team of engineers. We should choose the best one among others which fits the criteria and limitations, by group decision **(researcher's pre-observation form, 2).**

After the conversation, Defne followed the group's work and made sure they had a discussion and came to a conclusion. She started to pay attention to guiding students' learning as a part of design-centered teaching practices during teaching.

Figure 4. 16 Scene from Defne's Classroom in Lesson Study 2

Regarding representations, she used a limited number of daily life examples. On the other hand, she applied different representations such as videos, graphs, posters, and visuals while teaching engineering and mathematics disciplines. For example, she benefited from a visual to encourage students to understand the concept of limitations in the engineering design process, as seen in Figure 4.17. The budget allocated by the Turkish Formula-1 Federation for engineers was distributed to all groups. At the same time, Defne encouraged students to role-play with this visual.

Figure 4. 17 Example of Visual used in Engineering Notebook

The other visual that she employed was an engineering design process poster. The following dialogue was taken from Defne's classroom:

> **Defne:** In our previous STEM lesson, you designed Solar eclipse viewers. Do you remember? We will go through the same steps we went through while designing Solar eclipse viewers. Let's remember these iterative steps, which we call the engineering design process.
> **S1:** I remember there was a company. It asked for designing viewers to observe the Solar eclipse.
> **Defne:** You are right. It starts with an engineering design challenge; we are looking for a solution to daily life problems. As you see here (showing the

> poster), it starts with defining the problem, criteria, and constraints… **(researcher's pre-observation form, 2).**

Defne continued to go over to engineering design process step by step. Moreover, she drew upon engineering-related visuals and aimed to promote STEM careers using the visuals. An instance was observed during her teaching:

> **Defne**: Which occupational groups do you think are in this photo?
> **S1:** Repairman.
> **S2:** Mechanical engineers.
> **S3:** Computer engineers.
> **Defne:** You are right. A group of engineers is designing a car. So, has anyone heard of data analysis as a profession before?
> **S4:** Yes, I have heard. They keep reports about the car; they take notes.
> **Defne:** Definitely. Today your groups will include both engineers and analysts… How the people in this photo work:
> **S5:** as a team.
> **S6:** in a disciplined way **(researcher's pre-observation form, 2).**

In addition to utilizing engineering terminology, Defne started to stimulate students' interest in STEM careers as a part of engagement with engineering concepts after teaching part of lesson study 2. She also used activities and performed exercises to make students discover the concept of speed in the Application phase of REACT **(researcher's pre-observation form, 3).**

After the teaching, she gave six points out of ten for the implementation of the lesson because she thought that time management and classroom management were the main issues for her. She attributed these issues to the use of REACT. She stated that:

> I had difficult moments after the testing phase. I hardly managed the classroom, and there were unexpected situations. For instance, one group did not complete their design. Therefore, they could not calculate speed and draw line graphs. I could not know how to handle them, and I think using REACT limited me; I was confused about what to do at different phases of REACT **(post-interview, 2).**

Defne had limited knowledge regarding REACT before teaching, and this situation was also reflected in her teaching. Moreover, she added that REACT had some disadvantages in terms of dealing with misconceptions as follows:

> Students were active in all phases of REACT and were required to discover the speed concept independently. I could not say, "no, it is not velocity; it is speed," when I confronted the misconception in line with the nature of REACT. Students had to understand it through the activities. This might be a disadvantage at some points (**post-interview, 2).**

After teaching, Defne's knowledge about REACT increased, and she criticized using REACT with the STEM education approach in some respects. She did not offer any changes in the strategy for the revised lesson plan; however, she suggested that the flow of the lesson could be reconsidered. She suggested using more-daily life examples about speed after teaching about representations. She was aware that she could not implement some features of design-centered practices and warned Ece, the teacher of the revised lesson, to manage the time better. Lastly, Defne thought the visuals related to engineering careers and the engineering design process were effective (**post-interview, 2).**

In the reflection meeting, Defne had some suggestions concerning representations. She offered to use the drawing of the DST triangle as follows:

> **Defne:** The cooperating teacher recommended using the DST triangle, and I agree with her. Using this visual will help to overcome students' difficulties in determining the unit of speed, and they will understand the relationship between time, distance, and speed more concretely **(video-recorded reflection meetings, lesson study 2).**

She thought that this representation would help uncover students' misconceptions about speed. Additionally, the relationship between speed, time, and distance became more evident through this drawing, and students could easily infer the unit of speed. She also suggested infusing more daily-life examples, such as asking does the car's dashboard shows speed or velocity. Her ideas were accepted by the group members and added to CoRe. It could be said that Defne's knowledge of instructional strategies with respect to representations also improved after teaching. The other group members had some suggestions regarding design-centered practices, such as discussing the speed concept, especially in communicating the solution part, involving girls in the testing phase, etc. Defne agreed with them **(researcher’s field notes, reflection meeting of lesson study 2).**

During the observation of re-teaching, Defne was able to reflect on what had been discussed in the reflection meeting in her observation form. For instance, she noted that Ece drew the DST triangle effectively. Regarding design-centered teaching practices, she noticed that Ece involved girls in the testing phase but also noted that she skipped the researching the problem part. Defne also wrote that the concepts of speed in the engineering design process were discussed in a better way **(post-**

observation form, 2). It could be said that observation of re-teaching along with the reflection part improved Defne's knowledge of instructional strategies at the end of lesson study 2.

To conclude, Defne’s knowledge of instructional strategies met the features of the PCK-B category after completing lesson study 2. Although she proposed using REACT, she could not explain why this teaching strategy was selected in the STEM lesson plan. She carried out design-centered teaching practices with some limitations in her instruction. The reflection part helped her to improve her knowledge of instructional strategy regarding design-centered teaching practices to some degree; however, she still faced some difficulties in using design challenges. The most developed part of the knowledge of instructional strategies was representations for Defne. She was able to utilize representations in science and other STEM disciplines at the end of lesson study 2.

4.1.2.3.3. Lesson Study 3

Defne was an observer teacher during lesson study 3. The following presentations are mainly based on interviews, observation forms, and planning and reflection meetings.

In planning meetings, Defne was one of the participants who wanted to utilize the 5E learning cycle as a teaching strategy. She explained that she desired to try alternative strategies at the beginning of the study, and they opted to use REACT in the previous lesson study cycle. Moreover, she added that they had adequate knowledge about the 5E learning cycle and that the engineering design process was more compatible with 5E. Ece also shared Defne's thoughts, and they decided to continue with the 5E learning cycle. Defne had a different suggestion about the Engage part of the lesson plan compared to the first plan prepared by using the 5E learning cycle as follows:

> **Defne:** I have an idea. We integrated introducing the engineering design problem into the Explore part and used another activity to attract students' attention to the lesson. I think we should use the engineering design problem in the Engage part; we can make this problem attractive by preparing an animated video on Vyond. What do you say?
> **Ada**: You mean presenting an engineering design challenge in the Engage part?
> **Ece**: I like the idea. We both save time and also motivate students to the lesson.
> **Ada**: I also enjoy the idea. It will engage students because they pay attention to the animations **(video-recorded planning meetings, lesson study 3).**

After planning meetings, she explained her thoughts by comparing 5E and REACT when asked why they chose 5E:

> With 5E, we feel more confident. It is actually very easy to plan activities when you have mastered the strategy, but we have little knowledge about other strategies. We used REACT, and I think it worked in the STEM lesson. The features of the engineering design process and application-collaboration parts of REACT really fit with each other. On the other hand, it took more time to plan a STEM lesson with REACT, and I could not handle the problems during the lesson since I was not very familiar with the strategy **(pre-interview, 3).**

As seen above, having strong knowledge related to teaching strategy was one of the main factors that influenced Defne's choices of teaching strategy compatible with STEM.

Regarding design-centered teaching practices, Defne touched upon content-specific details and mentioned the significance of researching the problem and providing a scientific rationale for a design solution. She stated that:

> One of the critical points of our lesson was researching the problem. Because students will use the knowledge gained in this step in the engineering design process. So, researching the problem part is really important for grasping science concepts. After students determine the criteria and limitations, they will discover the thermal insulation materials and their characteristics. We have prepared material cards with photos and brief information about the materials, such as strength, lifetime, cost, effect on human health, etc. After this part, they will infer the materials that could be used in thermal insulation. We used material cards in the first lesson, but they were not very effective; we could not integrate them into the flow of the lesson. Actually, we could have done better for this lesson plan by utilizing technology; however, there were limited opportunities in the classroom to use technology. I believe the material cards are the best way to search for the problem in our situation **(pre-interview, 3).**

The number and details of design-centered practices in Defne's explanations increased. Another example of her enhanced knowledge is given below:

> We want students to determine the strengths and weaknesses of their designs. They should ask themselves, "how can we keep the soup hotter, in what ways our thermos design could be improved" types of questions. Re-design part was implemented towards the end of the lesson, we generally ran out of time, and we could not test their improved designs again; students only wrote in the engineering notebook. Actually, we expect them to re-test their improved design and collect the data again **(pre-interview, 3).**

She focused on the re-design part and complete iteration of the engineering design process, as seen above. The observation of teaching contributed to her enhanced knowledge of instructional strategies concerning design-centered practices. She mentioned the re-building of designs rather than conceptual re-design, which was missing in her previous explanations.

Moreover, she talked about representations specific to science and engineering. She underlined the importance of using daily-life examples in the elaboration part of 5E, such as discussing the thermal insulation principles in space suits. She connected these daily life examples with engineering, such as engineers had to find a solution for creating astronauts' space suits. Furthermore, she talked about the importance of organizing the data collection table, taking multiple measurements to ensure reliability, and interpreting the data using the table to support students' development of science process skills. Lastly, she offered to use visuals specific to engineering work to encourage students for STEM careers (**pre-interview, 3).** This demonstrated that her knowledge of instructional strategies concerning representations and engagement with engineering concepts improved after the planning meetings of lesson study 3.

During observation of teaching, she noted that the teacher of the lesson balanced the group work and completed all parts of the engineering design process. She completely agreed that giving engineering problem through animation and engineering-related visuals attracted students' attention. She thought the use of daily-life examples was adequate, and Ada used tables and performed activities during her teaching **(pre-observation form, 3).** Based on her observations, it could be indicated that she was able to recognize the features of design-centered teaching practices and representations specific to science and engineering in lesson study 3.

After teaching, she advocated that they used the 5E learning cycle better way when compared to lesson study 1. She stated that:

> I think preparing animation to present the engineering problem was very noticeable. It matched with the “engage” part of 5E; it triggered students' interest at the beginning of the lesson. Moreover, we wanted them to find the criteria and limitations of this animation rather than from a text. I think it worked. We applied the steps of 5E appropriately. Students explored the characteristics of thermal insulation materials in Explore phase, and then by using these features, they created their thermoses and tested them. Then, they shared their findings in

> line with the Explanation part. I am also comfortable with the Elaboration part this time; we integrated daily life examples involving science and engineering disciplines. We enabled students to deduce that engineers solve the problems faced by people and also enabled them to use their knowledge about thermal insulation in different situations… I had thought that 5E fit very well in the first lesson, but at that time, I think that we used 5E much more appropriately **(post-interview, 3).**

As seen above, Defne mentioned how characteristics of STEM education and the 5E learning cycle were harmonized after observation of teaching in lesson study 3 for the first time in the study. She supported her explanations with content-specific details. Her knowledge of instructional strategies with respect to choosing and rationalizing appropriate teaching strategies compatible with STEM progressed.

In the reflection meeting, Defne underlined that students should collect data from their re-designed thermos if enough time is allocated. Moreover, she recommended revising the activity in the explore phase, in which students classified materials in heat conduction. The activity was modified after her suggestions **(researcher's field notes, reflection meeting of lesson study 3).**

While observing the revised version of the lesson plan, Defne noted and criticized that the teacher of the lesson was active during explore phase. He tended to teach the topic through explanation and using symbolic representations of thermal conduction in solids, liquids, and gases. She also wrote that the posters that they prepared could not be used for the re-designing part because of time management problems **(post-observation form, 3).** Defne's observations indicated that she was able to recognize representations that the group did not discuss before and had enough knowledge about the teaching strategy, and realized the problems while implementing it at the end of lesson study 3.

In brief, Defne could relate the features of the 5E learning cycle and STEM education at the end of lesson study 3 while elucidating the reasons for their preferences in choosing teaching strategy. Many design-centered teaching practices were evident in her statements enriched with content-specific details. Representations in science and engineering were emphasized equally, and she elaborated on her understanding of engagement with engineering concepts. These points revelated that Defne was in the PCK-C category at the end of lesson study 3.

4.1.2.3.4. Lesson Study 4

Defne was the teacher of the revised version of the lesson plan in lesson study 4; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In planning meetings, Defne was undecided on which strategy to use while planning the last STEM lesson plan. The group members discussed using the 5E learning cycle and problem-based learning. Then, Defne suggested using project-based learning; however, she explained that completing a project might take more than two weeks later in the discussion. As a result, she agreed to use problem-based learning **(researcher's field notes, planning meetings of lesson study 4, video recorded planning meetings, lesson study 4, given in Ece's case).** When she was asked about her thoughts on the teaching strategy in the interview, she explained:

> I think we realized problem-based learning as a teaching strategy too late. It actually fits very well with STEM. We used 5E in the first one, which would be our first STEM plan; it was good to use a strategy we know well. Then, we tried REACT. It went well up to a point transfer phase that challenged us. We were always inclined to use 5E. Later, when we started to discuss what the alternative could be, Ece suggested this (problem-based learning). We looked at the steps of problem-based learning; in fact, it was very much in line with the engineering design process. It actually aligned with the STEM approach. We have not implemented it in the classroom yet, but it seems effective **(pre-interview, 4).**

As seen above, Defne summarized the process in terms of using teaching strategies compatible with STEM. She was surprised how the steps of problem-based learning and the engineering design process complement each other. It could be said that she was able to discuss alternative strategies used in STEM lesson plans rather than the 5E learning cycle, which displayed her improved knowledge about teaching strategies in STEM lessons. Defne provided further details about how problem-based learning matched with STEM lesson plans:

> We have noticed that defining the problem and exploring the problem parts fits well with defining and researching the problem parts of the engineering design process. This was one of the reasons we picked up this strategy. For instance, students will investigate about sound insulation concept from the science magazine to solve the problem, which is one of the steps of problem-based learning. They will assess different ways to solve the problem in the engineering design process. I think we will use the time better with problem-based learning. I have not used it before. We had just talked about it in our Science Teaching

> course but did not have a prepared lesson plan. We examined sample plans and discussed them in the group in planning meetings, and I think the information settled down. I think it will be even better after using it in the classroom **(pre-interview, 4).**

Defne stated reasons for choosing problem-based learning and became more knowledgeable about the strategy after the planning meetings of lesson study 4. Growth in her knowledge of teaching strategy influenced her preferences for teaching strategy and resulted in providing detailed reasons at the end of lesson study 4.

Regarding design-centered teaching practices and engagement with engineering concepts, she touched upon the details similar to lesson study 3. Her improved knowledge remained the same in terms of these two subcomponents of instructional strategies after the planning meetings of lesson study 4.

On the other hand, regarding representations specific to science, she highlighted using the KWL chart in the first part of the lesson. She indicated that:

> We will use this chart for the first time, but it looks like it will work. We want to see the students' prior knowledge about sound and wonder what they want to learn. So, it made sense to add the KWL table. It will direct research the problem part. In the end, students will fill out the last column in the chart that will show what they have learned about sound insulation before designing their sound-proof rooms **(pre-interview, 4).**

Defne pointed out how the KWL chart helps students to organize their learning in the design process. Moreover, she favoured using different representations specific to engineering and mathematics, such as the poster for communicating the solution and re-designing with the suggestion of Ada. She explained that it would be helpful to increase the quality of the last two steps of the engineering design process. The other engineering-related representation was using animated video about engineering careers, and she thought it would increase students' curiosity **(pre-interview, 4).** She also referred to promoting STEM careers and considered it part of a lesson, meaning not superficially attached to the lesson. Lastly, she mentioned the importance of using bar charts to visualize the data collected, interpret the data, and assess the effectiveness of the design **(pre-interview, 4).** It could be said that her representations became diversified after the planning meetings of lesson study 4.

Defne was aware of what had been discussed in the planning meetings about instructional strategies and reflected her understanding of the observation of teaching. She noted that problem-based learning was applied appropriately, and time management was also good. She agreed that the teacher of the lesson used representations correctly, such as drawing a data collection table, creating bar charts, using video, and employing activities such as improvisation and using a science magazine. She also noticed how design-centered teaching practices were implemented along with the career emphasis as a part of engagement with engineering concepts **(pre-observation form, 4).**

Defne focused on representations after observation of teaching in an interview. For instance, she stated:

> I really like the KWL chart; I have never used it before. I think it exactly overlapped with problem-based learning. Until today, we obtained students' prior knowledge through question and answer, but the K part was very effective for me. Students enjoyed filling in the W part; for instance, one group wrote that we wanted to learn about sound insulator materials for our design. This part guided them on what they needed to investigate… KWL chart and science magazine complemented each other very well at this point… The daily life examples that Ece used were well-chosen. I also plan to use these examples in my lesson too (**post-interview, 4).**

Defne talked about representations in science and other STEM disciplines. She was able to catch the daily-life examples that Ece used, which were not written in CoRe, that could be considered as evidence of her enhanced knowledge after the observation of teaching. Moreover, she touched on many design-centered practices. For instance, she did not highlight featuring of science concepts in the engineering design process at the beginning of the study; however, she deepened her understanding by providing detailed information at the end of the study:

> After researching the problem part, Ece asked about the common characteristics of sound insulator materials used in the groups. One group said that "they absorb sound", while the others indicated, "if it is hard, it will reflect, it will not absorb sound", and "if it is smooth, it reflects the sound; therefore, it should be rough". These were the expected answers, and students chose the materials in their design by considering these characteristics. Then, after completing testing, the results were apparent thanks to bar charts, and they had a chance to compare how different combinations of materials gave different results **(post-interview, 4).**

In the reflection meeting, a minor change was made in CoRe regarding instructional strategies. The new content was added to the science magazine, which students might investigate with Ada's suggestions, and Defne agreed to use it in her revised lesson **(researcher's field notes, reflection meetings of lesson study 4).**

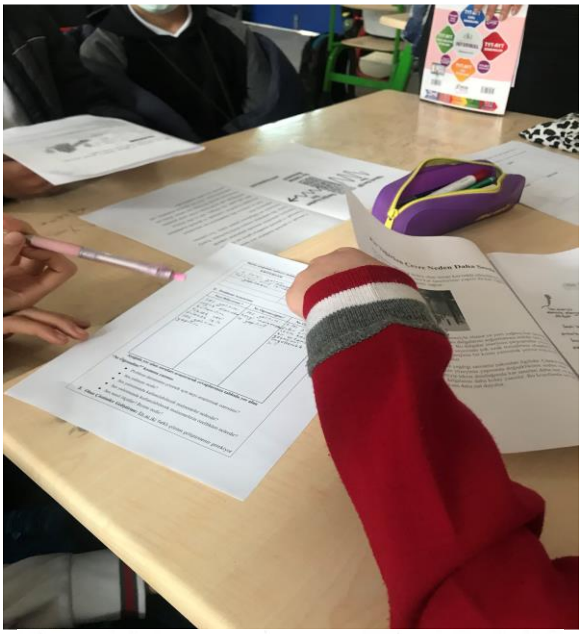
Defne taught the revised and final STEM lesson plan in lesson study 4. She completed all the steps of problem-based learning on time. Her instruction showed many features of design-centered teaching practices. She started by introducing the engineering design challenge and asked students to define criteria and limitations as a whole classroom. The students were willing to attend the lesson, as seen in Figure 4.18.

Figure 4. 18 Scene from Defne's Classroom in Lesson Study 4

Defne used representations specific to science, engineering, and mathematics in her lesson. She utilized many daily-life, science-related examples during her lessons. Moreover, the other visual representations specific to science were using KWL charts. She distributed KWL charts to the groups and explained that:

> We created a table for you. Now, you are supposed to write the things you know about sound and sound insulation in the K part. Then, you will write which questions you want to investigate to solve the problem that we have just defined. After forming your questions, you can use science magazine and your book to find the answers. Remember, we work as a group of engineers **(researcher's post-observation form, 4).**

She managed to coach students' groups and guide them through questions to complete their investigation and reach a solution about the features of sound insulation materials. Figure 4.19 shows a group of students filling out the KWL chart.



2. Problemi Araştırma:

Neyi Biliyorum ?	Ne Öğreneceğim?	Ne Öğrendim?
Sesin dalgalar halinde yayıldığı, Sesin boşlukta yayılmadığı	Ses yalıtımı ilgili daha çok bilgi	Ses yalıtımda kullanılan malzemeler: • Taş yünü • Storafor köpük • Pamuk Ses yalıtımında gözenekli, pürüzlü ve yumuşak malzemeler tercih edilir.

Figure 4. 19 Example of Students' Work in Lesson Study 4

After students had developed their prototypes, she drew a data collection table on the board. She used an application on her mobile phone to measure decibel values of sound coming out from students' designs for 15 seconds. The other telephone was placed in students' designs, as provided in Figure 4.20.

Figure 4. 20 Example of Students' Designs in Lesson Study 4

Defne first measured the decibel values of the empty box and then measured each group's values and took three measurements. She organized the data on the board and asked students to complete the table in their engineering notebooks. She also asked students to compose bar graphs using the data table. The following conversation was taken from her teaching after the testing process:

> **Defne:** We have completed the bar charts. How do you interpret these values? For instance, let's compare the first and second bar charts.
> **S1**: The empty box has the highest decibel value compared to others.
> **Defne:** You are right.
> **S2:** Our group has the lowest decibel value.
> **Defne:** Which materials did you choose to design your sound-proof music room?
> **S2:** We used eggcup because it was rough. We also used a sponge because of its porous structure.
> **Defne:** What it means to have the lowest decibel value in the bar chart?
> **S3:** Our music room absorbed the sound better; most of the sound was absorbed by the materials we chose.
> **Defne:** What about the fourth group? What do you want to say about your results?
> **S4:** It is very close to the empty box.
> **Defne:** What might be the reason?
> **S4:** We couldn't close the lid of the box completely; the sound escaped from there **(researcher's post-observation form, 4).**

As seen from the dialogue above, Defne managed to use graphs to compare students' designs. At the same time, she applied two design-centered teaching practices:

providing scientific rationale for design solutions and determining the design's weaknesses.

Additionally, she used different representations specific to engineering, such as video, posters, decision diagrams, etc. For instance, students prepared posters in Figure 4.21 and communicated their solutions and ideas for re-designing their prototypes.

Figure 4. 21 Example of Poster in Lesson Study 4

Lastly, with respect to engagement with engineering concepts, she utilized authentic problem that attracted students' attention and employed open-ended design challenge in which the groups offered different solutions. She dealt with STEM careers through the animated video participants prepared **(researcher's post-observation form, 4).**

In her post-individual CoRe, Defne preferred to use 5E again. Regarding design-centered teaching practices, she used an engineering design challenge and wrote a scenario that included an open-ended design challenge with criteria and limitations. She suggested that the Municipality of Izmir look for engineers to design a system to move out a historical artefact without damaging it to make room for a new recreational area. She prepared a game on Kahoot to explore the concept of basic machines. She used representations in science and other disciplines, such as visuals, drawings, and daily life examples. She emphasized the re-design part, which she thought was one of the neglected parts of the engineering design process throughout the study. Therefore, it could be said that she reflected her improved knowledge in her post-individual CoRe. Lastly, she paid attention to the engineering talk and drew upon visuals supported with questions to promote STEM careers **(post-individual CoRe).**

To summarize, Defne it could be inferred that Defne noticed alternative teaching strategies compatible with STEM education and applied most of the design-centered teaching practices in her teaching. Moreover, she was able to use varied representations in science and other STEM disciplines. It could be said that her knowledge of instructional strategies was consistent and in parallel with the typical PCK-C category at the end of the study.

4.1.2.4. Knowledge of Assessment

4.1.2.4.1. Lesson Study 1

Defne was the observer teacher in lesson study 1; therefore, the findings regarding knowledge of assessment were from her pre and post-interviews, observation form, planning, and revision meetings.

When Defne's induvial pre-CoRe was analyzed, it was seen that she only focused on assessing science content outcomes in parallel with the objectives she stated. She asked students to create arguments regarding genetically modified foods by preparing a poster. She aimed to assess students' posters by using a rubric. She did not provide any further details about her choice of assessment. Moreover, no indication of assessing prior knowledge of students was observed in her CoRe. It could be inferred that her knowledge of assessment concerning STEM education was limited at the beginning of the study **(pre-individual CoRe).**

In the planning meetings, Defne was not actively participated in the discussions; she agreed with Deniz's suggestion about assessing the engineering design process through the rubric **(researcher's field notes, planning meetings of lesson study 1).** She started to talk about assessing prior knowledge and engineering design process rather than science content outcomes in her interview as follows:

> We assess students' prior knowledge through questions after the video…We also prepared a rubric. There were criteria, limitations, and many other things to assess, so we decided to use an analytical rubric. We could not use multiple-

> choice questions because there will be a product and process of creating the product. I think the rubric will be helpful **(pre-interview, 1).**

As seen above, it could be implied that the planning meeting contributed to Defne's knowledge assessment with respect to what to assess to some degree. Moreover, the researcher asked how the rubric assessed the objectives of the lesson; Defne stated:

> Actually, I am not sure…The verb of our objective was "observed". On the other hand, we assess the process of creating a product and presenting it. We did not prepare anything to assess students' knowledge regarding the Solar eclipse; we concentrated on the engineering design process **(pre-interview, 1).**

She had confused about what they assessed in their CoRe. There were no objectives regarding engineering, but participants tended to assess the engineering design process. This demonstrated discrepancies in her knowledge with respect to assessment.

Similarly, she gave general explanations for their choices regarding the rubric. No content-specific examples were provided, and it was unclear how the assessment revealed students' understanding of the content. Moreover, she could not able to suggest a variety of strategies to assess students' learning after the planning meetings.

During observation of the first STEM lesson plan, she emphasized assessing students' prior knowledge in science, as she did after the planning meetings. She noted that Deniz used informal questioning and asked, "Did you remember how the Solar eclipse happened?". She also noted that Deniz questioned students' prior knowledge in engineering through "who is an engineer, what kind of work do they do?" at the beginning of the lesson. She totally agreed that the teacher of the lesson observed students' performance during the implementation of the engineering design process and helped students, especially in choosing the best solution and creating the prototype parts **(pre-observation form, 1).** Defne did not concentrate on science content outcomes and products of students, as well as using the budget sheet as an assessment while observing the lesson.

After teaching, Defne's explanations were less detailed, and she focused only on assessing the engineering design process again. Moreover, she did not recommend any other strategy to assess the objectives of the lesson **(post-interview, 1).** It could be inferred that Defne's knowledge of assessment with respect to what to assess and how to assess did not significantly change after the observation of lesson study 1.

Regarding revision based on assessment, she suggested that:

> I think the rubric assesses what we intended to teach. Some changes could be made to the items on the rubric. We can consider the different situations that emerged in the lesson while revising the rubric, especially when choosing the best solution. Students received fewer points for this item; as I observed, we should focus on this part in our next lesson **(post-interview, 1).**

As seen above, Defne started to talk about revision in the lesson by considering the students' performance on the rubric. In reflection meetings, she was one of the participants that made contributions to the revision of items in the rubric. For instance, the item related to proposing alternative solutions was "all group members suggest solutions" in the former version of the rubric and it was revised as "the group proposes at least two different solutions". The main focus was on assessing students' learning in the engineering discipline to understand their perspective before moving to the engineering design process **(video-recorded reflection meetings, lesson study 1).**

During the observation of re-teaching, Defne addressed many points discussed in the reflection meetings. For instance, she noted that Ada assessed students' prior knowledge in engineering through informal questions and provided additional explanations and examples based on students' answers. Another point that she wrote down was the use of formative assessment. She was aware of how Ada provided feedback to student groups in choosing the best solution **(post-observation form, 1).** These features indicated that reflection meetings influenced on Defne's knowledge of assessment regarding what to assess. On the other hand, many features of the sub-component of assessment were missing in her explanations at the end of lesson study 1.

To sum up, Defne's knowledge of assessment displayed the features of the PCK-A category since she assessed learners' understanding of science content only. Moreover, her assessment methods did not show variances at the beginning of the study. Defne moved from the PCK-A to the PCK-B category in relation to knowledge of assessment at the end of lesson study 1. She concentrated on assessing only one discipline of STEM education regarding what to assess component. She ignored the alignment with the objectives and assessment, and her understanding of the ways of assessing students' learners was limited.

4.1.2.4.2. Lesson Study 2

Defne was the teacher of the first version of the lesson plan in lesson study 2; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In planning meetings, Defne focused on assessing students' knowledge in science and mathematics. She discussed assessing mathematics-related objectives through short-answer questions **(video-recorded planning meetings, lesson study 2).** It could be inferred that she considered the different aspects of students' learning after the planning meetings compared to the previous lesson study cycle. Additionally, she emphasized assessing the learner's performance during the design process briefly:

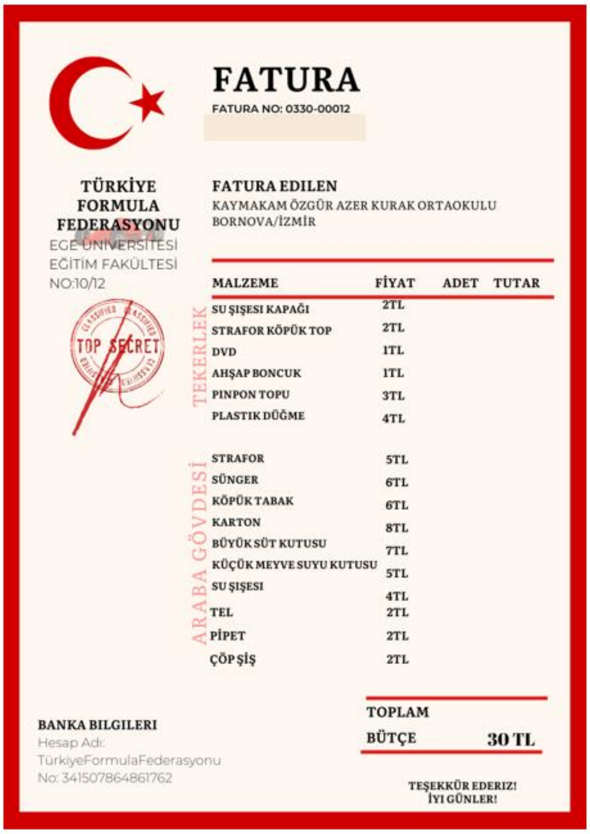
> We will use the rubric to assess the engineering notebook; we have an item for every step of the engineering design process. Based on my previous experience, it would support revising the lesson plan **(pre-interview, 2).**

However, she did not concentrate on how to assess students' products in her explanations **(pre-interview, 2).** Regarding how to assess, although she mentioned using word association and concept cartoon, her explanations were less detailed and did not include specific examples regarding the topic **(pre-interview, 1).**

Defne carried out the lesson and used a word association test to diagnose students' prior knowledge and misconceptions in speed topic. She took students' answers, and some of the answers included common misconceptions, such as velocity. However, she did not emphasize the points that students had problems with during the lesson **(researcher's pre-observation form, 2).**

Defne observed the students' performance during the design process, directed questions to the groups, and tried to give feedback. On the other hand, she skipped applying a rubric for assessing students' designs. Because of time management problems, she could not use concept cartoons, and she had to give short-answered questions as homework that needed to be implemented towards the end of the lesson **(researcher's pre-observation form, 2).** She could not implement many of the strategies that they planned for the assessment.

After the implementation of the lesson, she did not feel comfortable about the assessment and mentioned how managing the classroom challenged her and caused the assessment to be incomplete. She had suggestions related to the time of the implementation of the concept cartoon. She thought that it should be carried out before the design process. She did not mention using the budget as an assessment activity, as seen in Figure 4.22. She suggested adding additional short-answer questions to assess mathematics-related objectives because students experienced more difficulty than expected **(post-interview, 2).** It could be said that the teaching part of the lesson study contributed to her knowledge of assessment with respect to revision based on assessment.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	STRAFOR KÖPÜK TOP	2TL		
	DVD	1TL		
	AHŞAP BONCUK	1TL		
	PINPON TOPU	3TL		
	PLASTIK DÜĞME	4TL		
ARABA GÖVDESİ	STRAFOR	5TL		
	SÜNGER	6TL		
	KÖPÜK TABAK	6TL		
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TEŞEKKÜR EDERIZ!
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Figure 4. 22 Example of Budget Sheet used in Lesson Study 2

Group members did not accept her first suggestion regarding the concept cartoon. They advocated that it could be time-consuming when used in the first part of the lesson. On the other hand, the group revised the short-answered question with her suggestions and added extra items **(researcher's field notes, reflection meeting of lesson study 2).**

In summary, although Defne talked about the different parts of the lesson that were worth assessing, the greater focus was on science content outcomes. She provided details and examples for science discipline in general. Besides, she could not complete the assessment part of her teaching. For instance, the rubric for assessing students' products could not be implemented. She started to talk about various ways of assessment, such as concept cartoon, but no content-specific details were found in her explanations. She could not explain how the objectives and assessments were in line with each other. These features were matched with the PCK-B category concerning knowledge of assessment at the end of lesson study 2.

4.1.2.4.3. Lesson Study 3

Defne was the observer teacher in lesson study 3; therefore, the findings regarding knowledge of assessment were from her pre and post-interviews, observation form, planning, and revision meetings.

Defne was more of a listener in the discussions regarding assessment in lesson study 3; she did not make any suggestions regarding assessment **(researcher's field notes, planning meetings of lesson study 3).** After the planning meetings, she focused on assessing students' prior knowledge of science, science content outcomes, and the engineering design process. Different from the previous lesson plans, she pointed out the assessment of collaborative work in STEM lessons:

> We have prepared a self-assessment sheet to make students evaluate the group work. Collaboration is one of the skills that we want to emphasize in STEM lessons. The classroom is crowded, and we can miss how much each individual participated in solving the engineering problem. It will give help us at this point **(pre-interview, 3).**

As seen above, she focused on assessing skills different from the previous lesson studies. However, her knowledge of assessment with respect to how to assess remained unchanged after the planning meetings. She did not talk about different strategies employed for assessment in planning meetings, such as the Draw a Scientist Test, word association test, and poster. She provided general understanding, such as "we have used the diagnostic tree to assess science objectives of the lesson" **(pre-interview, 3).** She could not delve into the details of why they preferred to use specific assessment strategies. No proof regarding revision based on assessment was observed in her explanations.

During observation of the lesson, she noted that Ada asked informal questions about heat and temperature at the beginning of the lesson for diagnostic purposes to relate the topic with the new one. Moreover, she observed that using a diagnostic tree worked well and was suitable for students' levels. She wrote that Ada provided feedback to students about their wrong answers through correct explanations. Regarding students' products, she noted that Ada discussed the data from testing the design part and commented on students' thermos designs (**pre-observation form, 3).** As discussed in the planning meetings, she was unaware of presenting criteria for successful design before the design process.

While reflecting on the lesson, Defne mainly talked about assessing the science content outcomes through a diagnostic tree after observation:

> We used only a rubric in our first STEM lesson plan. However, we did not implement anything during instruction and could not provide feedback to students. While using a diagnostic tree, the teacher provided feedback to students and provided additional explanations regarding the topic. In this way, we applied the "evaluate" part of the 5E learning cycle more appropriately than the first one **(post-interview, 3).**

In the reflection meeting, Defne did not suggest anything about the type of assessment they used. The group also assessed the engineering notebook through a rubric. Ada drew attention to the re-design part in which students got lower grades, and Defne participated in her idea. She added that more emphasis should be given to this part **(researcher's field notes, reflection meetings of lesson study 3),** and this situation demonstrated that her knowledge of assessment regarding revision based on assessment was enhanced. While observing the revised version of the STEM lesson plan, she noted that the time allocated for using assessment sheets should be organized by the teacher of the lesson **(post-observation form, 3).**

Defne's knowledge of assessment did not significantly change after completing lesson study 3 and indicated the features of the PCK-B category. She could not establish a connection between the objectives of the lesson and the parts of the lesson that should be assessed. Moreover, except for science discipline, her explanations were too broad and superficial. No content-specific examples were found in her statements, and she did not discuss alternative assessment strategies.

4.1.2.4.4. Lesson Study 4

Defne was the teacher of the revised version of the lesson plan in lesson study 4; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

Defne focused on eliciting students' understanding of the sound concept and their misconception about this topic while discussing the part of learning that is worth assessing. Moreover, she talked about assessing the engineering design process and students' products. She enjoyed using the KWL chart with Ada's suggestions and suggested how to use it effectively in their lesson **(video-recorded planning meetings, lesson study, 3).** Different ideas came up in the planning meetings, such as strategies for assessing students' misconceptions in engineering and assessing mathematics objectives. In her interviews, Defne did not address these points **(pre-interview, 4).** Her explanations did not include specific details about the topic and how the assessment was in line with the objectives of the lesson. An example excerpt was given below:

> We prepared two rubrics. One of them was to assess the steps of an engineering notebook, and one of them was for students' designs. Moreover, we prepared multiple-choice questions. They will be applied by using Kahoot. So, we assessed the engineering design process and theoretical knowledge in science. Thanks to Kahoot, we can provide instant feedback on the student's answers **(pre-interview, 4).**

Regarding how to assess component, Defne generally did not suggest a new strategy for assessment in planning meetings. Moreover, she was not sure how specific assessment strategies helped them to understand whether the objectives of the lesson were reached or not **(pre-interview, 4).**

Defne observed Ece's lesson and noted that the assessment strategies they prepared were appropriately implemented. She focused on science content outcomes, the engineering design process, and students' products while filling out her observation form **(post-observation form, 4).** In accordance with her pre-interview, her focus was not on assessing mathematics objectives.

In the reflection meetings, she only suggested adding new science-related questions to Kahoot as a teacher of the revised lesson. However, the group member was not sure about this suggestion because of time management problems. The other points the group discussed were the importance of providing feedback to the groups in the design process and using word association and Kahoot, which Defne agreed with **(researcher's field notes, reflection meeting of lesson study 4).**

Defne taught the revised version of the lesson plan. She began to lesson by asking these questions to identify students' prior knowledge of science:

> **Defne:** How is the sound travelled?
> **S1**: Travels in waves.
> **S2:** It vibrates first and then spreads.
> **S3**: interacts with matter **(researcher's post-observation form, 4).**

Additionally, she used informal questions to diagnose students' prior knowledge in engineering:

> **Defne**: (she first showed the poster of the engineering design process). We have been using the engineering design process since the beginning of the semester. Now, I will close the poster and ask you to describe the steps of the engineering design process before introducing today's engineering problem. Okay, how do we start the engineering design process? Have you remembered?
> **S1:** We find the problem first. We have some criteria. Then, we make investigations.
> **Defne:** How did you investigate the problem in the previous STEM lesson?
> **S1**: We used cards, material cards.
> **Defne**: Yes, what is the next step?
> **S2**: We talk about different designs and then choose one of them **(researcher's post-observation form, 4).**

The dialogues continued in this way, and Defne related students' prior knowledge to the new topic by saying: "We have repeated the steps of the engineering design process. Today, we will use these steps to solve a new engineering problem about sound insulation. Let's have a look at our scenario".

Moreover, she applied formative assessment methods to assess students' learning in different parts of the lesson. For instance, after students completed researching the problem part, she walked around the groups and asked informal questions, such as, "what should be the properties of materials that you will use in your sound-proof music room?". She took answers from the groups and checked their understanding throughout the lesson. An example dialogue was given below: one group discussed whether to use cotton and bubble wrap in their designs. She asked:

> **Defne**: How the sound travels in space?
> **S1**: It does not travel in space.
> **S2**: Therefore, we should pick up bubble wrap. It has a hollow structure, and it is a better option for insulation **(researcher's post-observation form, 4).**

She put little emphasis on assessing the students' products. She did not present the criteria for successful design at the beginning of the lesson. She utilized a bar chart and determined the most successful design with students by comparing their data. However, she did not relate it to the criteria of success. Assessing mathematics objectives and calculating budget were not parts of Defne's lesson.

After students completed the steps of the engineering design process, she used informal questioning and summarized the lesson. She utilized Kahoot for summative purposes at the end of the lesson, as seen in Figure 4.23. The students gave answers as a group. If students gave the wrong answers, she asked a question to other students and gave the correct explanation at the end.

Figure 4. 23 Scene from Defne's classroom using Kahoot! In Lesson Study 4

In her post-individual CoRe, regarding what to assess, she focused on assessing science content outcomes, engineering design process, and mathematics. No indicators of assessing prior knowledge in science and other STEM disciplines were observed in her CoRe. Moreover, students' products were not assessed. Concerning how to assess, she utilized multiple-choice questions, a rubric, and a poster. Her assessment did not show great variability compared to CoRes prepared as a group during the previous lesson study cycles **(post-individual CoRe).**

It could be said that Defne did not equally concentrate on the different parts of the lesson to be assessed. She generally put one discipline at the center and ignored the others after completing lesson study 4, which were the typical features of the PCK-B category. Her knowledge of assessment with respect to how to assess did not show variances, and she could not reflect what had been discussed in the planning and reflecting meetings in her statement. Her knowledge of assessment remained in the PCK-B category at the end of the lesson.

4.1.2.5. Summary of Findings for Case 2

Defne's PCK for STEM represented the features of the PCK-A category at the beginning of the study, i.e., she designed a lesson for teaching a science topic when asked to prepare CoRe for a STEM lesson plan. She moved to the PCK-C category except for the knowledge of assessment component after completing four-lesson study cycles. Table 4.3. displays how Defne's PCK for STEM was changed after attending each lesson study cycle in detail.

Table 4. 3

Defne's Development of PCK for STEM in Four Lesson Study Cycles

	Before the Study	**Lesson Study 1**	**Lesson Study 2**	**Lesson Study 3**	**Lesson Study 4**
Curriculum	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**
Learners	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**
Instructional Strategies	PCK-A	PCK-B	PCK-B	**PCK-C**	**PCK-C**
Assessment	PCK-A	PCK-B	PCK-B	PCK-B	PCK-B

Defne's PCK for STEM moved toward the PCK-B category with all components at the end of lesson study 1. For instance, regarding knowledge of curriculum, she started to talk about integrating the engineering design process, but her focus was on establishing only science objectives for the STEM lesson plan. Besides, she experienced difficulties in relating science topics with other STEM disciplines. Moreover, she concentrated on assessing the engineering design process, demonstrating the discrepancy between objectives and assessment.

On the other hand, she made progress in terms of knowledge of curriculum and knowledge of learners at the end of lesson study 2. She reached the highest category in these two components, whereas her knowledge of instructional strategies and assessment showed the features of the PCK-B category. For example, she was able to set objectives for science and other STEM disciplines and extended her understanding of the scope of curricula from other STEM disciplines. Furthermore, she noticed learners' misconceptions in science, mathematics, and engineering and offered ways to detect and eliminate them in a balanced way. Nevertheless, she did not mention features of STEM education while discussing teaching strategies compatible with STEM, and some design-centered teaching practices were missing in her teaching and explanations. The assessment was centered on science content outcomes, and other STEM disciplines were given less importance.

Lesson study 3 and lesson study 4 demonstrated a similar pattern for Defne's PCK for STEM development as seen in Table 4.3, and Defne's knowledge of instructional strategies met the criteria of the PCK-C category differently from the previous lesson study cycles. She advanced her knowledge of instructional strategies with respect to teaching strategies and design-centered teaching practices and strategies for engagement with engineering concepts. She was able to list the reasons for choosing a particular teaching strategy by addressing the basic features of STEM education, implementing many design-centered teaching practices and using representations in STEM disciplines in a balanced way. On the other hand, her PCK for STEM concerning knowledge of assessment was still in PCK-B at the end of the study. She generally concentrated on one discipline of STEM, talking about assessment in lesson study 3 and lesson study 4. She did not sufficiently focus on assessing students' products and the mathematics content of the lesson. She had transitional PCK with respect to knowledge of assessment. It could be inferred that PCK for STEM components developed unevenly for Defne throughout the study.

4.1.3. Case 3: Ece

4.1.3.1. Knowledge of Curriculum

4.1.3.1.1. Lesson Study 1

Ece was the observer teacher in lesson study 1; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

Before the study, Ece set objectives only for science **(pre-individual CoRe).** She preferred to choose "design a model based on the conversion of electrical energy into heat, light or motion energy" from the 8^{th}-grade objectives. No objectives from other STEM disciplines were observed in her CoRe. Regarding relation to other science topics, no connection was established neither with the topics at the same grade nor the previous grades.

When she was asked the reasons for choosing this objective for her CoRe after the planning meetings, she said:

> Before starting the study, I had limited knowledge about STEM education, and I had difficulty choosing objectives from the curriculum. What came to mind was creating a model when I heard STEM. There are many objectives related to creating and presenting a model in the science curriculum. However, I never thought about that process until creating that model. I was always thinking more product and result-oriented. Therefore, the word "designing a model" attracted my attention for the first STEM lesson plan. I wrote a scenario and then asked students to create models **(pre-interview, 1).**

She considered objectives that included the statement of "models" while preparing her CoRe. She had a simplistic understanding regarding STEM education which was reflected in her choice of objective at the beginning of the study.

In the planning meetings, Ece came up with the idea of setting an objective regarding the basic properties of planets. She suggested that students might design rockets by considering the features of different planets. As the discussions progressed in the group, she tended to continue with Ada's idea. She said:

> **Ece:** I kind of give up my idea. Which planet will we choose, and how will we provide the environment there (on the planet) in the classroom? I am also

> concerned about whether this is a daily-life problem **(video-recorded planning meetings, lesson study 1).**

She further explained her initial ideas as follows in the interview:

> I think mine was a good idea, too; however, I had many question marks in my mind regarding applicability. Students need to provide alternative solutions and create prototypes. How to test their prototypes and collect data parts were unclear to me; how could we provide conditions on different planets in a classroom setting? So, I gave up on this idea. On the other hand, Ada's idea of designing Solar eclipse viewers was more solid and applicable to students **(pre-interview, 1).**

As seen above, the main reason behind her preference was the conformity of the objectives in the science curriculum to the engineering design process. She also touched briefly that objectives should be related to daily life-problem.

The group modified the science objectives in the planning meetings; however, Ece did not go into detail about the reasons for the modification. Regarding setting objectives for other STEM disciplines, she added that she took a glance at the introduction part of the science curriculum regarding engineering practices and the engineering design process right after the lesson study started. On the other hand, she indicated she had never examined mathematics and technology and design curricula before the study **(pre-interview, 1).** Her knowledge of curriculum with respect to setting objectives in other STEM disciplines was deficient after the planning meetings of lesson study 1.

Concerning relation to other science topics, she mentioned that students should know about the motions of the Sun and Moon from the 5th grade. Moreover, she talked about students will learn about space technologies in the following year regarding astronomy topics **(pre-interview, 1).** It could be said that she was able to make connections between science topics after the planning meetings of lesson study 1. No relation to other STEM disciplines was found in her explanations.

Ece observed the first version of the STEM lesson and took some notes regarding the components of the curriculum. She realized that science was partially connected to other STEM disciplines. On the other hand, although she touched on relation to other science topics in the pre-interview, she ignored that Deniz did not make these connections in his lesson **(pre-observation form, 1).**

After observing the lesson, she did not provide any suggestions related to revising the objectives of the lesson and how to connect STEM disciplines more effectively **(post-interview, 1).** However, she was actively involved in the discussions in the reflection meeting when it came to the objectives. Ada triggered discussion in the group that their CoRe was more comprehensive than their objectives, and Ece totally agreed with her. She proposed to add "design a viewer to observe Solar eclipse and test it" as an objective that addressed the steps of the engineering design **process (video-recorded reflection meetings, lesson study 4) (see the dialogue in Ada's section).** The group participated in her idea and wrote new objectives. This demonstrated that the reflection part of the lesson study contributed to her understanding of setting objectives in STEM lesson plans.

During the re-teaching, she noticed different points as opposed to observing the first version of the lesson plan. For instance, she noted that Ada touched upon the eye health topic and stressed that students would learn about it in the following topics. Moreover, she wrote that through the calculation of the budget, mathematics was more obviously integrated into the revised version of the STEM lesson plan **(post-observation form, 1).**

In brief, Ece's knowledge of curriculum exhibited the features of the PCK-A category at the beginning of the study. She utilized only science objectives, and relations to other science topics and STEM disciplines were unclear. Her PCK level increased to the PCK-B category after attending lesson study 1. Although she talked about establishing objectives only for science content after the planning meetings, she argued for setting objectives for engineering after the reflection meetings to some degree. However, her understanding of setting objectives for other STEM disciplines was still limited and open to development. She could connect science topics, but no clear evidence was found in her statements about relating science to other STEM disciplines' objectives.

4.1.3.1.2. Lesson Study 2

Ece was the teacher of a revised version of the lesson plan in lesson study 2; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Ece suggested continuing with the objective regarding balanced and unbalanced forces and proposed designing an equal arm scale and writing a scenario about it. Ada objected to her idea and indicated that no creativity and re-design process could be applicable if they continued with this objective which Ece agreed with her later. Ece also triggered the discussions in the group to write engineering objectives. She proposed to write, "students will be able to design race car with the highest speed" **(video-recorded planning meetings, lesson study 2).** She extended her understanding of writing objectives for other STEM disciplines after reflection meetings of lesson study 1.

When she was asked to explain the reasons for changing her mind about science objectives, she stated:

> I consider it objective regarding balanced and unbalanced forces, and students might design equal arm scales. However, I realized students would not generate more than one solution while designing scales. Most probably, they all might design the same scales at the end of the lesson. We could not produce real-life problems about this objective. We want them to think about different perspectives and develop critical and creative skills. At this point, Ada's idea seemed logical to me; designing a car with the highest speed could include different designs, different variables might contribute to the speed of the car, and we can make students develop these skills. Additionally, integrating mathematics would be easier with Ada's idea **(pre-interview, 2).**

As seen above, Ece's knowledge of instructional strategies and curriculum interacted with each other. Since Ece had limited knowledge of design-centered teaching practices, it influenced her choices of objectives at the beginning of the lesson study. As her knowledge of instructional strategies developed through the discussions, she provided reasons for choosing objectives in a detailed way. Moreover, Ece mentioned that objectives should serve the purpose of developing 21st-century skills based on daily life problems in STEM lesson plans. She also expressed the importance of integrating knowledge from different disciplines while deciding the objectives. It could be said that Ece elaborated on her understanding of the reasons for choosing science objectives for STEM lessons at the end of the planning meetings of lesson study 2. Lastly, she was conscious of the limitations of the science curriculum. She underlined that they included the concept of "distance travelled" in their lesson, although it was a limitation to handle students' misconceptions **(pre-interview, 2).**

As opposed to lesson study 1, Ece examined the mathematics and technology and design curricula in the planning meetings and stated her thoughts as follows:

> I think examining other curricula rather than science can be very instructive for preparing STEM lesson plans. For instance, the technology and design curriculum includes objectives regarding the engineering design process and practices. I did not think before that these could be written as objectives. We included them in our second lesson, which was more helpful for the teacher and the students. For example, it "evaluates the design according to the determined criteria". This is an objective that meets exactly what we want to do. In the same manner, I had not examined the mathematics curriculum before. I do not know why…After examining, I started to understand which knowledge and skills students needed to develop in the mathematics discipline. For instance, whether students were familiar with ratio topics, creating graphs, recording data, and transforming it into graphs. Students will be recording their car's speed and form two different line graphs to compare their car's speed visually in this lesson plan. So, as a teacher of the lesson, we need to know them in advance **(pre-interview, 2).**

Ece started to talk about topic-specific details while examining the mathematics and technology and design curriculum and connected the objectives from other STEM disciplines with science content. Additionally, she mentioned the vertical and horizontal relationship in the science curriculum regearing the lesson plan they prepared as follows:

> In my opinion, students need to know the force and the resultant force from the previous topic. At the same time, they need to know about the friction force, especially while proposing a solution to the problem and creating prototypes. The tires of their designed car should be carefully chosen to minimize the friction between the ground and the wheel; they should have this knowledge in our lesson **(pre-interview, 2).**

Ece was aware of which topics were related to their STEM lesson and in which grade level these concepts were covered, as seen in her statement.

Ece observed Defne's lesson and took notes on her observation form. For instance, she noted that connections between science and mathematics were sufficient and apparent in the lesson. Similarly, she considered that science and engineering were related to each other, but no specific details were provided in her observation form. She ignored the relation to other science topics in her observation form **(pre-observation form, 2).**

After observing her teaching, she had one solid suggestion regarding the objectives of the lesson. She advocated that:

> The (science) curriculum says there should be no mathematical formulas while teaching speed topic. However, as far as I observed, students had difficulty understanding the speed concept and unit of speed. We should use the DST triangle as Ezgi Teacher suggested and remove the limitation in the curriculum **(post-interview, 2).**

She increased her knowledge about the scope of the science curriculum and suggested taking out one limitation to overcome students' difficulties while learning the speed concept. This issue was first brought forward by Defne, the teacher of the first version of the lesson, and Ece supported the idea by giving the reasons above. As a result, the mathematical formula for speed was included as a part of CoRe after reflection meetings **(video-recorded reflection meetings, lesson study 2).** It could be inferred that as her knowledge of learners with respect to students' difficulties improved, her knowledge of curriculum also developed.

Ece taught the revised version of the lesson plan. She was able to relate science and mathematics objectives in her instruction. Since she was aware that creating line graphs was within the scope of 7^{th}-grade curriculum, she explained to her students that:

> **Ece:** Today, we will create graphs after the testing phase. You will use the data from your designed cars. But you have not learned the details of creating and interpreting line charts. I will make you understand through the example I provide **(researcher's post-observation form, 2).**

Furthermore, she reminded the students of the previous STEM lesson by emphasizing objectives related to the engineering design process:

> **Ece:** What did we design in your previous STEM lesson?
> **S1:** Viewers
> **Ece:** Yes, what was our problem? Do you remember?
> **S2:** We designed viewers to observe the Solar eclipse safely.
> **Ece:** Definitely, you are right. Today we will solve another problem but use the same procedure. What were the steps we followed; do you remember them?
> **S3:** We used an engineering notebook.
> **Ece:** Yes, actually, we will use the steps in the engineering notebook, which are called the engineering design process. Do you remember now? Today, our purpose is to carry out this process to design the race car with the highest speed (showing engineering design poster in Figure 4.24.) **(researcher's post-observation form, 2).**

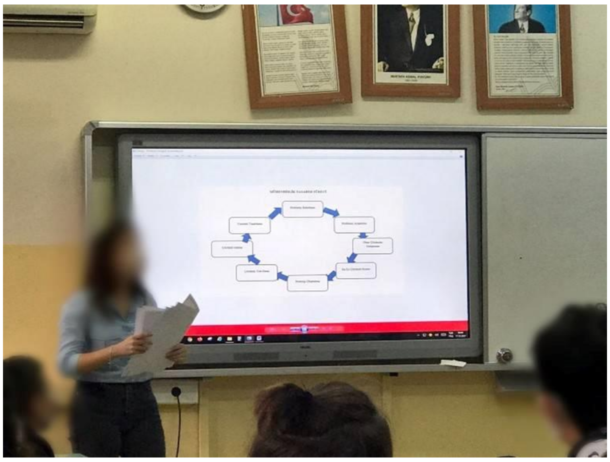

Figure 4. 24 Scene from Ece’s Lesson in Lesson Study 2

As seen from the dialogue above, she first took students' ideas and then reminded them engineering-related objectives of the lesson explicitly by showing a poster (Figure 4.24). Moreover, she considered the changes in the science objectives and included mathematical formulas as a part of the lesson. In terms of relation to other science topics, she discussed force and friction force concepts while creating their prototypes **(researcher’s post-observation form, 2).**

To conclude, Ece's knowledge of curriculum moved from the PCK-B category to the PCK-C category at the end of lesson study 2. She was able to propose objectives in other STEM disciplines and showed a deeper understanding of why to use objectives from other curricula in preparing STEM lessons. Moreover, she made progress in giving the reasons for choosing science objectives in parallel with the fundamental characteristic of STEM education. She also noticed the connection between other science topics and other STEM disciplines sufficiently.

4.1.3.1.3. Lesson Study 3

Ece was the observer teacher in the first and second versions of the STEM lesson plan in lesson study 3; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

In the planning meetings, the group agreed on choosing the objective of thermal insulation; however, there were several ideas for engineering design challenges associated with this objective. For instance, Ece offered to compose an engineering design challenge for designing thermally insulated cloth for astronauts or designing thermally insulated storage boxes for foods. However, she changed her mind and gave up designing space clothes. She indicated that the testing process of thermally insulated cloths would not be feasible in a classroom environment **(researcher's field notes, planning meetings of lesson study 3).** Ece later explained the reasons for choosing science objectives as follows:

> Actually, we could have chosen to design a thermally insulated storage box. The principles of designing a storage box and thermos were the same. However, the engineering design challenge of the thermos activity seemed to include more real-life problems than my idea. Therefore, I accepted Ada's idea. Then, we changed the original objective in the curriculum a little. Because the objective was focused on thermal insulation in buildings. But thermal insulation is not only applicable in buildings. We aimed to make students understand the principles of thermal insulation, and then use these principles to solve the engineering problem. In this way, we could achieve the science and engineering objectives of the lesson. Moreover, students will have a chance to develop an understanding of the daily applications of thermal insulation principles in our lesson **(pre-interview, 3).**

Ece's statements were content-specific, and she provided a clear understanding of modifying the existing objectives in the science curriculum. She directed criticism and found the science objective narrow-scoped. She also reflected on her understanding of the features of STEM education while choosing objectives such as being suitable for engineering design challenges and providing engaging and authentic context for students.

Moreover, she also touched upon a new engineering-related objective they had not written in previous CoRes. She favoured adding "developing careers awareness during the engineering design process" into CoRe in planning meetings. She voiced her ideas as follows:

> We wrote engineering design process-related objectives in the previous lesson and found them very effective. It should be included in STEM lessons, such as creating a thermos using the engineering design process. Besides, I think it was very ideal for writing an objective regarding career awareness. One of the goals of the science curriculum is also concentrated on this point. We have been emphasizing STEM careers like engineering and data analyst in our lessons verbally and mostly implicitly up to now. But writing it as an objective made it concrete, and we added extra activities and visuals to achieve this objective **(pre-interview, 3).**

As seen above, she talked about one of the goals of the science curriculum as well as the significance of writing engineering-related objectives. She mentioned specific details and enlarged her view about setting objectives for other disciples in addition to science. She added:

> We did not integrate mathematics into our first lesson plan. We had no idea how to integrate mathematics. Similarly, there were problems with integrating engineering. When we examined the mathematics curriculum, our perspective was beginning to change. When I compare the first and this plan, I have a more holistic understanding of the objectives. Now that we think of the process more holistically, we can think of all disciplines at the same time. I am not fully in control over the mathematics curriculum, but I am getting used to it. On the other hand, I feel competent and come up with ideas much more easily. choosing science objectives from the curriculum for STEM lessons **(pre-interview, 3).**

Ece was able to make more connections between different curricula after completing the planning meetings of lesson study 3. In terms of relation to other science topics, she related to the topic with 5^{th}-grade objectives which were heat and temperature **(pre-interview, 3).** On the other hand, vertical connections were missing in her statements after the planning meetings.

Ece observed Defne's lesson and noted that all the objectives of the lesson were covered on time. She noted that the thermal insulation topic was connected to the heat and temperature topic from the previous year **(pre-observation form, 3).** What she observed was in parallel with her statements before implementation. As indicated above, she was conscious of horizontal relationships but not knowledgeable enough to detect whether vertical relationships existed in the lesson. She also considered that the engineering objectives were explicitly connected to science objectives.

After teaching, she had no suggestions for revising the objectives of the lesson. She thought that objectives in CoRe were suitable for STEM lessons **(post-interview, 3).**

Different from these points, Ece developed her knowledge of curriculum with respect to relation to other science topics after observation of re-teaching. She realized and noted that Deniz could make connections to the previous topic at the same grade level and dealt with the particulate nature of the matter in his instruction **(post-observation form, 3).**

These findings revelated that Ece was in the PCK-C category regarding knowledge of curriculum after attending lesson study 3. As in the previous lesson study, she could modify objectives with logical explanations and provide a comprehensive understanding of setting objectives for STEM disciplines. Relations to other science topics and STEM disciplines were apparent in her explanations.

4.1.3.1.4. Lesson Study 4

Ece was the teacher of the first version of the lesson plan in lesson study 4; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Ece participated in the idea of Ada about concentrating on sound insulation objectives. She did not have any other suggestions about choosing the science objectives. Moreover, Deniz and Defne offered writing mathematics-related objectives, and she participated in their ideas **(video-recorded planning meetings, lesson study 4).**

When she was asked to compare her pre-individual and the last collective CoRe in terms of curriculum, she said that:

> Actually, my initial perspective was choosing the verbs of objectives, such as designing a model and preparing a project. I totally thought about preparing a model for my first STEM lesson plan. But now, I can prepare a STEM lesson plan with various objectives. For instance, "determine the characteristics of thermal insulator materials" is an objective in the 6^{th} grade, and I created a STEM lesson plan by using this one. I do not need to choose objectives that include models and project statements anymore. My point of view on this issue has definitely changed **(pre-interview, 4).**

Moreover, Ece developed her understanding of the science curriculum and felt more competent while choosing objectives for planning STEM lessons. She added:

> When choosing objectives in our curriculum (science curriculum), the first thing that we consider is its' suitability to apply the engineering design process. We have been discussing from the beginning of the process what we might do in the design process with this objective. While doing this, we give weight to the problems from everyday life, which might attract students' attention, and we want to maximize their engagement in the lesson. What is more, we choose science objectives that allow integration of mathematics and want students to develop skills, especially critical thinking and creativity. In this plan, we prefer to continue with the sound insulation concept. We will ask students to solve the

> problem of a noisy music room by following the steps of the engineering design process and integrating collecting and interpreting data through bar charts **(pre-interview, 4).**

As seen above, Ece extended the reasons for choosing science objectives to prepare a STEM lesson plan at the end of lesson study 4. Her explanations included the key elements of STEM education with respect to deciding on the objectives. The network of STEM disciplines was evident in her statements. She further explained her thoughts on writing engineering and mathematics-related objectives:

> We are used to writing science objectives while planning a regular science lesson. This helps us to understand how much we achieve at the end of the lesson. With this point of view, I realized that we should include objectives of other STEM disciplines. For instance, writing the steps of the engineering design process is very important to our lesson or creating a bar chart and interpreting it. I know it is not in the same grade level in the mathematics curriculum, but we considered it while planning. After writing them as objectives, we have a chance to assess them and understand to see what we have achieved (**pre-interview, 4).**

The abovementioned statements demonstrated the consistency between Ece's knowledge of assessment and curriculum. As her knowledge of what to assess and how to assess increased, she became aware of the importance of setting objectives for science and other STEM disciplines at the end of lesson study 4. Concerning relation to other science topics, she touched on both vertical and horizontal relations:

> Students must have learned that sound is energy, its properties, speed, and how it is transferred in different mediums. The objectives do not cover frequency and wavelength concepts… Students learn about sound concepts in the 3rd grade for the first time. Then, there are objectives about sound technology and lightning in the 4th grade (**pre-interview, 4).**

Ece was the teacher of the first version of the STEM lesson in lesson study 4. She aimed to make learners remember the topics they learned in previous lessons. The example dialogue was taken from her classroom:

> **Ece:** Let’s remember the last week’s lesson first. How does sound travel?
> **S1:** Through the waves
> **Ece:** Does it travel in only one direction?
> **S2:** It travels in all directions by vibration.
> **Z:** You are all right. Today we will move on to the next topic of sound concepts and try to solve a problem I will provide you in a minute **(researcher’s pre-observation form-4).**

Moreover, she related science to engineering and helped students to remember the knowledge learned in previous STEM lessons. She also interconnected mathematics to the science topics taught:

> **Ece:** As you see in the testing part of the engineering notebook, you are supposed to create bar charts and then compare their data through these graphs. You have learned to draw bar charts in the mathematics lesson in the previous year, we will remember them today **(researcher's pre-observation form-4).**

Ece completed the objectives of the lesson on time. She thought that the objectives of the lesson were adequate and suitable and did not recommend any changes after teaching **(post-interview, 4).** The group member also did not want to make any changes regarding objectives **(researcher's field notes, reflection meeting of lesson study 4).**

Ece wrote objectives for each STEM discipline separately in post-individual CoRe after completing the study. She directly took science and mathematics objectives from the related curriculum while planning her lesson. The interconnectedness among STEM disciplines was explicit. Furthermore, she paid attention to what knowledge was required to learn the topic from the previous grades **(post-individual CoRe).**

To sum up, these features reflected the highest category, PCK for STEM, concerning knowledge of curriculum at the end of the study. Ece moved to the PCK-C category during lesson study cycle 2, and her advanced knowledge of curriculum was reflected in other lesson study cycles as well. When lesson study 4 is considered, planning meetings and teaching parts were the most influential parts in her improvement of curriculum knowledge.

4.1.3.2. Knowledge of Learners

4.1.3.2.1. Lesson Study 1

Ece was the observer teacher during lesson study 1. The following presentations are mainly based on interviews, observation forms, and planning and reflection meetings.

Before the study, Ece wrote that students might have misconceptions about "transforming electrical energy to other forms of energy" **(pre-individual CoRe),** which could not be considered a misconception when the related literature was examined. Regarding difficulties, she noted only science-related difficulty, which was that students might struggle to determine the variables. She did not specify any prerequisite knowledge students should know before coming to the lesson **(pre-individual CoRe)**. It could be inferred that her knowledge of learners was limited before participating in the study.

In the planning meetings of the first lesson study cycle, the discussions about listing misconceptions and difficulties did not go deeper. The group wrote two science-related misconceptions about the positions and size of the Sun, Earth, and Moon and a few difficulties for science and engineering disciplines with Ada's suggestions in collaborative CoRe **(researcher's field notes, planning meetings of lesson study 1).**

Ece touched upon only science-related misconceptions after the planning meetings. However, the number of misconceptions that she mentioned increased when compared to her pre-individual CoRe as follows:

> Students might have misconceptions about the positions of the Sun, Earth, and Moon During a Solar eclipse, like me when I was a middle school student. Moreover, as Deniz mentioned, there were some visuals that students prepared on the classroom wall (in cooperating school), the distance between planets was drawn as equal, and the sizes of the planets were the same. After Deniz increased my attention, I realized that students might have these misconceptions **(pre-interview, 1).**

The possible sources that Ece talked about were her own experiences as a student and her observations in the cooperating school. She could not be able to present an understanding of why students had these misconceptions after the planning meetings of lesson study 1. She favoured using question and answer to detect students' misconceptions and provide explanations to handle them **(pre-interview, 1).** Other specific methods to detect and eliminate students' misconceptions were missing in her statements.

With respect to difficulties, she talked about general points about engineering-related difficulties:

> Students might have difficulties working as a team. One student in the group might insist that his/her solution is the best one without listening to other solutions. They might also experience difficulties producing solutions to the problem we will provide for them **(pre-interview, 1).**

Although Ece's explanations were discipline-specific, she began to consider engineering-related difficulties after the planning meetings. However, she did consider these difficulties in the planning process. She also added that she was not sure about students' knowledge of who the engineer was and was not sure this was a difficulty that they might confront in the classroom. Ece also considered that since the Solar eclipse is an abstract topic, students might have difficulty understanding it **(pre-interview, 1).**

While observing Deniz's lesson, Ece did not note any misconceptions that emerged in science and other STEM disciplines. On the other hand, she realized engineering-related difficulties showed up during the lesson that was not in CoRe. She wrote that students had difficulty understanding the criteria and limitations and identifying them in the engineering design challenge **(pre-observation form, 1).**

After observation of teaching, she talked about her concerns about whether students would know about engineering as a profession, and she realized that most of the students had no prior knowledge regarding engineering **(post-interview, 1).** In parallel with her observations, she did not specify any misconceptions during post-interviews. The researcher reminded her of some instances of the lesson and asked her whether she remembered these instances. She remembered some of them and started to make comments as follows:

> I remember the dialogue about engineers. Deniz asked a "who is an engineer" type of question and most of the students replied, "civil engineers." I think we should provide more and different examples of engineers, such as food engineers, genetic engineers, and so on. Deniz tried to do this **(post-interview, 1).**

Although she remembered those instances, she could not be able to label them as engineering-related misconceptions after observation of teaching in lesson study 1.

Concerning learner's difficulties, Ece specifically mentioned engineering-related difficulties:

> The students could not be able to define the criteria and limitations. Actually, the examples Deniz provided were adequate. As I expected, producing solutions to the problems challenged them. Deniz walked around the groups and asked them some questions, such as, "what are you planning to do". Some students in the group did not participate in the activity. Deniz also had difficulty involving every

> student in the group in the design activity. Maybe, he would reconsider the distribution of roles in the group **(post-interview, 1).**

As seen above, she started to realize the difficulties that students might confront in the engineering discipline; however, no evidence of science or mathematics-specific difficulties was seen in Ece's explanations. In the revision meeting, science-related misconceptions and difficulties remained the same, while engineering-related difficulties and misconceptions were added in CoRe. Ece was not actively involved in this part of the discussions **(researcher's field notes, reflection meetings of lesson study 1).**

During the observation of re-teaching, Ece was able to reflect on the discussion among the group in her form. For example, she was able to catch how Ada handled students' difficulties in determining criteria and limitations and noticed the examples Ada provided that were not written in CoRe. She also noted that students experienced difficulties in choosing the best solution. Regarding misconceptions, she noted that students had alternative ideas about the work of engineers and noted that "students thought engineers measure the houses". She also noted that the teacher of the lesson provided correct explanations to overcome this misconception **(post-observation form, 1).**

In brief, Ece's pre-individual CoRe included difficulties and misconceptions only in science which met the criteria of the PCK-A category at the beginning of the study. Ece moved from the PCK-A category to the PCK-B category after completing lesson study 1. She started to talk about engineering-related misconceptions and difficulties, but the details of detecting and overcoming these were not adequate. Moreover, she superficially mentioned science-related difficulties and misconceptions and no evidence of mathematics-related difficulties was observed in her explanations. It could be inferred that she provided difficulties and misconceptions in one STEM discipline and gave less importance to the other STEM disciplines. These features were in parallel with the PCK-B category.

4.1.3.2.2. Lesson Study 2

Ece was the teacher of a revised version of the lesson plan in lesson study 2; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, the discussions were centered on science-related misconceptions. Ece suggested that writing students might have misconceptions that "speed and velocity are the same concepts" with Deniz's contributions. Defne brought up some ideas for mathematics-related difficulties. When researchers asked how they could deal with these difficulties in the lesson, Ece said: We can add mathematical formulas after the testing process in the engineering notebook. If we give the formula after the graph drawing, we can draw attention to the unit of speed". Ece also recommended engineering-related difficulties while filling out CoRe (**video-recorded planning meetings, lesson study 2).**

She attributed the sources of science-related misconceptions mainly to the everyday language. This was the first time she was provided with a different reason except for her prior experience with the origins of misconceptions:

> I know this misconception from my prior experiences. Moreover, the concept of velocity is more frequently used in everyday language. If my parents were science teachers, or if I had a chance to learn by doing, I believe I could have learned correctly. For me, the way of using scientific language in an everyday environment had too much effect on our knowledge **(pre-interview, 2).**

Ece did not mention misconceptions in other STEM fields, although a mathematics-related one was discussed in the planning meetings. On the other hand, she started to talk about using different methods rather than question and answer to identify learners' misconceptions. She stated:

> We will use the word association test at the beginning of the lesson. We are interested in what comes into students' minds when they hear about the speed concept. Whether the concept of velocity will emerge, we prepared a concept cartoon, and we will apply it towards the end of the lesson. We aimed to observe whether their misconceptions would be eliminated after employing the engineering design process **(pre-interview, 2).**

As seen above, Ece extended her knowledge of learners concerning identifying and overcoming students' misconceptions in science after the planning meetings.

Regarding difficulties, she mentioned science, engineering, and mathematics-related difficulties as follows:

> I think students will experience difficulty designing cars by considering the criteria, such as making the tires turn properly. They might have difficulty reaching the idea of speed because their cars will complete a track, which will be 2 meters. They will measure time and make inferences about whose car has the highest speed. They need to think about the distance travelled in a unit of time. This might be challenging for them. Moreover, we expect them to create two different graphs; they might have difficulty converting the distance travelled-time graph into speed-time graphs. Especially drawing a line graph for constant speed will be difficult for them **(pre-interview, 2).**

Ece was able to list students' difficulties in STEM disciplines after the planning meetings of lesson study 2. Her consciousness about the difficulties in other STEM disciplines except science increased. She also indicated that since they were expecting these difficulties, the teacher of the lesson would provide examples for drawing graphs and feedback about how to grasp the concept of speed from the activity **(pre-interview, 2).**

Ece observed Defne's lesson and realized and noted the difficulties she mentioned before the implementation of the lesson. Moreover, she added one more science-related difficulty, which was determining the unit of speed in her observation form, which was not written in CoRe. Concerning misconceptions, she wrote that the speed-velocity misconception occurred in the lesson, and it could not be handled at the end of the lesson **(pre-observation form, 2).** No mathematics and engineering-related misconceptions were encountered in her observations.

After observing teaching, she had some suggestions about detecting and handling science-related misconception:

> Our purpose was to understand whether students had misconceptions when they came to our lesson. I mean, before starting a STEM lesson plan about speed, we wanted to know what they had in their minds. I think we should change the implementation time; we should apply it earlier…We defined the speed. Actually, we expected students that would reach the concept through the activity we had prepared. I mean, they compared what if the distance travelled was the same, but the measured time for completion of the track was different for cars, planes, etc. There was nothing about the velocity in our lesson. We should add it and make a comparison between the speed and velocity concepts to address the misconception (**post-interview, 2).**

Ece suggested changing the time of implementation of the word association test, which aimed to identify science-related misconceptions. She added that students were talking about the velocity concept and thought that the pre-determined misconception was not overcome after completing the STEM lesson. Ece said that she examined students' engineering notebooks, and they answered some questions by referring to velocity.

Regarding difficulties, Ece touched on science, engineering, and mathematics-related difficulties in the pre-interview:

> Defne explained how to create line graphs; she walked around the groups and guided them. She made them transfer the data collection table into line graphs. Before she explained, none of the groups could draw their graphs…I observed that they had difficulty specifying the unit of speed. While students were presenting their prototypes, they could not indicate the unit of speed. They just said our speed was 6, for example. Defne asked some questions, such as, in what seconds, how many meters does your car travel? However, it did not really work. I think we should use the DST triangle to handle this difficulty **(post-interview, 2).**

As seen above, Ece was able to detect what she discussed before the implementation with respect to misconceptions and difficulties. She was aware of the difficulties and how the teacher of the lesson attempted to get through them. Ece also stated that designing a car according to the criteria and choosing the best solution parts were challenging for students. She provided topic-specific examples and detailed explanations after observing, teaching, and reflecting on the lesson.

In the reflection meetings, Defne made some suggestions as a teacher of the lesson, and Ece agreed with them because she stressed similar points in the post-interview. She especially insisted on using the DST triangle and removing the limitation of the curriculum **(researcher's field notes, reflection meetings of lesson study 2).** It could be stated that as her knowledge of curriculum improved, her knowledge of learners also evolved.

Ece was the teacher of the revised lesson. As discussed in the group meeting, she utilized the word association test earlier in the lesson. She wrote some students' answers to the board, such as velocity, running, kilometer, second, etc. She was able to identify the pre-mentioned misconception. She used the DST triangle and the improvisation activity that Defne implemented to overcome it. Then, she wrote mathematics formulas for speed and velocity and highlighted that these were the two different concepts through correct explanation. However, she had no time to implement the concept cartoon to determine whether students held the misconception later in the lesson **(researcher's post-observation form, 2).**

Toward the end of the lesson, Ece asked one student from one of the groups to draw a constant speed-time graph on the board (Figure 4.25). The student started to draw the line graph with ascending slope. Ece did not realize students' mathematics-misconception at first. After the students completed the graph, she noticed and warned students that:

> **Ece**: Please look at the graph you have created. It is similar to the next one (distance travelled-time graph). Our speed is constant, right?
> **S1:** Yes, it is 6m/s.
> **Ece:** But your speed is increasing here. The graphs can be in ascending slopes or zero slopes. We have placed the speed on the horizontal axis, which is 6 m/s through 2 meters. So, there was no change. We should re-think the graph you have drawn **(researcher's post-observation form, 2).**

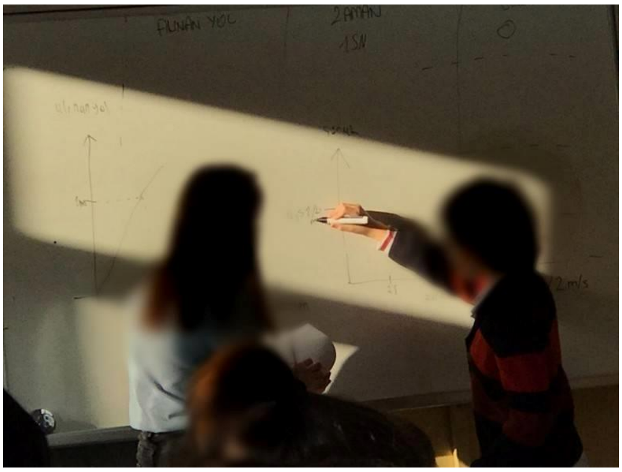

Figure 4. 25 Scene from Ece's Lesson in Lesson Study 2

As seen from the dialogue, she detected mathematics-related misconception and tried to overcome them through explanation and demonstration.

Regarding difficulties, she paid attention to what had been discussed in the reflection meeting and her observations of the first version of the lesson plan. For instance, she thought that students might have difficulty in drawing a graph and provided the examples below:

Ece: (drew the table below). There are vertical and horizontal axes; we write the distance travelled on the vertical axis and the time on the horizontal axis. The car travelled zero meters in zero seconds, so this is the starting point. Then the car travelled 5 meters in 1 second; I marked 5 meters on the road taken, 1 second in time, and connected the dots **(researcher's post-observation form, 2).**

Distance travelled (m)	0	5	10	15	20
Time (second)	0	1	2	3	4

Additionally, Ece guided the groups in terms of forming the graphs from their data and interpreting them. The other instance regarding how she detected and handled science-related difficulties were given below:

Ece: What is the unit of speed?
S1: Meter.
S2: Time.
Ece: Let's have a look at the DST triangle. We multiply speed and time to calculate speed, right? In the same manner, while calculating speed, we divide the distance travelled by time. So, we divide the meter by seconds. Then, what would be the unit of speed?
S3: Meter/second.
Ece: Definitely. If I want to measure the distance I travel in the classroom, should I use a meter or a kilometer?
S4: Meter.
Ece: Then, I want to travel to Aydın. Should I use a meter or a kilometer?
S5: Kilometer.
Ece: Yes, if the distance is long, we use kilometers and hours for the unit of speed **(researcher's post-observation form, 2).**

Regarding engineering-related difficulties, she noticed that choosing the best solution challenged student groups. At this point, she addressed the decision table in engineering notebooks and helped students that they had to consider the criteria and limitations to decide which solution would work better. It could be said that she was conscious of students' difficulties in science and other STEM disciplines after re-teaching part and sought ways to eliminate them.

In the re-reflection meeting, Ece mentioned that she initially did not recognize students' misconceptions in mathematics but provided correct explanations to clarify them **(researcher's field notes, reflection meetings of lesson study 2).**

In summary, Ece's knowledge of learners reflected the PCK-C category after completing lesson study 2. In other words, she moved from the PCK-B category to the PCK-C category, which is PCK for STEM. She was able to list misconceptions in line with the relevant literature. She started to talk about self-experience as a teacher and everyday language as possible sources of misconceptions. She broadened her understanding of detecting and handling misconceptions and difficulties in science and other STEM disciplines in a balanced way at the end of lesson study 2.

4.1.3.2.3. Lesson Study 3

Ece was the observer teacher in the first and second versions of the STEM lesson plan in lesson study 3; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

The discussions about difficulties and misconceptions concentrated on the science and engineering disciplines in the planning meetings of lesson study 3. Ada guided the group by writing a misconception that "there is only one successful design," and Ece agreed with her. She added that she realized this misconception in the previous STEM lesson plan. Moreover, Deniz asserted that students might think "cold is transferred," Ece indicated that she had never thought it was a misconception before **(video-recorded planning meetings, lesson study 3).**

After completing CoRe, Ece addressed what was discussed in the group meetings:

> Actually, Deniz proposed a misconception that was new to me. I had never thought from this perspective. I think it will definitely emerge in our lesson. I believe that the everyday use of scientific language is the primary thing that contributes to this misconception. Moreover, the other possible misconception that could come up in our lesson is that thermal insulators are the source of heat. Because students might think that they can cause an increase in temperature since they are the source of heat…I observed the misconception about the engineering design process in Defne's lesson. Because students talked about "our design is the successful one, our design is the right way". Students might have an alternative understanding that the solution that the most successful group is the right and only way to solve the problem. We should indicate that "there is not only one solution to the problem, but there are also different combinations of thermal insulator materials, and some groups' combinations worked better **(pre-interview, 3).**

As seen above, Ece could talk about the likely origins of misconceptions, and she provided topic-specific details in lesson study 3. She also benefited from self-experiences as an observer teacher while stating misconceptions.

Regarding difficulties, she focused on science and engineering-related difficulties. She started choosing the best solution part would be difficult for students based on her prior observations as a teacher. She also expressed that choosing the appropriate combination of materials would be challenging in the engineering design process; therefore, they prepared material cards by considering students' difficulties **(pre-interview, 3).** With respect to science-related difficulties, she stated that:

> Students have difficulty in determining the units. While I was implementing the lesson plan about speed, I experienced this. I think a similar situation will happen in temperature and heat topics. Moreover, they might struggle with reading thermometers because they are not familiar with them; the teacher is doing demonstration experiments generally in the classroom **(pre-interview, 3).**

It could be inferred that Ece considered students' difficulties while planning a STEM lesson and her knowledge became more sophisticated.

During observation of the lesson, Ece paid attention to the pre-mentioned misconceptions and difficulties. For example, she noted that "thermal insulators are the sources of heat", "cold is transferred," and "there is only one successful design" misconceptions emerged in the lesson, and the teacher of the lesson partially overcame them through correct explanation. She also noted that these misconceptions came up through questioning. She realized that students had difficulty in reading and using the thermometer and choosing the appropriate materials for their design solutions in parallel with the collaborative CoRe **(pre-observation form, 3).**

After observation of teaching, she reflected on the lesson in terms of misconceptions and difficulties. For example, she talked about engineering-related misconception as follows:

> The group with the most temperature changes said we would not take our thermos design; we would not bring it home because it was unsuccessful. I think we should attract their attention to the redesign part at this point. We should emphasize that they can learn about the most successful design, re-think, re-build and re-test their designs. Ada tried up to a point. She said that they should use other group data in the redesign process. On the other hand, the redesign part is one of the points that challenge them. This part on engineering notebooks is generally empty. **(post-interview, 3).**

Ece pointed out the redesign part of the engineering design challenge to handle engineering-related misconceptions after observation of teaching. Moreover, she noticed that science-related misconceptions arose in the lesson:

> The students considered window glass a heat source in a thermal-insulated house. This was a misconception that we wrote in CoRe. Another student said, "sleeping bag keeps us warm". Indeed, Ada did not provide any explanations; she continued with the activity. She could not be able to eliminate it. If I was a teacher of the lesson, I would say that thermal insulator materials are not the source of heat. Then, I would give examples of thermal insulation materials and make a comparison between insulators and conductors… I also realized that one student asked whether we should measure heat, and Ada said no. However, she could have emphasized that it was not directly measured. She did not detect and clarify it **(post-interview, 3).**

Ece was able to detect misconceptions that were not included in the CoRe, demonstrating her enhanced knowledge concerning learners.

In the reflection meeting, Ece mentioned science-related misconceptions about measuring heat together with Defne, and the group revised the CoRe. The other change that was made in CoRe was introducing how to use thermometers since students have difficulty in reading and collecting data through them, and Ece agreed with the idea **(researcher's field notes, reflection meeting of lesson study 3).**

During the observation of re-teaching, different from the previous observation form, she missed one engineering-related misconception that had not emerged before. One of the students stated that the engineers and scientists were doing the same job, and she could not be able to detect it **(post-observation form, 3).** However, she realized it while reflecting on the lesson in the re-reflecting meeting **(researcher's field notes, re-reflection meeting of lesson study 3).**

To conclude, Ece's statements demonstrated the features of the PCK-C category at the end of lesson study 3, similar to lesson study 2. She broadened on her understanding of the possible origins of misconceptions and difficulties, as well as identified them in all STEM disciplines included in the lesson plan. Her explanations were in detail and topic-specific instead of being discipline-specific, and there was a balance between the different disciplines with respect to misconceptions and difficulties.

4.1.3.2.4. Lesson Study 4

Ece was the teacher of the first version of the lesson plan in lesson study 4; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Ece suggested writing two science-related misconceptions as follows:

> **Ece:** I suggest writing "sound propagates in space and sound propagates circularly" misconceptions. I found an article, and sixth grade students had these misconceptions in that study. We might use the diagnostic tree to understand whether the misconception is eliminated after completing the engineering design process. We can add these misconceptions as items in the diagnostic tree.
> **Defne:** Maybe, students might think sound propagates linearly too. We should also write this to CoRe. Giving instant feedback when we confront misconception is very important for me, and the diagnostic tree might help us at this point **(video-recorded planning meetings, lesson study 4).**

Moreover, she was also involved in the discussion regarding engineering-related difficulties **(researcher's field notes, planning meetings of lesson study 4).** After planning meetings, she was able to talk about misconceptions in STEM disciplines with detailed descriptions as follows:

> I think they might have confused between thermal insulation and sound insulation and have a tendency to use the same understanding while designing their sound-proof music room. Except for that one, I totally agree with Deniz's suggestions for the misconception that sound travels in a linear way. I think we can confront this misconception in our lesson. I plan to ask a question about it. K part of the KWL chart might be helpful for us at this point too. On the other hand, students indicated that engineers and scientists were the same people in Deniz's lesson. Ada reminded us of this situation, and we included it in the CoRe. Lastly, we applied a draw an engineering test and found that engineers were working alone in the drawing. Actually, I was surprised by this result. Because they had worked collaboratively since the beginning of the semester, we thought we should do something different rather than explaining, "you are a group of engineers". We prepared an animated video to address this misconception **(pre-interview, 4).**

As seen from the excerpt, she elaborated on her understanding of how to deal with misconceptions and how to consider them in the planning process. Moreover, she mentioned her own mathematics-related misconception that was not discussed in the planning meetings:

While we were discussing the type of graphs, I realized that only discrete and countable data could be used in bar charts. Moreover, there should be a space between columns referring to no connection between the data. For instance, we will use the data from four different groups to create bar charts. Their data are not related to each other; the space between them represents this idea. Students might have these types of alternative conceptions at this point, too **(pre-interview, 4).**

Ece stated possible mathematics-related misconception in accordance with the literature by reflecting on her self-experience after the discussions in the planning meeting.

Regarding difficulties, she mentioned science, mathematics, and engineering-related difficulties before they occurred:

They might have difficulty choosing the appropriate materials for creating their prototypes for the music room. We also experienced difficulty about what could be the properties of materials that are used in sound insulation, whether it should be rough or smooth etc. Therefore, we prepared a science magazine to research the problem and minimize students' difficulties… They generally write just two solutions to the problem, as we have seen in engineering notebooks. The number of groups that wrote three different ideas is very few. We actually prepared a table to facilitate this process. Working as a team, communication with the group is also challenging. I will be careful about guiding the groups… They might probably have difficulty creating bar charts because drawing line graphs was also challenging in my STEM lesson **(pre-interview, 4).**

Ece was able to learners' difficulties with both science and other STEM disciplines. To eliminate the possibility of occurring them, she paid attention to them while planning the lesson, which showed her increased knowledge with respect to learners.

Ece was the teacher of the first version of the lesson. As she planned, she asked some questions to reveal students' science-related misconceptions:

Ece: How sound propagates?
S1: It propagates as waves.
Ece: In only one direction? In a linear way?
S2: No, it propagates in all directions
Ece: Sound has movement as it propagates; what is it?
S2: Vibrations **(researcher's pre-observation form, 4).**

Since Ece was alerted to possible misconceptions, she asked the questions mentioned above on purpose and decided that there were no misconceptions regarding how sound propagates. Concerning mathematics-related misconception she mentioned in the pre-interview, she explained how to graphs in detail by referring to her own misconceptions:

> **Ece:** What is the difference between line graphs and bar graphs?
> **S:** (no answer).
> **Ece**: Remember the lesson about designing a speed car. We created line graphs there.
> **S1**: Yes, we connected dots.
> **Ece:** Exactly. We connected dots, I mean, your car's speed in one second, two seconds, and so on. However, today, we have different types of data. We have group names on the horizontal axis and your decibel values on the vertical axis. I can count the group names, right?
> **S2:** Yes, we have four different groups.
> **Ece:** On the other hand, I could not count the decibel.
> **S3:** You measured it through the application.
> **Ece:** Definitely. Let's create bar graphs… (after completing forming of graphs). We have space between the columns because the data of "Sessiz and Yalıtımcılar" (group names) are unrelated; you have collected your data independently, correct? **(researcher's pre-observation form, 4).**

As seen from the dialogue, she asked some questions to detect students' misconceptions about this issue and then explained the topic by considering the mathematics-related misconceptions she realized before implementing the lesson. She tried to eliminate them through explanations and giving examples.

Additionally, she caught engineering-related misconception in her lesson too. When she was asked about the difference between scientists and engineers after showing the animated video, some students said that they were doing the same job or gave wrong answers as "scientists do not design anything, they do not produce". She identified them through questions and explained to them as Deniz suggested in the planning meetings **(researcher's pre-observation form, 4).**

With respect to difficulties, she noticed that students struggled to understand sound absorption and reflection principles. At those times, she addressed the science magazine and asked additional questions to the students while walking around the groups. Moreover, some groups could not create bar graphs to compare their designs with other groups. She identified them and supported them by giving explanations. She was also conscious of students' difficulties in the engineering design process, especially in producing more than one solution and choosing the best one. Ece ensured that the students filled out these parts in the engineering notebook **(researcher's pre-observation form, 4).**

After teaching the lesson, Ece explained that she was planning to revise mathematics-related misconceptions in CoRe and suggested expanding the content of the science magazine to assist students' learning the science concepts that could be used in solving the engineering problem **(post-interview, 4).**

Ece opened her ideas to the discussion in the reflection meeting. No one in the group was aware of the mathematics-related misconception that Ece mentioned. The idea seemed reasonable among the group members, and they reached a consensus to revise CoRe with respect to misconceptions. Moreover, after Ada suggested revising the content of the science magazine because of students' difficulties, Ece intensely participated in her idea. **(video-recorded reflection meetings, lesson study 4).**

After attending the cycles of lesson study, Ece wrote science and engineering-related misconceptions in her post-individual CoRe. She utilized question and answer to detect these misconceptions and prepared a video to address students' misconceptions in engineering. Similarly, science and engineering-related students' difficulties were found in her CoRe **(post-individual CoRe).**

In conclusion, Ece's PCK concerning the knowledge of learner was strong at the end of the lesson study cycles. Her explanations met the PCK-C category, which is PCK for STEM. She was able to talk about misconceptions and difficulties in science and other STEM disciples by giving equal weight to each discipline and making topic-specific emphasis. Moreover, she considered them both in the planning process and teaching process. She also made suggestions based on her teaching experiences in the reflection part of the study.

4.1.3.3. Knowledge of Instructional Strategies

4.1.3.3.1. Lesson Study 1

Ece was the observer teacher in the first and second versions of the STEM lesson plan in lesson study 1; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

Before starting the study, Ece did not utilize any specific teaching strategy. She planned a group work and provided a problem regarding energy transformation. She divided the classroom into three groups, and each group was responsible for different types of energy transformation; for example, one group for electrical energy converted to heat energy, the others for kinetic and light energy. Each group was given a different scenario, and the problem was not related to daily life. She did not use any representations and design-centered teaching practices **(pre-individual CoRe).**

In the planning meetings, Ece was the first participant who advocated using the 5E learning cycle to prepare their first lesson plan. The other group members also favored using 5E after Ece's suggestions. Ece added that she felt comfortable using 5E and could not think of any other alternative teaching strategy for their first lesson plan. Moreover, she was actively involved in the discussion about design-centered teaching practices. For instance, she indicated that there should be many available and appropriate materials in the classroom so that students could propose several solutions to the problem or introduce the idea to the client while writing open-ended design challenges **(video-recorded planning meetings, lesson study 1).**

Ece was asked to explain how STEM education and 5E were compatible with each other in the interview, and she said that:

> Actually, preparing a lesson plan with 5E is easy to use. We know each step in detail and what we should do in these steps. It guides the teacher very well. I think we easily integrated STEM education into these steps. I am not sure about the Elaboration phase only. On the other hand, the exploration phase requires students to explore the concepts; therefore, we added possible solutions, chose the best solution, and created and tested prototype parts in this step **(pre-interview, 1).**

Ece's reason for choosing 5E was related to her familiarity with the strategy after the planning meetings. Her explanations were discipline-specific, and no topic-specific descriptions of how each part of 5E was compatible with the basic features of STEM education were found.

With respect to design-centered practices, her explanations were too broad:

> We tried to implement the process engineers go through when designing a product. We planned to make students study collaboratively and increase their communication skills in the group. We want them to find a solution to the

> problem. They will propose different solutions that may contribute to developing creativity skills. Moreover, they will discuss each solution with its positive and negative aspects to choosing the best one. This might lead to the development of critical thinking and decision-making skills **(pre-interview, 1).**

As seen from the excerpt, she started to talk about how STEM education had an influence on improving 21st-century skills such as creativity and critical thinking skills and mentioned some of the design-centered practices, like choosing the best solution. It could be said that no specific details about designing Solar eclipse viewers were provided concerning design-centered teaching practices, and her understanding was limited at the end of the planning meetings of lesson study 1.

Regarding representations and activities, Ece mentioned science and engineering-related representations. For instance, she emphasized the role of the decision table in choosing the best solution part as follows:

> I think students might have difficulty in determining the positive and negative aspects of a design in the form of a sentence. Using a decision table will be helpful for concretizing and supporting them in the decision-making process. They will consider the criteria and limitations while choosing their final solution because we put the criteria and limitations in the table. We also have another table at the end (in the re-designing part). We provide an opportunity to assess the strong and weak parts of their design through the table; we make their jobs easier in this way **(pre-interview, 1).**

As seen above, in addition to design-centered practices, she touched upon representations specific to engineering with justification. Moreover, she mentioned using animation to attract students' attention to the lesson and using information cards to assist students in researching the problem part, as she suggested in the planning meetings **(pre-interview, 1; researcher's field notes, planning meetings of lesson study 1).** Regarding strategies for engagement with engineering concepts, she started using "criteria, limitation, trade of" concepts in her explanations.

During observation of the first STEM lesson plan, she noted that the steps of the 5E learning cycle were implemented successfully. She partially agreed that the steps of the engineering design process were appropriately applied, but some steps needed additional time. Moreover, she partially agreed that the Solar eclipse concept was discussed in the context of the engineering design process. She considered that engineering terminology was used to some extent during the lesson (**pre-observation form, 1).**

After observation of teaching, she found using 5E effective in STEM lessons but added that time should be managed in a better way and the Evaluation phase should be given more time **(post-interview, 1).** Moreover, she started to talk about more design-centered practices after observation of teaching as follows:

> I think determining the criteria and limitation part should be skipped faster because developing a prototype required more time than we expected…The point that caught my attention was that the two groups did not examine the information cards. They found them useless, as far as I heard. One group member can be given a task to read it **(post-interview, 1).**

Ece realized the use of information cards was not very effective; however, she could be able to connect it with researching the problem, which is one of the design-centered teaching practices. As seen above, her explanations were general, and many design-centered practices were missing.

Ece did not offer any modifications in teaching strategy in the reflection meetings. She brought material cards up for a discussion, and Defne also participated in her thought. They argued about how to make these cards more effective; however, Deniz, as a teacher of the lesson, recommended extracting material cards from the flow of the lesson, and the group agreed with him. Ece also shared her ideas about devoting more time to developing the prototype. Lastly, she pointed out that the engineering talks should be more emphasized by indicating that Deniz did not define and use the "prototype" concept until the last minutes of the lesson **(researcher's field notes, reflection meetings of lesson study 1).**

While observing the revised version of the lesson plan, Ece paid attention to the different points regarding design-centered teaching practices. For example, she noted that Ada managed the group worked properly and guided students' learning and how engineering careers were covered in the lesson **(post-observation form, 1).**

In brief, Ece's knowledge of instructional strategies met the criteria of PCK-A at the beginning of the study. She did not employ a teaching strategy compatible with STEM education. Moreover, no evidence for design-centered teaching practices and representations were found in her pre-individual CoRe, and activities were limited. On the other hand, she moved from the PCK-A category to the PCK-B category after completing lesson study 1. She started to propose teaching strategies compatible with STEM with limited understanding. She was not aware of alternative ones, and her justifications were discipline-specific. Moreover, her knowledge of instructional strategies with respect to design-centered teaching practices developed to some extent; however, some of them were missing. She was able to use representations and activities in engineering in a detailed way but superficially in other STEM disciplines.

4.1.3.3.2. Lesson Study 2

Ece was the teacher of a revised version of the STEM lesson plan in lesson study 2; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

In the planning meetings, Defne suggested using an alternative teaching strategy such as REACT. Ece also supported the idea because of its context-based nature but remarked that she had prepared a lesson plan using REACT at just one time. She was unsure whether she had sufficient background knowledge related to strategy. After these discussions, the group decided to use REACT **(video-recorded planning meetings, lesson study 2).** She further explained her thoughts in the pre-interview:

> I think it is (REACT) very similar to the 5E learning cycle. Their first three steps are almost identical. We want students to work collaboratively on the engineering problem, and REACT helped us at this point. But preparing activities, especially in the Application and Transfer phases, challenged us. We always use 5E; therefore, using a different strategy was good for me. I think I might use REACT in STEM lesson plans in future lesson plans **(pre-interview, 2).**

As seen above, Ece's knowledge about the alternative strategy started to enhance, but she could not extend her reasons for choosing REACT in the STEM lesson plan. The underlying reason for choosing REACT was to learn about the characteristics of a new strategy in the planning and teaching phases of lesson study.

With respect to design-centered teaching practices, Ece mentioned some practices for the first time in the study. For instance, she underlined the significance of featuring science concepts in the engineering design process:

> We focused on creating a prototype in the previous lesson plan. As far as I observed, the Solar eclipse topic was not covered; we just asked some basic questions about the eclipse. We generally focused on the product. We used the engineering design process in this lesson plan too, but our priority is not creating a prototype; we want to teach some essential science concepts, too **(pre-interview, 2).**

As seen above, Ece criticized that the science and engineering activities were separated in the previous lesson, which showed she broadened her understanding of design-centered teaching practices. Moreover, she implicitly touched on conducting research to solve the problem:

> We put two F1 cars in the engineering notebook. One of them was designed more than 40 years ago, and one of them was designed in 2000s. We aimed to stimulate students' interest in the problem and encourage them to examine the existing car designs in order to gain insight into designing their own cars. Maybe, they might go home and do additional research after the lesson **(pre-interview, 2).**

Regarding representations, Ece talked about science and engineering-specific representations. She indicated that using a video from a running race might help students to relate the topic to daily life experiences and increase their motivation to learn **(pre-interview, 2).** Additionally, she gave explanations about engineering-specific representation:

> We prepared a decision table in the re-designing part. Students might only think of the positive aspects of their designs. However, we want them to develop a more holistic understanding and be aware of the negative parts of their design and think critically. We can do this through the table easily **(pre-interview, 2).**

In terms of strategies for engagement with engineering concepts, she started to talk about promoting STEM careers as follows:

> We are talking about career awareness. We can attract students' attention with the activities we created. We can integrate different careers in our lesson as we did in this plan, such as data analysis, automotive or mechanical engineering. We should emphasize their work and the importance of teamwork (**pre-interview, 2).**

Moreover, she indicated that the engineering problem they wrote in lesson study 2 was more attractive for students than the first one. She referred that the engineering design problem was more authentic for students.

Ece monitored Defne's lesson and noted that the Transfer phase of REACT could not be implemented as planned because some activity sheets were not applied because of time limitations. Regarding design-centered practices, she totally agreed that students discussed the speed concept during the engineering design process. She indicated that the steps of the engineering design process were followed to a certain extent. She considered using representations such as graphs, videos, and tables adequate. Lastly, she noted that emphasis on engineering talk and STEM careers was sufficient in the lesson **(pre-observation form, 2).**

After observing teaching, Ece gave nine points out of ten for the implementation process. If Defne had carried out the Transfer phase effectively, she said she would give ten points. Furthermore, she stated that using REACT was appropriate in STEM lessons without providing additional information **(post-interview, 2).**

Regarding design-centered teaching practices, she elaborated on her understanding of promoting science concepts in the engineering design process:

> One group had difficulty choosing tires. They argued that the friction with the tires and the ground should be minimal to have a car with the highest speed, just as we wanted. They were learning about science concepts in the engineering design process. They solved this problem by trial and error; they conducted little tests on their own **(post-interview, 2).**

Moreover, she did not write anything about the re-design part, which was missing in Defne's instruction. However, she reflected on this issue in the interview:

> There were two groups that did not make their race cars work. They could not draw the graphs and evaluate their designs either. I think we need to involve them in the lesson through the re-design process, but it was not effectively integrated into our lesson. These groups should realize the flaws in their designs, fix them, and re-test in the re-designing part. They might change the body of the car or the wheels of the car. In this way, they might collect their own data and transform it into graphs **(post-interview, 2).**

Ece also recognized that the teacher of the lesson was able to manage teamwork and take criteria and limitations into account to solve the problem. It could be said that she began to notice some design-centered teaching practices, as in the examples above, after observation of teaching. On the other hand, her explanations about representations and activities were too general **(post-interview, 2).**

In the reflection meetings, generally, suggestions from Defne were discussed. Her main suggestion was about the representations specific to science. She recommended using the DST triangle and more daily-life examples in the revised lesson. Ece was a listener in these discussions. Moreover, Ada suggested involving girls not only in the writing phase of the engineering design process but also in the testing phase. Ece said she had not paid attention to this issue and participated in her idea **(video-recorded reflection meetings, lesson study 2).**

Ece was the teacher of the revised version of the STEM lesson plan. She carried out the steps of REACT properly. She widely used symbolic representations, such as the DST triangle, data collection table, decision table, and figure of the engineering design process **(researcher's post-observation form, 2).** Moreover, she touched upon design-centered practices through the use of representation. It could be inferred that she was careful about the discussions in the reflection phase and tried to include them in her instruction. The participants discussed the importance of producing alternative solutions in the reflection meetings of lesson study 1, which was emphasized in Ece's instruction. She also facilitated using science concepts in the engineering design process at the beginning of lesson study 2, and this situation was mirrored in her instruction. The below conversation was taken from one group while Ece was walking around the groups:

> **Ece:** Why did you choose ping pong balls as tires?
> **S1:** We did not choose a styrofoam ball. Because it is very rough and creates more friction with the racetrack, we would have less speed if we used this.
> **S2:** That is why we chose the ping pong ball so that the friction force is less and it goes more speed **(researcher's post-observation form, 2).**

Another point argued in the reflection meeting was engaging girls equally in all parts of the engineering design process, and Ece reflected on this situation in practice. On the other hand, although Ece determined the role of clients, identified criteria and limitations, and modeled students' solutions before creating prototypes, there were some limitations in her understanding of design-centered teaching practices. For instance, the lesson plan included the former version of race cars so that students could make investigations about the earlier versions of designs and prior solutions. This was one of the fundamental parts of the lesson plan, and Ece rushed into the producing alternative solutions part at this point without applying this part. Additionally, she did not employ the re-design part and did not talk about why the design succeeded or failed. Students were not given the opportunity to troubleshoot the flaws in their designs **(researcher's post-observation form, 2).** Therefore, it could be said that Ece could not be able to complete the entire cycle of the engineering design process.

Regarding strategies for engagement with engineering concepts, Ece underlined that students would be in the role of engineers and promote STEM careers. The use of engineering talk was involved in the lesson, but it was not the focus of the instruction **(researcher's post-observation form, 2).**

To conclude, Ece's instruction exhibited the features of the PCK-B category at the end of lesson study 2. She made progress in terms of grasping the characteristics of an alternative strategy; however, the preferences of choosing this particular strategy in the STEM lesson plan remained unclear. Moreover, Ece extended her knowledge regarding design-centered teaching practices, but there were still some missing points in her instruction and statements. On the other hand, she was able to use representations and activities in science and other STEM disciplines at the end of lesson study 2.

4.1.3.3.3. Lesson Study 3

Ece was the observer teacher in the first and second versions of the STEM lesson plan in lesson study 3; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

In the planning meetings, Ece was involved in the discussions while deciding on the teaching strategy. With Ece's suggestion, the group tended to use the 5E learning cycle as in the first lesson study cycle. Then, she offered to use 4E instead of 5E. When the researcher asked about their differences, she answered that there was no Engage part in 4E. Then, she changed her mind and indicated that Engage part was necessary for STEM lessons to attract students' attention to the engineering design challenge and they might use role-play at this stage **(video-recorded planning meetings of lesson study 3).**

When she was asked to list the reasons for choosing the 5E learning cycle, she indicated that:

> I think it is suitable for the STEM lesson plan. We can use the time more efficiently. REACT was the strategy that we did not know well. Because we did not know the strategy very much, we had difficulties arranging the steps. We may prefer to use problem-based or project-based learning in the next plan. However, we have little theoretical knowledge about them **(pre-interview, 3).**

As seen above, familiarity with the strategy was the main reason for Ece to select a teaching strategy. It could be inferred that having less background knowledge about the teaching strategy impeded them from using. She was further asked to explain what made this lesson plan a STEM lesson plan; she touched upon design-centered teaching practices as follows:

> The primary thing is designing a thermos by using specific steps. Students will be given a problem to solve. Then, while solving the problem, they will learn about the science concepts, thermal insulation, and the properties of materials used in thermal insulation. We wanted to direct them to the internet resources for making an investigation, but we had limited opportunities in the classroom. Therefore, we prepared material cards. We want a student to think like engineers and solve problem. While doing this, they need to be careful about the limitations, which are budget and time in our case. They should develop decision-making skills to choose the best solution that meets the criteria, such as keeping the soup hot for at least 20 minutes, being easy to carry, etc. Collecting data and filling the table according to the data obtained are also essential to decide on the thermos design while solving the problem. I think these are the features that make our lesson plan different from the typical science plans on this topic **(pre-interview, 3).**

As seen above, Ece provided rich descriptions regarding the design-centered teaching practices utilized in this STEM lesson plan and made topic-specific explanations.

In addition to visual and symbolic representations, Ece enriched her explanations with daily-life examples in science and engineering disciplines as opposed to previous lesson study cycles. For instance, she said she would give the example of different areas in which the thermal insulation principles had been used, such as space cloths, and related this topic to how engineers solve daily-life problems **(pre-interview, 3).** It could be said that the number of representations was increased in Ece's statements at the end of the planning meetings. She also stated that the visuals and life stories of two engineers would promote students' understanding of what engineers do at work and increase their career awareness.

During the observation of teaching, Ece totally agreed that the use of representations specific to science and engineering was sufficient, and they attracted students' attention. She noted that the steps of the engineering design process were appropriately applied except for re-designing. She specifically paid attention to the discussion of science concepts in the engineering design process. She found the use of engineering terminology adequate **(pre-observation form, 3).** It could be inferred that she was able to reflect on her understanding in observation of the lesson.

When Ece was asked to explain her thoughts about using 5E learning after observation of teaching, she elaborated her understanding by matching the features of 5E and STEM education as follows:

> I think 5E is very suitable for STEM education. In our first lesson, we also used 5E, but I think this plan was more effective and fluent (than the first one). We gave the engineering problem through an animated video in the Engage part different from the first one. It really attracted students' attention; I felt that we engaged them in the lesson. In the next step (Explore) our primary goal is to make students explore the concepts, and we combined this step with researching the problem. The materials cards worked well here, I think…The exploration continued with testing and collecting data, and the groups explained their design solutions. Moreover, we gave daily examples, such as the ice cream truck and sleeping bag, which assisted their learning. All in all, it was a good lesson plan, and I gave 10 points out of 10 **(post-interview, 3).**

As seen above, Ece deepened her understanding of the reasons for choosing a particular strategy after observation of teaching in lesson study 3. She made a comparison with the first CoRe in which they used the same strategy. Then, she connected the steps of the 5E learning cycle with the key elements of STEM education for the first time in the study. Regarding representations and activities, and strategies for engagement with engineering concepts, she talked about similar things that she mentioned in the pre-interview.

In the reflection meeting, the discussions were centered on making the re-design part more effective with the suggestions of Defne, and Ada and Ece participated in their ideas. Moreover, the group added a visual representation to represent heat loss in the buildings. Ece made no suggestions with respect to teaching strategies **(researcher's field notes, reflection meetings of lesson study 3).** During the observation of re-teaching, Ece noted that the beginning of the lesson was teacher-centered, which was not appropriate for the 5E learning cycle that displayed her strong knowledge about the strategy. Moreover, she was able to realize the representations specific to science that were not written in CoRe and applied by the teacher of the lesson **(post-observation form, 3).**

Ece made a transition from the PCK-B category to the PCK-C category at the end of lesson study 3. She was able to list her reasons for choosing an appropriate strategy by connecting the characteristics of STEM education while reflecting on the lesson. Moreover, she focused equally on representations and activities in science and other STEM disciplines. Most of the design-centered teaching practices were apparent in her explanations. These features were in line with the PCK-C category, and Ece reached the highest level at the end of lesson study 3.

4.1.3.3.4. Lesson Study 4

Ece was the teacher of the first version of the STEM lesson plan in lesson study 4; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

In the planning meetings, Ece guided the discussions in the group regarding choosing an appropriate strategy for their CoRe. The below conversation was taken from their discussions:

> **Ece:** I think we should try a new strategy. Right now, we are familiar with STEM, and we have gained enough knowledge. I am suggesting using problem-based learning.
> **Deniz:** I think we should choose the 5E learning cycle again. In the second lesson plan, we used REACT and experienced difficulties. Because we did not know the strategy (REACT) very well, I think it will be the same if we use problem-based learning.
> **Ece:** But the steps of problem-based learning and engineering design process are very suitable for each other. There is problem identification, doing research, and solving the problem parts in problem-based learning. We are doing a similar thing, actually; I think they are naturally fit.
> **Ada:** I totally agree with Ece.
> **Defne:** I am actually a little hesitant. On the one hand, using a strategy that I do not know very well scares me. But it is an excellent opportunity for us to learn in the group…I think, I am also in favor of using problem-based learning **(video-recorded planning meetings, lesson study 4).**

After the planning phase, Ece's explanations became content-specific about using problem-based learning:

> I think the parts of the engineering design process and problem-based learning matched very well. For instance, there should be motivating and real-world, and open-ended question in problem-based learning, and we did it and enriched it by putting some criteria and limitations. My favorite part was exploring the problem and acquiring information step. We combined this step with researching the problem and prepared a science magazine for this. We integrated the KWL chart to help students learn sound and sound insulation. This was the first time I used the KWL chart. Students will use some basic mathematical concepts, do the measurements and make their decisions about their design by considering data by looking at graphs…Moreover, I think it will give us an advantage in terms of time because, in some lessons, we could spare enough time for the assessment **(pre-interview, 4).**

As seen above, Ece augmented her knowledge about the characteristics of problem-based learning and mentioned that her main reasons for choosing problem-based learning were being compatible with the engineering design process and providing context for integrating different disciplines.

Concerning design-centered teaching practices, Ece made a comparison with her first individual CoRe and explained that her first CoRe was lack of design-centered teaching practices and could not be considered a STEM lesson plan **(pre-interview, 4).** She talked about many design-centered teaching practices. For instance:

> We prepared a science magazine to make students explore the concept of sound insulation. For instance, we put an example article, "Why is the environment quieter when it snows?" They will research and infer that sound insulation materials should be soft and porous and use this knowledge in their designs **(pre-interview, 4).**

As seen above, Ece emphasized the importance of science content required to solve the engineering problem, which she ignored in lesson study 2 during the teaching phase. She was also aware of the importance of full iteration of the cycle by giving content-specific examples. She added that collecting and interpreting data would be crucial for their lesson to understand whether their solutions would solve the problem **(pre-interview, 4).**

Her focus was on science and other STEM disciplines regarding representations and activities. For instance, she talked about the importance of role-play as an activity in their lesson plan, which students would put into engineers and data analysis shoes. Moreover, she explained that the KWL chart would be effective in understanding their prior knowledge of the sound concept and revealing their misconceptions before starting the lesson. She was aware of using visual representations in terms of communicating the solutions:

> We will use the poster to share the solution part. Students will introduce their design and the results of data analysis by explaining how much budget they would use. They will also be asked to interpret the bar charts at this point. Every group will examine the other's studies. I believe using a poster will be effective in summarizing the students' works and will be helpful in re-designing part. We will make their jobs easier for the re-design part **(pre-interview, 4).**

Ece was able to talk about multiple modes of representation in science and other STEM disciplines and underlined the importance of creating opportunities for students to enhance their communication practices in science, engineering, and mathematics.

In terms of strategies for engagement with engineering concepts, she drew upon her experience in their previous lesson plan by stating:

> According to my observation, the least developed part of students' career awareness was collaborative work. Therefore, we prepared an animated video in which a group of engineers from different branches and scientists work together **(pre-interview, 4).**

Ece implemented the first version of the lesson plan. She employed the steps of problem-based learning as planned in the CoRe and completed it on time. Her instruction was enriched with many design-centered teaching practices. For instance, she started the lesson by introducing the open-ended engineering problem from a real-world context. The groups identified the criteria and limitations. She distributed the roles in the groups, such as engineers and data analysis. Then, students filled out the KWL chart and started investigating the problem using the science magazine, as seen in Figure 4.26.

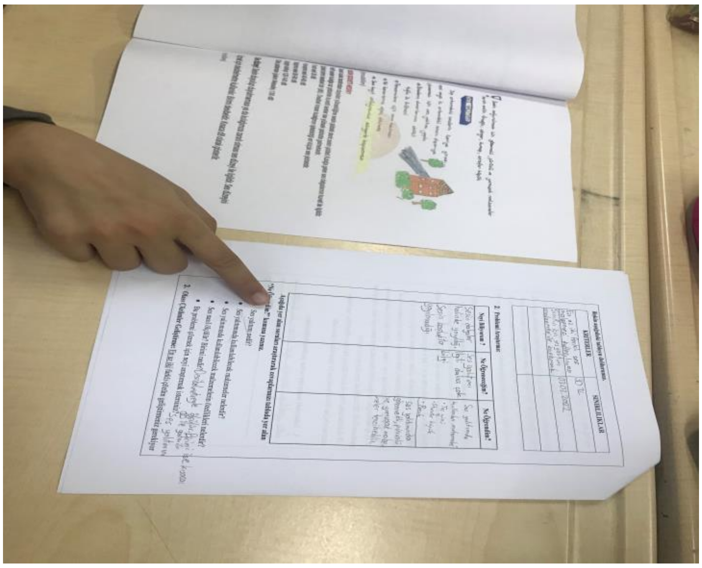

Figure 4. 26 Example of Students' Work in Lesson Study 4

Ece was able to manage the groups and encourage students to collaborate with others in this process. She was in the role of facilitator in these discussions to aid them in gaining necessary science content knowledge for their design solutions. The following dialogue was taken from one group:

> **Ece:** What do you think about the characteristics of sound insulation materials?
> **S1:** They absorb the sound.
> **S2:** Yes, they should be porous and soft.
> **Ece:** Why do you think so?
> **S2**: If it is rough, the sound might be reflected.
> **Ece:** Then, what are your alternative solutions for solving the problem?
> **S1:** We are still discussing, but we have talked about using bubble wrap since they have spaces between them. The sound could not travel in space. Moreover, using a sponge is also appropriate, I think. We will calculate our budget and then decide.
> **Ece:** You are doing okay; please fill out the decision table correctly while choosing your best solution **(researcher's pre-observation form, 4).**

The groups created and tested their design solutions. Ece placed the mobile phone in students' sound-insulated boxes and took measurements of decibel values with the help of the data analysis of the group. Then, she created a data collection table. Data analysis contributed to the drawing bar chart by transforming the data in the table into a chart. Then, some time was allocated to the groups for preparing their posters, and she applied conceptual re-designing combined with communicating the solution part. The following dialogues were taken from her instruction:

Ece: How your design solution met the criteria?
S1: We used three different materials, eggcup, felt, and cotton. We placed the materials inside the room. Our decibel value was 48, so it could be much better. Our budget was under the limit; it is 24 TL.
Ece: What would you like to change in your design?
S1: We had a problem with the cover. We did not consider putting sound insulator materials on the cover of the box as the other group did. Besides, we think we should use more soft material instead of felt, such as fiber **(researcher's pre-observation form, 4).**

As seen from the excerpt, she could not encourage students to re-building their products because of time limitations; however, she discussed the weakness and strengths of their designs verbally and asked students to explain the points that need to be improved.

Regarding the representations, the number of daily-life examples was increased in her instruction. For example:

Ece: Why do we need sound insulation?
S1: So that the sounds inside do not come out.
S2: We measured how much sound escaped from our sound-proof music rooms.
Ece: Yes, for example, have you seen the noise barriers on the roadside? There are many sound barriers in Izmir, for example, near the Hospital of Ege University. The purpose of building them is to block the traffic noise so that it would not bother the people living near that area. Or using trees as sound barriers on the roadway reduces noise pollution **(researcher's pre-observation form, 4).**

With respect to engagement with engineering concepts, she paid attention to using the engineering talk as a part of the lesson since students were in the role of engineers and data analysis. Additionally, she showed the animated video about engineers at work, as seen in Figure 4.27. After showing the video, she asked several questions, such as "What are the engineering branches that attracted your attention in the video". Ece underlined how the group of engineers collaboratively worked as they did. She also pointed out that engineers worked not only in construction areas but also in offices and industrial plants **(researcher's pre-observation form, 4).**

Figure 4. 27 Scene from Ece's Lesson in Lesson Study 4

After teaching, Ece gave nine points for the implementation of the lesson. She thought that managing time was one of the most significant advantages of using problem-based learning. The only suggestion provided by Ece was to integrate some technologies in researching the problem part **(post-interview, 4).**

Concerning design-centered teaching practices, she mentioned many of them. For instance, she reflected on the applying re-design part in her lesson as follows:

> I think we should revise the format of the poster and add a re-design part to it. I had the intention to apply the second test for their revised products, but there were several activities that I aimed to conduct in the following parts of the lesson. Therefore, I decided to employ a re-design part by discussing the strengths and weaknesses of students' designs **(post-interview, 4).**

She also explained that the science magazine activity worked really well to assist students' learning. Students learned about the science content needed to solve the problem through the magazine and the discussions in the group. She added that she felt more comfortable managing and guiding the groups during collaborative work. Ece indicated that there should be an empty box representing the uninsulated music room, which should be included in the data collection part. The bar charts should include data from the empty box; in this way, students might be provided a better opportunity to evaluate the effectiveness of their designs **(post-interview, 4).**

Furthermore, her explanations included representations specific to science, engineering, and mathematics. For example, she stated that:

> I found the use of the KWL chart very effective. It motivated the students toward the issue they would investigate. I realized that students connected the sound insulation topic to the thermal insulation topic in K part. Then, I guided the discussions carefully in this group and tried to correct them in researching the problem part. The other group noted that "we would like to learn more about the materials used in sound insulation". After seeing this statement, I realized that KWL is useful to support their learning. It is definitely appropriate for the steps of problem-based learning **(post-interview, 4).**

In the reflection meeting, Ece indicated that problem-based learning fit their purposes, and the teaching part deepened her understanding of the strategy. She suggested using some educational technologies to research the problem; however, the group members objected to the idea because of the limited technologies in the classroom. Secondly, she recommended using a re-design part in the poster format, which was accepted by the group members. Lastly, she mentioned that multiple measurements should be taken for the reliability of the results for each group, and there should be an empty box representing the uninsulated music room to compare students' designs. The group members participated in her idea and revised the flow of the lesson based on Ece's suggestion **(video-recorded reflection meetings, lesson study 4).** Her observation notes from the re-teaching part were in parallel with her explanations **(post-observation form, 4).**

In her post-individual post-CoRe, Ece utilized problem-based learning, which demonstrated her advanced knowledge of instructional strategies. With respect to design-centered teaching practices, she wrote an authentic engineering design problem in which students will work for the client and integrate the engineering design process. She used Predict-Observe-Explain to research the problem, and students conducted mini experiments to collect data and learn about the science concept used in their designs. In brief, she completed the entire cycle. Moreover, she utilized representations specific to science and other STEM disciplines, such as decision tables, video, and poster. Lastly, she used videos to promote students' career awareness in STEM fields **(post-individual CoRe).**

Ece's descriptions and her instruction demonstrated the features of the PCK-C category, which is PCK for STEM. She was able to suggest a different teaching strategy compatible with STEM in the last CoRe. She made progress in the preferences for using specific teaching strategies with content-specific details. Moreover, she was able to adopt a variety of representations and activities in science and other STEM disciplines in a balanced way. She employed many elements of design-centered teaching practices at the end of lesson study 4, which met the criteria of PCK-C at the end of the study.

4.1.3.4. Knowledge of Assessment

4.1.3.4.1. Lesson Study 1

Ece was the observer teacher in the first and second versions of the STEM lesson plan in lesson study 1; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

The analysis of Ece's pre-individual CoRe demonstrated that she concentrated only on assessing science content outcomes. She planned to use the rubric and peer evaluation form to understand whether the students achieved the objectives of the lesson. She did not consider assessing students' prior knowledge as well **(pre-individual CoRe).**

In the planning meetings, Ece focused on assessing the engineering design process with the suggestion of Deniz. Moreover, she offered to prepare a different rubric in which the groups would evaluate each other's work; however, the group members decided to create one rubric that the teacher would use after the lesson **(video-recorded planning meetings, lesson study 1).**

After the planning phase, Ece stated that they did not consider assessing students' prior knowledge. When she was asked to explain the match between the objective of the lesson and the content of the rubric, she said that:

> We expect students to develop a viewer to minimize the harmful effects of Solar eclipse. They will observe the Solar eclipse through the design, so our assessment was toward the product. Actually, our objective was too broad. I think it is suitable; maybe we can revise the objective and add a "create a product" statement. I have some question marks about the assessment **(pre-interview, 1).**

The abovementioned explanations showed that she had limited understanding regarding the parts of the STEM lesson that were worth assessing. She was not sure whether the content of the rubric would measure the objective stated in CoRe.

With respect to how to assess, she provided broad explanations as given below:

> I think using a rubric gives feedback to the teacher. The teacher might assess the whole process of the lesson through the rubric. There are many things to be considered to assess in the STEM lesson plan. Rubric enables objective assessment **(pre-interview, 1).**

Ece touched upon the fact that they preferred a rubric with formative purposes. Her assessment was general and included no content-specific details at the end of the planning meetings of lesson study 1.

During observation of the first version of the lesson plan, Ece wrote that students' prior knowledge about the Solar eclipse was assessed through some questions. She added that more time should be devoted to the assessment part at the end of the lesson **(pre-observation form, 1).** Her form did not display any evidence of formative assessment.

After observation of teaching regarding what to assess sub-component, Ece's knowledge remained unchanged. She again focused on assessing the engineering design process by giving fewer details **(post-interview, 1).** On the other hand, she put her concerns into words about the connection between objective and assessment as follows:

> I think we can reconsider the objective. We can write "design viewers to observe Solar eclipse. The objective was too broad for our lesson; therefore, I had difficulty in deciding whether the items in the rubric were assessing our lessons or not **(post-interview, 1).**

Her knowledge of assessment with respect to revision based on assessment started to evolve after observation of teaching. After assessing the students' engineering notebook through the rubric, she suggested revising the objective of the lesson. On the other hand, she did not focus on assessing students' products or the moments that Deniz provided feedback to the students in her explanations.

In the reflection meetings, the group assessed the engineering notebooks. Ece was one of the participants suggested writing some additional items into a rubric, such as communicating the solution, and the group member accepted her idea **(video-recorded reflection meetings, lesson study 1).** She was actively involved in the discussion about revising the objectives **(see knowledge of curriculum in Ada's section).** This showed that her knowledge of assessment with respect to revision based on assessment started to evolve. The group also discussed assessing students' prior knowledge in science and engineering, and Ece did not make any comments at this point **(researcher’s field notes, reflection meetings of lesson study 1).** However, she reflected on this discussion in her observation form. She jotted down that Ada assessed students' prior knowledge in science and engineering and indicated that revision of the objective made the assessment more suitable **(post-observation form, 1).** Participants also discussed the importance of formative feedback, especially in producing alternative solutions and choosing the best solution based on the lower grades in the rubric. However, Ece could not catch and note these points during the observation of teaching.

In conclusion, the analysis of pre-individual CoRe depicted that Ece was in the PCK-A category at the beginning of the lesson since she assessed only science content outcomes. On the other hand, she made a transition from the PCK-A to the PCK-B category at the end of lesson study 1. She started to talk about assessing learners' understanding of science and engineering content; however, the emphasis was on the engineering design process. She did not touch on assessing students' products through a criteria list or rubric. Moreover, she did not intend to employ multiple assessment strategies. These features met the criteria of the PCK-B category.

4.1.3.4.2. Lesson Study 2

Ece was the teacher of the revised version of the STEM lesson plan in lesson study 2; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

In the planning meetings, Ece was not involved actively in the assessment-related discussions. She generally listened to other group members' ideas and indicated whether she agreed or not. For instance, Defne suggested preparing short-answered questions to assess the mathematics objectives of the lesson, and Ece liked the idea **(video-recorded planning meetings, lesson study 2).**

Although Ece did not make suggestions in the planning meetings, she addressed assessing science and mathematics content after the planning meetings as follows:

> We planned to use a concept cartoon after employing the engineering design process to check whether misconceptions about speed would be eliminated. We also have some short-answered questions about speed in the activity sheets that were going to be carried out in the Application phase. These will give a clue to the teacher about students' learning about the speed concept. Similarly, we have another short-answer question in REACT phase that would help us to assess mathematics-related objectives **(pre-interview, 2).**

Ece concentrated more on how to assess students' learning in science content outcomes, and mathematics remained in the background in her explanation.

Moreover, Ece talked about assessing engineering outcomes and students' products:

> We again use the rubric to assess the engineering design process steps objectively. The teacher will use it right after the lesson to assess engineering notebooks. In the first lesson plan, most groups got lower grades in generating possible design solutions. We realized it, and then Ada put more emphasis on this part in the second version of the lesson…We have another rubric for students' products, unlike the previous plan. If their car designs complete the whole track, they will get 40 points. If their design completes between one meter and two meters, they will get 30 points, and so on. We can compare which design solution will solve the problem better at the end of the lesson. We can determine the car with the highest speed that meets the criteria **(pre-interview, 2).**

The abovementioned explanations showed that Ece started focusing on the engineering design process and students' products. Her assessment was general and did not include content-specific details.

Her knowledge of assessment with respect to what to assess began to become varied compared to the previous lesson study cycle. Regarding how to assess sub-component, she mentioned formative assessment methods, especially rubric and summative methods, that would be applied at the end of the lesson. She provided specific examples of the reasons for choosing the rubric in the lesson. Moreover, Ece was aware of how the results of the assessment helped them in putting more emphasis on some parts of the lesson. This demonstrated her improved knowledge regarding revision in instruction based on the assessment **(pre-interview, 2).** Ece did not mention diagnostic assessment to elicit students' prior knowledge in science and other STEM disciplines or the use of word association after the planning meetings.

During the observation of the lesson, Ece noted that the concept cartoon was not used effectively because of time management problems. She also noted that the rubric for assessing students' products was not applied in the lesson. She added that some questions prepared for summative purposes were given as homework **(pre-observation form, 2).** Ece was not aware of assessing students' prior knowledge or how Defne moved between the groups to support students' ongoing studies and provided feedback for them for formative purposes.

After observation of teaching, Ece gave a few details about the assessment of the STEM lesson. She thought that the place of the concept cartoon might be changed, and the rubric for assessing students' designs should be applied after completing the engineering design process **(post-interview, 2).** She did not provide an understanding of how the objective of the lessons was aligned with the assessment methods they prepared. Moreover, no suggestions were made by Ece in the reflection meetings. The **(researcher's field notes, reflection meetings of lesson study 2).**

Ece was the teacher of the revised version of the lesson plan. She applied the word association test for diagnostic purposes in the Relating part of REACT right after showing the video, as discussed in the reflection meeting. She divided students into groups of two and asked them to complete a word association test in five minutes. Then, she took answers from the groups. There were several answers, such as velocity, time, running, meter, etc. She noted down the answers to the board. However, she could not be able to modify the flow of the lesson based on the answers. The misconceptions emerged in this process, and she did not re-visit students' answers showed up in this phase. Similarly, she did not employ concept cartoon to reveal whether students' misconceptions about science were eliminated or not. The assessment sheet, including the multiple-choice and open-ended questions in mathematics content, was given as homework because of time limitations (**researcher's post-observation form, 2).**

Lastly, Ece neither presented the criteria for assessing students' products nor applied them after students' completed their designs. She did not integrate it into the lesson. On the other hand, she walked around the groups, observed students' performance and discussion, and provided feedback to the groups, especially in proposing solutions to the problem part (**researcher's post-observation form, 2).** It could be inferred that Ece could not be able to apply many assessment methods that they prepared in planning meetings during teaching. In the re-reflecting phase, Ece indicated that she could not arrange the time properly; therefore, she gave up the assessment part to complete the engineering design process. She added that she forgot to employ a rubric for assessing students' products since it was not implemented in the previous version of the lesson plan, too **(video-recorded reflection meetings, lesson study 2).**

In brief, Ece's explanations included different disciplines regarding what to assess component; however, her focus was more on science content outcomes, especially in the teaching phase. She did not pay attention to assessing students' products, their prior knowledge, and mathematics content. Her explanations included less-details and could not be able to tie fully to the objectives of the lesson. These features in her instruction met the category of the PCK-B after completing lesson study 2.

4.1.3.4.3. Lesson Study 3

Ece was the observer teacher in the first and second versions of the STEM lesson plan in lesson study 3; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

In the planning meetings, Ece was more of a listener and participated in friends' ideas **(researcher's field notes, planning meetings of lesson study 3).** She talked about using the diagnostic tree to assess science objectives and a rubric for the engineering design process after the planning meetings:

> I have not used a diagnostic tree before. I think it is very suitable for detecting misconceptions through the diagnostic tree. We added some items, such as "wools are a source of heat," based on the misconceptions that might emerge during the lesson. If students choose this exit in the diagnostic tree, the teacher of the lesson might provide the correct explanations…We have been using the rubric from the beginning of the study, and it is really helpful. We objectively assess the whole process; we put each part of the lesson into the rubric. For instance, if students test their designs but do not fill out the data collection table, they will get two points. In a similar manner, if they share their findings by referring to criteria and limitations, they will get three points. If one of them is missing, they will get lower points from the rubric. We have an objective regarding designing a product through the engineering design process, and we will assess it using the rubric **(pre-interview, 3).**

As seen above, Ece was able to concentrate on assessing different parts of the STEM lesson after the planning meetings of lesson study 3. Moreover, she started to talk about the alignment between the objectives and the parts of the lesson worth assessing. In terms of how to assess, Ece talked about formative and summative assessment methods and mentioned several types of instruments, such as poster, self-assessment, budget sheet, Draw an Engineer Test, rubric, and diagnostic tree. Her knowledge was deepened about how they would use the results of the assessment as follows:

> We will apply "Draw an Engineer Test" in our lesson. As far as we observed, students tend to think of engineers as males working in the construction area. We have a chance to assess their learning on this topic. Then, we can re-arrange our lesson based on the result of this test **(pre-interview, 3).**

Ece observed Ada's lesson and wrote that informal questioning regarding science content was used at the beginning of the lesson. She considered the diagnostic tree appropriate for the student level, and the teacher of the lesson applied it correctly. She realized that the self-assessment sheet was not implemented. Regarding assessing students' products, she noted that the thermos designs were evaluated verbally by considering the data collected by students (**pre-observation form, 3).**

While reflecting on the lesson, Ece pointed out the importance of assessing students' products:

> We should be more precise about assessing students' thermos designs. We should explain to them how their design will be evaluated, and we will put emphasis on the data collection process. For instance, we should explain that they will take multiple measurements, and we are looking for the thermos design with the least temperature difference that meets the criteria and limitations at the same time **(post-interview, 3).**

After observing teaching, Ece extended her understanding of assessing students' products and informing students about the assessment criteria.

In the reflection meetings, Ece suggested applying the diagnostic tree individually rather than in a group activity; however, Ada objected to this idea. She advocated that it took too much time if applied individually, and discussions among the groups were productive while choosing the correct exit in the diagnostic tree **(video-recorded reflection meetings, lesson study 3).** Ece and Ada triggered discussions in the group that assessment criteria should be provided to the groups before the design process. During the observation of re-teaching, Ece noted that the teacher could not implement some assessment methods, and she criticized that Deniz explained the criteria for assessing students' products after students finished them **(post-observation form, 3).**

It could be stated that Ece made a transition from the PCK-B category to the PCK-C category with respect to knowledge of assessment after completing lesson study 3. She concentrated on assessing students' prior knowledge of science, science content outcomes, engineering design process, and students' products in a balanced way and giving content-specific explanations. She underlined that how students' products will be evaluated should be provided to the students after introducing the engineering design challenge. She emphasized the connection between assessment and the objectives of the lesson and mentioned a variety of assessment strategies. These features in her instruction met the category of PCK for STEM in terms of knowledge of assessment.

4.1.3.4.4. Lesson Study 4

Ece was the teacher of the first version of the STEM lesson plan in lesson study 4; therefore, the findings were from her pre and post-interviews, observation form, planning, and revision meetings.

Ece was actively involved in the discussion regarding assessment in the planning meetings. Exemplifying dialogues about assessing students’ products were given below:

> **Ece:** We should develop a criteria list to assess students’ insulated music room.
> **Deniz:** But we have a rubric?
> **Ece:** No, I did not mean it. It is for assessing the engineering design process objective. We should prepare something specifically for the insulated music room. Whether their music room included at least two different insulator materials or not exceeding the budget, developed as a result of teamwork, and so on. To check whether their designs meet the criteria and limitations.
> **Ada:** Yes, we should prepare and present this list to the students right after introducing the engineering problem. It does not make sense when you present it after solving the problem **(video-recorded planning meetings, lesson study 4).**

As seen from the excerpts above, Ece paid attention to assessing the engineering design process and students' products, similar to the previous lesson study cycle. She was able to justify the reasons for using the rubric by giving specific examples. She added that they would assess the mathematics content by the item prepared specifically in the rubric. Moreover, she underlined that the objective of increasing students' career awareness in engineering would also be assessed in their last lesson **(pre-interview, 4).**

Moreover, she emphasized the importance of assessing students' prior knowledge of science content as follows:

> We generally elicited students 'prior knowledge through the questions we asked at the beginning of the lesson. This will be the first time I will apply the KWL chart, and we will have a chance to understand what they already know about sound insulation **(pre-interview, 4).**

Concerning how to assess, Ece talked about different assessment methods, such as the KWL chart, word association test, multiple-choice test, and budget sheet. She talked about how they would utilize summative assessment:

> We prepared a multiple-choice test through Kahoot! We aimed to assess students' understanding of sound insulation. We supported questions with daily-life examples and added the properties of sound insulator materials to the questions. It will be applied to the group of students, and we will provide the results of the test to the cooperating teacher. It will be a sort of quiz. I also plan to talk about the items in the question after students give their answers. If there is any misunderstanding, I can try to fix it immediately. This is one of the main reasons we choose Kahoot instead of applying it in pencil-paper format **(pre-interview, 4).**

As seen above, Ece planned to apply summative assessment and formative assessment in her lesson. She explained their preferences in choosing a particular assessment and the method with content-specific details.

In the teaching phase, Ece utilized diagnostic assessment through informal questions and the K part of the KWL chart about sound and propagation of sound. Moreover, she used informal questioning to elicit students' understanding of the steps of the engineering design process and then explained it using the poster.

Regarding formative assessment, Ece monitored the students' performance during the design process and tried to complete their deficiencies regarding the topic. For instance, some groups were discussing whether the principles of sound insulation or reflection should be used in the design process; Ece summarized the topic and showed the related parts in a science magazine to make students investigate further. Then, based on this observation, she stressed this point in other groups **(researcher's pre-observation form, 4).**

Regarding assessing students' products, she presented the criteria list they prepared and informed students that their sound-insulation music room designs would be assessed based on this list. Moreover, she verbally provided feedback about students' designs as follows:

> **Ece:** Yes, we all completed the testing process. Here is the data we collected (referring data collection table and bar chart). There are different decibel values, as you have seen. How do you interpret these bar graphs?
> **S1:** The third group's decibel values show little change; they solved the problem in the best way.
> **Ece**: Yes, but remember the criteria list. We should consider whether your designs meet the criteria and limitations in communicating the results part **(researcher's pre-observation form, 4).**

Additionally, she applied the word association test on engineering content (Figure 4.28) individually after completing the design process and showing the animated video about engineers and scientists. She asked students to fill out the test and gave them five minutes. After, she took some answers as follows:

> **Ece:** What would our lives be without engineers? I want to hear your answers.
> **S1:** There would be no computers. Or the computers would be huge.
> **S2:** Cars would not exist.
> **S3:** Broken things could not be repaired.
> **S4:** There would be no buildings.
> **S5:** There would be no technological developments.
> **S6:** Sound-insulated buildings would not exist.
> **Ece:** You did great. None of these things would exist without engineers **(researcher's pre-observation form, 4).**

Ece skipped this assessment part quickly, and she did not realize some answers, such as "broken things could not be repaired."

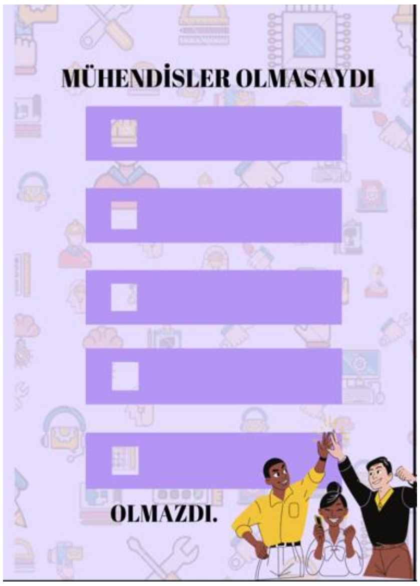

Figure 4. 28 Example of Word Association used in Lesson Study 4

Regarding summative assessment, Ece carried out a multiple-choice question at the end of the lesson, as seen in Figure 4.29.

Figure 4. 29 Scene from Ece’s classroom using Kahoot! in Lesson Study 4

The groups answered the questions in Kahoot! The following dialogue was taken from her instruction:

> **Ece:** As far as I see, one group considered that the sound insulation materials should be rough and thin. Why do you think so?
> **S1:** We pressed the wrong button in a hurry.
> **Ece:** It is okey. What have you discussed in the group then?
> **S1:** We were going to select the "rough and smooth" answer.

> **Ece:** Why?
> **S1:** Because the group that used eggcup and fibre had lower decibel values. They absorbed sound better **(researcher's pre-observation form, 4).**

After teaching, Ece reflected on her instruction with respect to assessment and mentioned the use of word association to assess engineering outcomes:

> I think their answers were very good. They said engineers work in teams, which is one thing we emphasized in the animated video. They directly explain that technology and its products would not exist without engineers. There was too much connection with our topic. For instance, there would be no thermal-insulated buildings, just like there would be no sound-insulated buildings. I cannot say that I have detected a misconception here. I think we assessed the objective in the best way **(post-interview, 4).**

She also mentioned that the use of Kahoot, criteria list, and rubric were very effective and did not propose any changes regarding assessment methods and the time of the assessment **(post-interview, 4).**

In the reflection meetings, Ada expressed concerns about the word association. She said that some misconceptions emerged, such as engineers fix things, which should be cleared up immediately. She added that more feedback should be given while implementing it. Ece participated in her idea and indicated that she had not realized the student's answer **(researcher's field notes, reflection meetings of lesson study 4).** It could be inferred that Ece's knowledge of assessment concerning how to assess advanced after the reflection meetings.

In her post-individual CoRe, Ece focused on assessing science content outcomes and engineering outcomes equally. She also concentrated on students' prior knowledge in science and engineering through informal questions. She prepared a rubric for assessing students' products and a self-assessment group worksheet that groups assessed their performance during design process and a Kahoot including multiple-choice questions. To sum up, Ece's knowledge of assessment was consistent with the prior lesson study cycle. She was in the PCK-C category at the end of lesson study 4. She was able to align closely with the objectives and parts of the lesson worth assessing in multiple disciplines of STEM by giving them equal weight. She employed diagnostic, formative, and summative assessment and was able to modify her lesson by considering the results of the assessment. Her assessment included a variety of methods to assess different parts of STEM lessons that reflected the features of the PCK-C category.

4.1.3.5. Summary of the Findings for Case 3

The constituent components of Ece's PCK for STEM showed the features of the PCK-A category prior to the study. She wrote only science objectives, considered learners' difficulties in science, and prepared a rubric as an assessment in line with the science objectives when asked to prepare a STEM lesson plan. She did not utilize any particular teaching strategy. It could be inferred that she had topic-specific PCK at the beginning of the study. On the other hand, she made a transition to the PCK-C category with respect to all components of PCK for STEM at the end of the study. The time of the development of each component showed some differences. Table 4.4. presents Ece's development of PCK for STEM in each lesson study cycle.

Table 4. 4

Ece's Development of PCK for STEM in Four Lesson Study Cycles

	Before the Study	**Lesson Study 1**	**Lesson Study 2**	**Lesson Study 3**	**Lesson Study 4**
Curriculum	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**
Learners	PCK-A	PCK-B	**PCK-C**	**PCK-C**	**PCK-C**
Instructional Strategies	PCK-A	PCK-B	PCK-B	**PCK-C**	**PCK-C**
Assessment	PCK-A	PCK-B	PCK-B	**PCK-C**	**PCK-C**

After completing lesson study 1, all components of Ece's PCK for STEM switched from the PCK-A to the PCK-B category simultaneously, as seen in Table 4.4. She started to talk about the integration of different disciplines; however, she mainly concentrated on one discipline of STEM, and the coherence among STEM disciplines was less developed. For instance, she mentioned teaching strategies compatible with STEM with limited understanding, did not discuss many-design-centered teaching practices and touched on representations specific to engineering.

Moreover, some of the PCK for STEM components for Ece moved to the PCK-C category, while some remained in the PCK-B category at the end of lesson study 2. For example, Ece was able to establish objectives for science, engineering, and mathematics and connect these disciplines more apparently, and elaborate her understanding of science, mathematics, technology and design curricula. She also paid attention to learners' misconceptions and difficulties in science and other STEM disciplines in an equal way in her teaching and explanations. On the other hand, she faced some difficulties in explaining how particular teaching strategy and STEM education harmonized and was not able to implement many design-centered teaching practices, such as learning from failure. She paid less attention to assessing students' performance during the engineering design process and students' products than to assessing science content outcomes.

Referring to Table 4.4, all PCK components were improved for Ece after attending lesson study 3 and lesson study 4. She was able to balance STEM disciplines as a result of participating in lesson study cycles. For example, she was able to enrich her instruction with many design-centered teaching practices, used activities and representations specific to science and other STEM disciplines, and utilized a variety of assessment methods such as word association test, criteria list, rubric to check learners' understanding in different disciplines of STEM education compared to the previous lesson study cycle. It could be concluded that Ece's PCK for STEM consisted of more coherence among STEM disciplines at the end of the study.

4.1.4. Case 4: Deniz

4.1.4.1. Knowledge of Curriculum

4.1.4.1.1. Lesson Study 1

Before starting to lesson study cycles, Deniz chose two objectives from the 8th grade science curriculum, "students will be able to classify elements as metals, semimetals, and nonmetals on the periodic table and explain how groups and periods are formed in the periodic system." He did not utilize the design process, and no other objectives were observed in his pre-individual CoRe. Furthermore, he did not relate the topic with other science topics and other STEM disciplines. After the planning meetings, he explained his thoughts on the objectives in pre-individual CoRe as follows:

> While preparing the STEM lesson plan, I was studying for KPSS, and I focused on the periodic table at that time. The topic was difficult for me, and I also thought that students might have misconceptions about this topic like me. This is the reason why I chose these objectives. I considered that I could use the STEM education approach, and students could work in groups and compare the parts of the periodic table with each other and learn. I mean, one group for metals, one group for nonmetals, etc. **(pre-interview, 1).**

As seen above, Deniz did not possess a basic understanding of STEM education, and this was mirrored in his choice of selecting objectives. He preferred to choose an objective with limited subject matter knowledge. In other words, he chose objectives for the STEM lesson plan to improve his subject matter knowledge about the periodic table before starting the study.

Deniz was the teacher of the first version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz focused on objectives, including the verb "model," and proposed to make a Solar eclipse model. His naïve understanding of design-centered teaching practices influenced his choice of science objectives. At the beginning of the initial planning meetings, the group participated in his idea; however, as the discussions went deeper in the next meetings, Ada objected to his idea by emphasizing there should be alternative solutions to the problem and creating a Solar eclipse model would not meet these criteria **(video-recorded planning meetings, lesson study 1).** The example dialogues about this point were provided in Ada's section.

Deniz's primary reason for choosing objectives from the science curriculum was subject matter knowledge about the Solar eclipse. He thought that having solid subject matter knowledge about this topic led them to continue with this objective **(pre-interview, 1).** His explanations for setting objectives for STEM lessons were too general and did not include basic features of STEM education. Moreover, he said that he had not examined the mathematics curriculum yet.

In relation to relation to another topic in science, he did not know anything about the prior and the following topics in the curriculum. He said: "students should know about the Earth, universe, and stars. Actually, it looks like a fourth-grade topic to me, but I should check" **(pre-interview, 1).** In other words, he did not realize the curricular saliency because stars and the universe were the 7^{th} grade topics. No relation to other STEM topics was observed in his explanations after the planning meetings of lesson study 1.

Deniz was responsible for teaching the first version of the lesson plan in lesson study 1. He did not make relation to other science topics throughout his lessons. Moreover, he superficially connected to Solar eclipse topic to other STEM topics. For instance, he explained, "We are going to design Solar eclipse viewers by utilizing the engineering design process." However, he did not effectively relate the budget sheet and engineering design process. For instance, whether the Solar eclipse viewers, which were made at the lowest cost, were functioning was not emphasized during the lesson **(researcher's pre-observation form, 1).**

After teaching, Deniz questioned whether he should touch upon the eye topic while talking about how Solar eclipse viewers protect our eyes as follows:

> I am not sure that students know the answer to the question of what a cornea is. Students should know the cornea and iris so I can explain this topic. It is about sense organs, but I do not know in which grade level it is covered **(post-interview, 1).**

The eye topic was placed in the following units of 6^{th} grade. As seen above, his knowledge of curriculum with respect to relation to other science topics remained unchanged after teaching. On the other hand, he started thinking about revising the science objectives they wrote after the teaching. He explained that:

> Our objective was "observe the Solar eclipse." We did not write additional explanations for the objective. In fact, according to this objective, the teacher would use ready-made Solar eclipse viewers or make students design one (viewer). It is up to the teacher. I thought that why we did not cover the whole process because we had engineering practices to achieve. Our main objective is a Solar eclipse, but we can think about other objectives as supporters **(post-interview, 1).**

Deniz began to consider that the science objectives were not comprehensive enough to cover STEM lessons; however, he still had limited knowledge of curriculum about setting objectives for other STEM disciplines. He did not have concrete suggestions about how to modify objectives after teaching.

In the reflection meetings, Deniz was not very active in objective-related discussions as a teacher of the lesson. The other group members put ideas about revising the objective, and Deniz just participated in the final idea **(researcher's field notes, reflection meetings of lesson study 1).**

In brief, Deniz's knowledge of curriculum exhibits the features of the PCK-A category prior to the study. He set objectives only for the science discipline, and no relation to other science topics was found in his pre-individual CoRe. After attending the first lesson study cycle, his knowledge of curriculum shifted to the PCK-B category. He started to speculate about alternative objectives for STEM discipline rather than science after teaching but they were not explicit. His reasons for choosing objectives were vague and he did not provide understanding about the relation of the topic to other science topics and other STEM disciplines which were the evidence for the PCK-B category at the end of lesson study 1.

4.1.4.1.2. Lesson Study 2

Deniz was the observer teacher in lesson study 2; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz did not offer any objectives. Instead, he criticized what the group members suggested. For instance, Ece and Defne offered to continue with balanced and unbalanced forces, while Ada suggested picking up objectives regarding speed. Deniz commented that he favored Ada's idea because of students' misconceptions. He started to provide detailed explanations about the reasons for choosing science objectives compared to the previous lesson study cycle. Moreover, Deniz suggested writing objectives related to the engineering design process for the first time in the study in the planning meetings and indicated that:

> **Ece:** I think we should write "designs the vehicle that completes the racetrack in the shortest time."

> **Deniz:** Instead of it, I think we should "design a product by using the engineering design process." It is more comprehensive and suitable for our purposes.

When he was asked for further explanations about the reason for setting objectives for engineering, he stated that:

> Our courses (in the undergraduate engineering program) always involved design. The first-year objectives in this program were really similar to the technology and design curriculum. We always designed, thought critically and analytically, re-design, and applied the principles of reverse engineering. After experiencing the first plan and engaging in the discussions in the group, I realized that the engineering notebook was very similar to what we did in the engineering program **(pre-interview, 2).**

As seen above, Deniz mentioned his prior experiences as a former engineering student and combined these experiences with classroom experiences as a teacher. As a result, he proposed to set objectives for other STEM disciplines in the planning meetings. Furthermore, he began to criticize the mathematics curriculum:

> I checked on the mathematics curriculum after Defne mentioned writing mathematics objectives. I thought students had already learned about creating line graphs, but I noticed they had not. This surprised me because it was placed in the 7^{th} grade level in the mathematics curriculum… The technology and design curriculum seemed different to me. What caught my attention was that there were objectives in this curriculum that we wanted to achieve in our STEM lessons. I was shocked by how this curriculum was aligned with our purposes while preparing our lesson plans **(pre-interview, 2).**

In addition to setting objectives for the engineering design process, Deniz noticed how they could utilize mathematics objectives for their STEM lesson plan with the help of discussions in the group meeting. His understanding of the curriculum with respect to setting objectives in science and other STEM disciplines started to improve. Furthermore, he was conscious of the limitations of the science and mathematics curriculum. He added:

> Our curriculum (science curriculum) had some limitations; for example, it said not to cover the velocity concept. In mathematics, there were also some limitations. However, I feel more confident about handling the limitations of the science curriculum compared to the mathematics curriculum. I am more comfortable about extending the limitations of speed and velocity concepts because I know that the concept of speed could not be learned without mentioning velocity because of common misunderstandings about these concepts **(pre-interview, 2).**

As seen above, Deniz's knowledge of learners interacted with his knowledge of curriculum, and his awareness was increased about the scope of the science curriculum to eliminate students' misconceptions compared to lesson study 1. Although he established connections between science and other STEM disciplines, his explanations did not touch upon relations with other science topics.

Deniz observed the first version of the lesson plan. Although Defne's lesson included clear connections between science and mathematics and engineering objectives, Deniz ignored this issue in his observation form. He used general terms such as "the topic was connected to the previous science topic" **(pre-observation form, 2).** It could be referred that he did not notice what he talked about relating to the objectives of mathematics and engineering in the pre-interview.

While asked in the post-interview, he did not provide any explanations about this point too. He had no further suggestions about revising the objectives after observation of the lesson.

The reflection meeting included discussing modifying the science objectives by removing limitations and adding mathematical formulas for the speed concept. Deniz did not express an opinion about this issue; he participated in the group's ideas **(researcher's field notes, reflection meetings of lesson study 2).**

While observing the revised version of the lesson plan, Deniz noted that the teacher of the lesson established a connection between science and engineering objectives through the use of the engineering design process. He also wrote that removing limitations from the objectives made the lesson more effective in terms of handling students' misconceptions **(post-interview, 2).**

To summarize, Deniz's knowledge of curriculum was improved to some extent, indicating alignment with the PCK-B category after completing lesson study 2. The planning meetings were influential with respect to setting objectives for other STEM disciplines. He began to mention writing engineering objectives and considering a mathematics curriculum; however, his emphasis was still more on science-related objectives. He superficially talked about the need for writing objectives for other STEM disciplines, and no content-specific details were found in his understanding.

Moreover, he related the topic to other STEM disciplines with some limitations and had some problems relating the other topics in science which were the features of the PCK-B category.

4.1.4.1.3. Lesson Study 3

Deniz was the teacher of the revised version of the lesson plan in lesson study 3; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz suggested an activity about designing a thermal insulated and full-sized animal house for birds or cats. His idea generated a discussion in the group, and participants did not participate in his opinion as follows:

> **Deniz:** Creating thermal-insulated buildings is very common. We can think about designing a shelter for animals. For example, for birds. We can make students create thermal insulated cages so that birds can live outside in winter. They can create a real-size cage.
> **Defne:** I am thinking of the same objective, but I am closer to thermos as an engineering design problem. I think the logic of the cage is very different. How do we make the cage thermal insulated? Can't we think of it as a closed box?
> **Deniz:** I think designing a cage is based on a daily-life problem. Maybe we might concentrate on animals in general, not consider birds.
> **Defne:** But I think the optimum temperature at which they should live is critical. For example, will we choose an animal that lives on the poles, or will we choose from the animals we see on the street? It is an important point, and it is not in the scope of our objective **(video-recorded planning meetings, lesson study 3).**

The participants advocated that many variables must be considered while designing the full-sized animal house. Deniz gave up his idea after intense discussions He was asked to explain his initial thoughts about the objective further, and he stated that:

> I have searched for sample STEM lesson plans on thermal insulation concepts and was inspired by one of them. I thought that we could effectively integrate mathematics while designing an animal house. However, my friends raised their concerns during discussions, and they were right on many points. For example, which animal would we choose, or the animal house would be full-sized, how could we place the animal, and what is more important, the testing prototypes part would be ineffective and be disconnected from real life. At first, I did not enjoy the idea of designing a thermos. Then, I realized that students would use many different combinations of thermal insulator materials and might create different thermoses to be tested. The final version of the lesson plan is better than my initial suggestion **(pre-interview, 3).**

As seen above, Deniz considered basic features of STEM education while choosing objectives, such as proposing more than one solution and testing based on daily-life issues. It could be inferred that he was able to extend the reasons for choosing science objectives for STEM lessons compared to previous lesson study cycles. Moreover, Deniz's knowledge of curriculum improved with respect to understanding the objectives of the curriculum. He could explain why they needed to modify science objectives in CoRe as follows:

> When we asked who the engineer was in the classroom, students tended to say, "civil engineers." In the same manner, if we ask them what insulation is, they most probably only consider "buildings." The curriculum focused on thermal insulation only in buildings. We want to change this understanding by revising the objective. Engineering design challenge about creating thermos would serve our purposes. After the lesson, students will think about organ transplant bag, how the organs are transferred, and why don't ice creams melt when moving to another city. They will understand the science and engineering behind these questions **(pre-interview, 3).**

Deniz underlined applying science and engineering practices as the main reasons behind revising the science objective. On the other hand, he had little general knowledge of the mathematics curriculum. He did not demonstrate a more profound understanding while talking about engineering-related objectives as well:

> In the first two STEM lesson plan, we tried to make students understand who an engineer is and what engineering is. There was little emphasis on career awareness. We aimed to develop career awareness with this lesson plan and wrote objectives **(pre-interview, 3).**

As seen above, his rationale for writing the engineering objective was not solid. Additionally, Deniz had difficulty relating the topic to other science topics and other STEM disciplines in his explanations, and he could not provide answers to this question when asked **(pre-interview, 3).**

In parallel with his statements in pre-interviews, Deniz did not recognize the relation of the topic with other science topics during his observation. He considered the connection between science and other STEM disciplines sufficient, but no specific instances were noted by him **(pre-observation form, 3).**

After observation of teaching, he did not have any suggestions about revising the objectives; however, he began to consider vertical relations in the science curriculum and advocated that the teacher of the lesson should address the particulate nature of topics, which was the topic before thermal insulation, to make students understand the thermal insulation concept better **(post-interview, 3).**

Deniz was responsible for the revised version of the STEM lesson plan in lesson study 3. He reflected his observation of teaching in his instruction. The below conservation was taken from his classroom:

> **Deniz:** I have a question. I have two solids in my hand. One of them is a conductor, and one of them is an insulator. Why do you think so?
> **S1:** Insulators have regular particles, but conductors have discrete particles **(researcher's post-observation form, 3).**

He delved into the details of solids, liquids, and gases as he realized and mentioned in the post-interview. On the other hand, he had limited knowledge of curriculum in relation to other science topics. The below conversation was taken from his classroom:

> **S1:** Why did aluminum foil not burn when we poured hot water into our thermos design?
> **Deniz**: It is about melting points. The melting point of aluminum is high. You will learn about them in high school **(researcher's post-observation form, 3).**

Students had already learned about the concept of melting point in the previous grade, and Deniz did not have enough knowledge to make relations between science topics during his lesson.

To conclude, the abovementioned features met the PCK-B category at the end of lesson study 3. He was able to give detailed explanations for science objectives but less detailed in other STEM disciplines, and content-free explanations were observed in his statements. The focus was still on science content, and the objectives of other STEM disciplines were mentioned superficially. Moreover, the content of the lesson is related to other science and STEM disciplines with some limitations.

4.1.4.1.4. Lesson Study 4

Deniz was an observer teacher in the first and second versions of the STEM lesson plan in lesson study 4; therefore, the findings regarding knowledge of assessment were from her pre and post-interviews, observation form, planning, and revision meetings.

In the planning meetings, Ada triggered the discussions in the group in terms of choosing science objectives. She suggested using objectives related to sound insulation, and all group members participated in her idea without presenting any alternative ideas. However, Deniz directed some questions to the group members, for instance, whether they would cover the objective about acoustic applications (the objective following sound insulation) while preparing CoRe. This situation showed Deniz's advanced knowledge about the scope of the science curriculum. The group decided not to include acoustic applications in their CoRe because of time considerations. What was different from the previous cycles was that Deniz suggested writing mathematics objectives (example dialogue was given in Defne’s section). He proposed that groups should compare their data through the use of bar charts. However, he added that he did not possess enough knowledge of in which grade level creating a bar chart objective was placed in the mathematics curriculum **(researcher’s field notes, planning meetings of lesson study 4).** He further explained his ideas for setting objectives for mathematics:

> We must establish the relationship between graphics and design and make comments. After students will create their graphs, how they interpret the graph is really important. We can think of graphs as a summary of the design process **(pre-interview, 4).**

As seen above, Deniz mentioned discipline-specific details about writing mathematics-related objectives. He added a few ideas about the objectives of other STEM disciplines; however, he did not have control over the scope of mathematics and engineering objectives. It could be inferred that Deniz was able to connect science, engineering, and mathematics with some limitations. When he was asked to compare his pre-individual CoRe and the last collective CoRe, he stated, "I only wrote objectives from one discipline (in pre-individual CoRe); it was a regular science lesson plan". He thought engineering objectives were needed to solve daily life problems **(pre-interview, 4).** His statements were too broad and did not include key features of STEM education.

Regarding other science topics, he demonstrated slight improvement at the end of the planning meetings. He mentioned that students should have learned that sound is an energy and the unit of sound **(pre-interview, 4).**

While observing Ece's lesson, Deniz's understanding was mirrored in his observation form. He did not write any observations about how Ece related the topic to other science topics. He only noted that the connection between science and engineering was adequate during the lesson **(pre-observation form, 4).**

After observation of teaching, Deniz did not offer any changes in the objectives of the lesson **(post-interview, 4),** and the group also shared the same opinion **(researcher's field notes, reflection meetings of lesson study 4).**

Deniz prepared post-individual CoRe by choosing science objectives from 7th grade and focused on astronomy topics. He directly took the objectives from the science curriculum, such as "prepare and present a basic model of the telescope and explain the function of the telescope". He tended to choose objectives, including the verb "model" for his post-individual CoRe. Although his CoRe included the engineering design process, there were no stated engineering-related objectives. He also did not set mathematics-related objectives, and mathematics was integrated implicitly in his post-individual CoRe.

To summarize, Deniz still demonstrated the features of the PCK-B category at the end of lesson study 4. During lesson study 4, although he mentioned writing mathematics-related objectives, he had a surface understanding of the scope of the mathematics curriculum. Similarly, the reasons for writing engineering objectives and their connections with other STEM disciplines were missing in his representations. His focus was on science-related objectives at the end of lesson study 4. He developed his knowledge of relation to other science topics to some degree after planning meetings, but he was not conscious of curricular saliency. His post-individual CoRe also reflected the characteristics of the PCK-B category because the focus of objectives was on science content, and the network of topics was restricted.

4.1.4.2. Knowledge of Learners

4.1.4.2.1. Lesson Study 1

Deniz was the teacher of the first version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

Deniz focused only on science-related misconceptions and difficulties in his pre-individual CoRe, like other participants. He thought that students might experience difficulty in classifying the elements in the periodic system according to their properties. He wrote about one science-related misconception that "students might consider hydrogen as metal". He did not cover any misconceptions and difficulties in other STEM disciplines, and the number of science-related misconceptions and difficulties were quite limited in his pre-individual CoRe.

In the planning meetings, Deniz shared her observations as a practicing teacher in cooperating school. He realized that students constructed the solar system model in a science lesson, and all planets were of the same size and with equal distances in these models. The group members participated in his idea and wrote these points as science-related misconceptions in collaborative CoRe **(researcher's field notes, planning meetings of lesson study 1).**

When he was asked to explain the possible sources of these misconceptions, he said that:

> I actually know from my own misconceptions. I was always confused about the positions of the Sun, Earth, and Moon during an eclipse. During the planning phase, I still held this misconception. Moreover, the relative sizes of the Moon, Earth and the Sun might also be confusing, for instance, whether the Moon is big enough to cover Earth during the eclipse **(pre-interview, 1).**

The sources of science-related misconceptions stemmed from Deniz's own experiences after the planning meetings of lesson study 1. When he was asked about the possible misconceptions in other STEM disciplines, he indicated that he had no clue about this question. Furthermore, he started to talk about the way of handling science-related misconceptions if they emerged:

> I will draw the diagram of the Solar eclipse on the board. Then, I will point out the visuals of the Solar eclipse on the classroom wall and ask students to make comparisons. In this way, I will eliminate their misconceptions **(pre-interview, 1).**

With respect to difficulties, Deniz only stated that since the Solar eclipse was an abstract concept, it would be difficult for students to grasp the content. The group had discussed some engineering-related difficulties, and Deniz ignored these points in the interview.

Deniz was the first preservice teacher who applied the first STEM lesson plan. Although he stated that he would handle science-related misconceptions about Solar eclipse through drawing, he did not apply it during his lesson. He partially detected science-related misconception by asking a question. The following excerpt was taken from his teaching:

> **Deniz:** We can use viewers to observe the Solar eclipse. Any other ideas?
> **S1:** We can use telescopes.
> **Deniz:** Yes… However, we should change the filter first **(researcher's pre-observation form, 1).**

Deniz quickly moved to the engineering design challenge after providing the brief information above. He did not delve into the reasons for it and did not make further attempts to eliminate student's misconception.

The other instance happened regarding engineering-related misconceptions:

> **Deniz**: I want to ask a question. Can you tell me who an engineer is?
> **S1**: Civil engineers.
> **Deniz**: What do civil engineers do?
> **S1**: Build homes.
> **S2**: Construct something
> **Deniz**: Is it all? What about genetic engineering? Software engineers? **(researcher's pre-observation form, 1).**

As seen from the conversation, Deniz partially recognized that students considered civil engineers the only kind of engineering. He just gave two examples from other engineering branches and continued his lesson. Moreover, the student had a misconception about engineering as a profession, such as engineers build, construct, and so on. However, Deniz could not be able to detect them and create follow-up discussion to correct misconception. He only provided examples from other engineering fields and skipped to the next question. These explanations were not helpful for students to eliminate their engineering-related misconception **(researcher's pre-observation form, 1).**

Concerning difficulties, he recognized some engineering-related difficulties and modified his instruction. For instance, after introducing the engineering design challenge, he asked what the criteria and limitations of the given design challenge were. There were no answers from the classroom, then he asked:

> **Deniz:** Do you know the meaning of the criteria?
> **S1:** It is the property of something.
> **Deniz:** It is the property that we want to be in our designs. What about limitations?
> **S:** (no answer).
> **Deniz:** For example, I have limited materials when creating my prototype. You can only use the material that we brought to you today. Moreover, I have to complete this lesson plan in three hours. This is a limitation for me, I have many activities prepared, and I must complete them on time to be successful **(researcher's pre-observation form, 1).**

Deniz was able to identify how students experienced difficulty in determining the criteria and limitations of the engineering design process. The group assumed that students were knowledgeable about the terms in the engineering design process in the planning meetings; however, Deniz recognized this part was challenging for students during the teaching part. He attempted to overcome it by asking additional questions and providing relevant examples. On the other hand, the science concepts stayed in the background during the lesson; therefore, no science-related difficulties were detected and handled **(researcher's pre-observation form, 1).**

After teaching, Deniz started to extend his understanding of engineering-related misconceptions and difficulties. He stated that:

> I asked about the criteria for the design challenge, and no one answered. No one has heard of it before. I feel I need to support the definition with examples. I think we should add this as a difficulty in CoRe. The same goes for engineering; I added extra questions and examples because students had difficulty understanding. Who is an engineer, and what do they do? We should give these points more space in our next lesson **(post-interview, 1).**

Deniz did not mention any engineering-related misconceptions in the interview, and the researcher reminded the dialogues in the classroom about engineers and the work of engineers. Then, Deniz explained that:

> Actually, civil engineers are the most common answer (to the question of who is an engineer). Because when I was younger, when I said engineer, I also thought of civil engineers. I remembered that students said engineers built in my lesson. Nevertheless, I know that engineers are the ones who design and plan buildings—for instance, software engineers design games. I believe the question-and-answer technique is beneficial at this point. I should have asked more questions about this issue. I do not know whether the example of software engineers was adequate to change students' perspectives. I did not do anything to understand. We should definitely add this as engineering-related misconceptions **(post-interview, 1).**

Regarding science-related misconception written in CoRe, the researcher asked whether he identified any misconceptions in his lesson. Deniz answered that:

> I did not go too far on this topic. I distributed information cards and expected them to recognize them on their own. I planned that they would learn the correct information about the position and relative size of the Sun, Earth, and Moon through the information card. But it did not work very well in my opinion **(post-interview, 1).**

He did not make any attempts to detect science-related misconceptions. Instead, he expected students to eliminate their misconceptions on their own through the activity.

In the reflection meetings, in accordance with his teaching experiences, Deniz suggested writing engineering-related misconceptions in CoRe and proposed adding engineers from different fields as examples, as he mentioned in the post-interview. The group participated in his idea. Moreover, Deniz shared his experiences regarding how students experienced difficulty in determining the criteria and limitations. Defne and Ada also indicated the same points, and CoRe was revised **(researcher's field notes, reflection meetings of lesson study 1).** No change was made with respect to science-related difficulties and misconceptions.

Deniz showed the characteristics of the PCK-A category at the beginning of the study. He wrote only science-related misconception, and no details were found with respect to how to detect and eliminate it. He switched to the PCK-B category after completing lesson study 1 concerning the knowledge of learners. His focus was on engineering-related difficulties and misconceptions, and he started to provide explanations about handling them. However, he ignored science and mathematics-related difficulties and misconceptions during this process. In brief, it could be stated that he concentrated on one STEM discipline which was the main feature of the PCK-B category.

4.1.4.2.2. Lesson Study 2

Deniz was the observer teacher in lesson study 2; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

During the planning meetings, the group elaborated on their discussions with respect to science-related misconceptions compared to the previous lesson study cycle. Deniz was also involved in these discussions and asserted that he had a misconception about the difference between speed and velocity. He added that since he had just studied this topic for KPSS, he tried to eliminate them on his own. He said, "I wish we could have learned this topic with STEM education when we were in middle school" **(video-recorded planning meetings, lesson study 2).** Deniz suggested using a word association test to reveal students' misconceptions about speed, and the group was convinced. He did not interfere with the discussions about mathematics-related misconceptions **(researcher's field notes, planning meetings of lesson study 2).** Regarding difficulties, he touched on science-related difficulties in the planning meetings:

> I think students will experience difficulties in terms of the unit of speed. In daily life, we generally say the car's speed is 70. We only use numerical values; we do not use units. We do the same when solving problems. This part might be challenging **(video-recorded planning meetings, lesson study 2)**

In the pre-interview, the reason for offering to utilize the word association test was asked, and he explained that:

> I think it is very suitable. I took the "Misconceptions in Science" elective course. While we were talking about how to detect them, I remembered this method (word association test). It fits with related steps (of REACT); we will learn their misconceptions about speed before starting the engineering design process **(pre-interview, 2).**

As seen from the excerpt, Deniz suggested a different method of identifying and handling science-related misconceptions for the first time in the study. He underlined that the flow of the lesson should be modified based on students' misconceptions. He also stated that everyday language was the most significant factor that caused students' misconceptions about this issue.

Regarding difficulties, he concentrated on different science-related difficulties than planning meetings in the interview. He said that:

> The activity in the Application part of the lesson might be challenging for students because students were expected to reach a conclusion about the relationship between speed, distance, and time, such as which means of transportation will arrive in a shorter time on the same road will give a clue about their speed. We did not provide mathematical formulas directly; therefore, making inferences and reaching conclusions might be difficult for students **(pre-interview, 2).**

In addition to science-related difficulties, he explained that generating more than one solution could be difficult for students. Although some of his comments included misconceptions and difficulties in engineering and mathematics, he touched on discipline-specific details in general about these two disciplines.

During the observation of the lesson, Deniz noted that students had misconceptions about the difference between speed and velocity but did not specify how Defne handled them. He noticed that the teacher did not use the concept cartoon. Although he started to talk about mathematics-related misconceptions after the planning meetings, he could not be able to recognize them during the lesson. Lastly, he wrote that some groups had difficulty in producing alternative solutions to the problems, as he stressed before the implementation of the lesson **(pre-observation form, 2).**

His observations of teaching were mirrored in his explanations, and he only referred to science-related misconceptions as follows:

> Some students said, "we designed the car with the highest velocity," at the end of the lesson. Defne tried to fix it by explaining, "this was not velocity; this was speed" but I do not think these students changed their minds. We just emphasized that speed was related to distance travelled, and the speed was about displacement. If I were a teacher of this lesson, I would ask questions about speed after showing the video. I would create a discussion environment. If the children said velocity, I would explain the speed and velocity concepts in detail. Then, I would move to an engineering design challenge. We should definitely cover the velocity concept in our revised lesson. Defne quickly skipped the word association test **(post-interview, 2).**

Deniz considered the lesson ineffective in terms of handling science-related misconceptions. He did not make any comments on misconceptions in other STEM disciplines **(post-interview, 2).**

Concerning difficulties, he concentrated on engineering-related ones: "students had difficulty in testing their prototypes. Two groups also experienced difficulty in proposing more than one solution". Deniz did not notice how the teacher of the lesson tried to overcome these difficulties. Regarding mathematics, he only indicated that drawing graphs was difficult for students **(post-interview, 2).** He did not suggest revising the lesson or the probable origins of these difficulties.

In the reflection meeting, Defne, as a teacher of the lesson, proposed to change the implementation time of the concept cartoon, which Deniz agreed with. Similarly, the other participants talked about using the DST triangle. Deniz was not very active during these discussions **(researcher's field notes, reflection meetings of lesson study 2).** Furthermore, during observation of the revised lesson, Deniz did not recognize students' difficulties in mathematics; he only noted that Ece identified science-related misconceptions and tried to eliminate them **(post-observation form, 2).**

In brief, Deniz's explanations were consistent with the PCK-B category at the end of lesson study 2. Although he began to consider the possible sources of science-related misconceptions, his understanding of misconceptions in other STEM disciplines was limited. With respect to difficulties, his focus was on engineering-related difficulties, and little emphasis was given to science and mathematics-related difficulties. His explanations were general, and how to deal with these difficulties was missing in his explanations at the end of lesson study 2. His focus was on one STEM discipline while talking about misconceptions and learners which was in parallel with the features of the PCK-B category.

4.1.4.2.3. Lesson Study 3

Deniz was the teacher of the revised version of the lesson plan in lesson study 3; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz generated discussions with respect to science-related misconceptions. He mentioned his observations as a practicing teacher in the 5th grade, as provided below:

> **Deniz**: I observed the 5th grade science lesson last week. The topic was heat. One student said, "the cold is transferred from outside to the inside of the classroom when the window is opened in winter." I think this misconception might emerge in our lesson, too, while designing the thermos.
> **Ece**: I totally agree with you. It is again related to the discrepancy between scientific knowledge and everyday language.
> **Deniz**: We should stress that the heat always moves from hot to cold **(video-recorded planning meetings, lesson study 3).**

It could be inferred that Deniz was able to reflect on his self-experiences as a practicing teacher while planning the lesson and mentioned misconceptions in line with the literature. On the other hand, he liked the idea of writing engineering design challenge-related misconception with Ada's suggestions in CoRe in the planning meetings.

Deniz further explained his thoughts about misconceptions in science and engineering as follows:

> In the lesson that I observed (with 5th grades), the cooperating teacher asked, "why do we get cold when it rains?" and students answered that "the cold is transferred". At that moment, I realized that students might think that the rain is cold, the human is hot. So, the cold is transferred…On the other hand, they might have been confused about the thermal insulators as a source of heat; they tend to think they keep us warm like radiators. I think it is about the everyday language we use. We prepared daily-life examples to overcome this misconception, such as talking about the situation in the sleeping bag in the Elaboration part of the lesson…Ada suggested writing, "there is only one successful design," and I participated in her idea. It might emerge…We will use comics and then will discuss whether there are 100 types of cars or there are multiple designs of bridges. None of them is more successful than the others; we should emphasize these points **(pre-interview, 3).**

As seen above, Deniz drew upon his self-experiences as an observer teacher and the discussion in the group while talking about misconceptions in science and engineering after the planning meetings. He mentioned the possible sources of these misconceptions and was aware of the ways of handling them. He added that he did not expect any misconceptions regarding mathematics in this STEM lesson plan.

Concerning difficulties, he put emphasis on engineering-related ones:

> I think choosing the appropriate materials would be difficult. We must cover researching the problem part effectively before proposing and choosing solutions. They should understand the role of each thermal insulator in order not to experience difficulty in choosing suitable materials. Working in a group might sometimes be challenging. Moreover, since they were unfamiliar with conducting experiments and collecting data, it might be challenging to use and read thermometers. If they have difficulty in this process and cannot measure it correctly, testing the prototypes and reaching a conclusion about their design solutions will be affected… I do not think they will experience difficulties in creating a prototype by considering the budget as a limitation, they got used to it **(pre-interview, 3).**

Deniz was able to provide detailed descriptions of students' difficulties in STEM disciplines and reached a better understanding after the planning meetings of lesson study 3.

While observing Ada's lesson, he noted that students had difficulties differentiating between the heat conductors and heat insulators which were not written in CoRe. He also realized the difficulties of choosing appropriate materials for their prototypes and considered that the teacher of the lesson supported students effectively at this point. Moreover, Deniz identified the science-related misconception he suggested in the planning meetings and added that Ada partially corrected this misconception **(pre-observation form, 3).** Although he was conscious of the engineering design process-related misconceptions before the implementation, he could not be able to catch them during instruction.

On the other hand, he touched upon engineering-related misconceptions while reflecting on the lesson and mentioned that Ada managed to deal with them. Moreover, he talked about students' difficulties in differentiating the heat conductor and insulator materials in the activity and attributed it to the abstract nature of the science topic **(post-interview, 3).** Additionally, he stated that:

> Students used the thermometer in the wrong way. They used the wrong side of the thermometer to measure the temperature of hot water; they could not read the exact values on the thermometer. For instance, they could not decide whether it was 55 or 56 degrees. We should explain how to use and emphasize how heat and temperate are measured **(post-interview, 3).**

In the reflection meetings, Deniz realized the misconception that "heat cannot be measured" with Defne and Ece's suggestions. He indicated that he missed this misconception **(researcher's field notes, reflection meeting of lesson study 3).**

Deniz was responsible for the revised version of the lesson plan in the re-teaching part. He asked some questions to determine students' science-related misconception that "cold is transferred". The example dialogue was taken from his classroom:

> **Deniz**: How does heat flow between two substances with different temperatures?
> **S1:** From hot to cold.
> **Deniz:** Why do we get cold in rainy weather?
> **S1:** We release thermal energy, change of state occurs.

> **Deniz:** How is heat transferred?
> **S2:** From hot to cold **(researcher's post-observation form, 3).**

Moreover, he realized other science misconceptions and provided a correct explanation supported by daily life examples:

> **Deniz:** You have been introduced engineering design challenge; what is the problem here?
> **S1:** We will create a thermos having a thermos that heats the soup.
> **Deniz:** Okey…We will turn back to your explanation after completing the engineering design challenge.
> **Deniz:** (after completing the engineering design process, in the Elaboration part). The sleeping bag, as you see in this example, is not a source of heat. It only includes thermal insulator materials that minimize heat transfer between the outside and inside environments (Referring to Student1). Consider the thermos you have designed. Is it a source of heat?
> **S1:** No, we just put hot water in it.
> **Deniz:** Yes, and we used varied thermal insulators to minimize the heat transfer, as in the case of the sleeping bag **(researcher's post-observation form, 3).**

Above mentioned dialogue demonstrated that Deniz caught students' misconception and re-visited them in the appropriate part of the lesson later.

Moreover, Deniz recognized an engineering-related misconception that had never emerged since the beginning of the study:

> **S1:** (after the discussions about the What if the engineers do not exist). I think scientists and engineers are the same people; they are doing the same thing.
> **Deniz**: Why do you think so?
> **S2**: I think engineers design something and create things.
> **Deniz:** Yes, you are right. Let me explain this way (he wrote d=m/v formula on the board). Scientists work on these types of formulas. They study the relationship between concepts, for example, how density changes with the increase in volume. On the other hand, engineers use these principles to design; for instance, they design ships **(researcher's post-observation form, 3).**

As seen above, he detected that students had the misconceptions that engineers and scientists were doing the same things, which were not written in the first and second versions of CoRe. He tried to correct this misconception by comparing the engineers' and scientists' jobs and gave some significant differences between them. He did not go into detail about specific aspects such as the difference and similarities between the scientific method and engineering design process but he was able to conduct group discussions and guided the students.

In relation to the difficulties, Deniz tried to eliminate some of them before their occurrence based on their discussion in planning and reflection meetings. For instance, he explained how to use and read thermometers while collecting data from their designs. Moreover, he realized that students experienced difficulty in proposing more than one solution and guided the groups by stressing:

> **Deniz:** I know you want to immediately move on to creating the prototype with the materials. However, this is the next step. Firstly, we should produce at least two or three alternative ideas. We should discuss different solutions and try to reach the best one **(researcher's post-observation form, 3).**

Similarly, the re-designing part was challenging for students. Deniz assisted students in learning after difficulty was observed.

> **Deniz**: What would you change if you made this thermos design again?
> **S1**: Nothing.
> **Deniz:** Is there anything that should be improved in your design? Can you make changes in choosing the materials? Is there a problem with the lid? Has the thermometer been placed so it can take a correct measurement without losing heat? **(researcher's post-observation form, 3).**

Since students had difficulty in re-designing part, Deniz directed some questions to make them consider their designs. Moreover, he was able to observe students' difficulties in determining the unit of heat and temperature, and he made comparisons and wrote them on the board to support their learning **(researcher's post-observation form, 3).**

After teaching, the group reflected on the misconceptions about engineers' work as follows:

> **Deniz**: When students hear of engineers, they think they work in the space station. Actually, the people who design the smallest technology, such as bridges, are engineers. The idea that they can be engineers and do these things seems unfamiliar. They had confusion about scientists and engineers. The scientists explore the relationships, work on formulas, and the engineers apply them to design products. This is the main idea.
> **Defne**: It was a misconception that we could not think of before the lesson; we should revise the CoRe and add it in our following CoRe. When a student asked that question, I thought to myself, how can I explain it? Deniz gave the difference well in my opinion.
> **Ece**: I think the process was very well managed. If that question came to me, I might need some time to answer **(video-recorded reflection meetings, lesson study 3).**

Deniz developed a deeper understanding in terms of difficulties and misconceptions in STEM disciplines at the end of lesson study 3. His focus was not on one discipline of STEM; he gave detailed descriptions of different disciplines in a balanced way. He sometimes used his knowledge before difficulties and misconceptions occurred. Sometimes, he handled them by asking additional questions and providing correct explanations, especially in science and engineering disciplines which were the focus of the third STEM lesson plan. These features in his PCK regarding the knowledge of learners met the criteria of PCK-C. In other words, he moved from the PCK-B category to the PCK-C category after completing lesson study 3.

4.1.4.2.4. Lesson Study 4

Deniz was the observer teacher in lesson study 4; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Ada suggested writing the misconceptions that Deniz confronted in the previous STEM lesson plan, which was about the work of scientists and engineers. Deniz supported Ada, and it was included in their final CoRe. When misconceptions were asked in the interview, Deniz stated that:

> In my last STEM lesson, misconceptions about the jobs of engineers and scientists emerged. I felt that everybody in the classroom thought the same about their jobs. I believe that I handled it effectively. Nevertheless, we will apply this lesson plan to another classroom, so it is good to write it as a misconception in our CoRe. We might face it again. Even if we do not confront, the teacher of the lesson might ask the question of differences between the scientists' and engineers' jobs **(pre-interview, 4).**

As seen in his statement, Deniz was aware of the misconceptions based on his self-experience as a teacher of the lesson and discussions in the planning meeting. He was also conscious of the abovementioned misconception and aimed to uncover it during the lesson by asking questions. On the other hand, the group decided to add a misconception that "engineers work alone," and Deniz did not provide any comments about it in the interview.

In terms of science-related misconceptions, Deniz talked about students might have alternative conceptions that sound travels in a linear way and that sound cannot pass from some objects. He added that he had never used the KWL chart before and was not sure whether it might help to identify these misconceptions **(pre-interview, 4).**

Deniz touched upon the ways of detecting misconceptions:

> In my first lesson plan, there was nothing about misconceptions. My purpose is to teach the content that I find challenging to learn personally. As I interacted with the students, I started to think about their misconceptions. I believe that critical questions play a key role. Then, we used the concept cartoon and word association test in our previous lesson plans, and we will use the KWL chart this time. I think using these different methods requires experience, and I feel more comfortable now **(pre-interview, 4)**

Regarding the learners' difficulties, he thought that students might be challenged in understanding that sound is energy since it is an abstract concept **(video-recorded planning meetings, lesson study, 4).** Moreover, he addressed that drawing a bar chart might be problematic because they already had experienced difficulties while transforming data into graphs in the second STEM lesson plan. He also remarked that working collaboratively in a group, choosing the best solution, and re-designing parts should be handled carefully. He added that the lowest scores in the analytic rubric generally belonged to these two parts and whoever taught the lesson paid specific attention to these parts **(pre-interview, 4).** Deniz was able to talk about difficulties in other STEM disciplines rather than science at the end of the planning meetings of lesson study 4.

Deniz monitored Ece's lesson and noted that the KWL chart worked well with respect to unveiling students' misconceptions about sound concept. He paid attention that students had difficulty in creating bar graphs and choosing and using the materials in the engineering design process **(pre-observation form, 4)** as indicated before the lesson.

After teaching, Deniz talked about engineering and science-related difficulties, which were absent in his observation form. Firstly, he pointed out choosing the best solution by considering the budget-challenged students. Secondly, students had difficulty in deciding whether sound absorption or reflection principles should be used in designing their music room. He stated that:

> To overcome this difficulty, Ece could utilize drawing; she could have drawn how sound travels on rough surfaces. It could be more concrete in this way. Maybe we should add some drawings to the science magazine **(post-interview, 4).**

Deniz was able to identify difficulties that were not in CoRe during the observation of teaching and made suggestions to deal with them using visual representations.

Concerning misconceptions, he extended his ideas about possible engineering-related misconceptions:

> We should arouse students' interest while asking about the differences between scientists and engineers to uncover their misconceptions. As in the previous lesson, we might provide the formula for density and then ask who discovered the density concept. We can talk about the scientist and his experiences who worked on density. Then, we can emphasize that a group of engineers, including mechanical, electronic, and marine engineers, work together to design naval architecture. In this way, we can handle the alternative conception that engineers work alone **(post-interview, 4).**

Deniz did not address "engineers work alone" misconception until the reflection part of the lesson study 4. However, he stated the misconception in line with the literature and suggested considering it in the planning process. He added that no mathematics-related misconceptions occurred during the lesson. No further descriptions were encountered in the reflection meetings and his post-observation form-4.

After attending the cycles of lesson study, Deniz was able to write science and engineering-related misconceptions and difficulties in his post-individual CoRe. **(post-individual CoRe).** To conclude, Deniz's PCK with respect to the knowledge of learners was in line with the PCK-C category at the end of lesson study 4. He emphasized at least two STEM disciplines evenly while discussing learners' difficulties and misconceptions. He was able to provide explanations in line with the literature and ways to identify misconceptions and difficulties in a detailed way at the end of the study.

4.1.4.3. Knowledge of Instructional Strategies

4.1.4.3.1. Lesson Study 1

Before the study, Deniz preferred to use direct instruction supported by question-answer to design a STEM lesson plan. He aimed to explain the periodic table and then divide students into groups. He expected the groups to dye metal, nonmetal, noble gas, etc., differently in the periodic table. The group work in his CoRe did not include collaboration, and no other design-centered teaching practices were observed. He did not benefit from representations **(pre-individual CoRe).**

Deniz was the teacher of the first version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz did not want to use any specific teaching strategy at first. Instead, he indicated they could only use the engineering notebook. Then, he proposed REACT but stated that he was not sure how to plan a lesson by using REACT because of his lack of experience. The discussions between Ece and Defne about using 5E for their first STEM lesson plan encouraged him to continue with 5E **(video-recorded planning meetings, lesson study 1).** On the other hand, Deniz was actively involved in the discussions concerning design-centered teaching practices, and some of the example dialogue was provided in Ada's section. Another conversation was taken from the planning meetings:

> **Ada:** I think each individual in the group should suggest at least one solution to the problem. Later, they should discuss which one should be the group’s opinion.
> **Deniz:** I think it is not necessary.
> **Ada**: Why not? What do you suggest?
> **Deniz:** I think every group should have one solution. Suppose we divide the class into six groups. Thus, we will have six different solutions at the end of the proposing solutions.
> **Ece**: Then, how will the group decide the best solution?
> **Deniz**: Each group will continue with their own solutions and test them.
> **Ece:** It does not make sense to me. I think it goes against the nature of the engineering design process. Because we want small groups to generate alternative solutions and choose one of them, each group will have different solutions after these discussions at the end.
> **Ada**: I completely agree with that. As I said before, we want them to develop critical thinking and decision-making skills. Each group should have their alternative solutions and pick one of them **(video-recorded meetings of lesson study 1).**

As seen above, his knowledge of instructional strategies with respect to design-centered practices was very limited. His limited knowledge was reflected in the discussions about proposing more than one solution to solve the problem and considering criteria and limitations to choose the best solution. Furthermore, he did not actively participate in the discussions about representations; he was more of a listener.

When he was asked to compare his pre-individual CoRe with their first collaborative CoRe regarding knowledge of instructional strategies after planning meetings, he stated, "there was no creating and testing prototypes in my first lesson plan; I can say that this is the biggest difference." He extended his thoughts about his individual CoRe in relation to design-centered teaching practices as follows:

> I want students to create a periodic table model (in pre-individual CoRe). The situation of hydrogen and noble gases might confuse students. They might get confused deciding whether the elements are nonmetals or transition metals. I want them to group the elements and create their models. When they are finished, they should understand which elements are placed wrong in the periodic table, and they can have a chance to correct their models and re-design the model **(pre-interview, 1).**

As seen above, Deniz could not integrate some basic features of STEM education. He was still considering that creating a periodic table model was sufficient for the STEM lesson plan and thought that placing elements in the correct places in the periodic table matched with the re-design part. Therefore, it could be stated that he experienced difficulties in offering open-ended design challenge and implementing the engineering design process properly. Moreover, there was no daily-life problem to be solved observed in his explanations.

Furthermore, when he was asked about why they preferred to choose the 5E learning cycle, he gave fewer details about what they had done in each step of 5E as follows:

> We have not applied any strategy other than the 5E learning cycle up to now. We have learned Predict-Observe-Explain, and REACT but always use 5E; we are more comfortable with it. I suggested REACT because of its familiarity with the 5E learning cycle. However, we have been learning about STEM education, so it is easier to use a strategy we know well **(pre-interview, 1).**

As seen above, his main reason for selecting the 5E learning cycle was familiarity with the strategy and having solid background knowledge regarding the strategy. He did not relate how the strategy and characteristics of STEM education fit each other.

Concerning representations and activities, he talked about using animation about the Solar eclipse would attract students' attention. For this reason, it was suitable to use it in Engage part of the lesson. He mentioned representations specific to engineering briefly:

> We summarized the process by preparing a decision table for choosing the best solution and re-designing parts. We want to show students what are the essential parts that are worth discussing in this process. In this way, students might discuss the positive and negative sides of their prototypes **(pre-interview, 1).**

Deniz was the first participant who applied the STEM lesson plan in the classroom, as seen in Figure 4.30. He implemented the steps of the 5E learning cycle as written in CoRe; however, he had some time management problems and did not carry out the evaluation part. Moreover, he could not use drawings for the Solar eclipse model **(researcher's pre-observation form, 1).**

Figure 4. 30 Scene from Deniz's Classroom in Lesson Study 1

With respect to design-centered teaching practices, his instruction included some problems. For instance, while he was giving instructions about the engineering notebook, he said:

> **Deniz:** The third step (of the engineering design process) is proposing solutions to the problem. You should think about alternative solutions. You do not need to think about three different solutions; just generating two solutions is enough for this step **(researcher's pre-observation form, 1).**

As seen from the excerpt, he narrowed down to alternative solutions just two in his instruction. Moreover, some groups did not choose the best solution, designed two different Solar eclipse viewers, and tested them separately within the group. Deniz could be able to detect and handle this issue **(researcher's pre-observation form, 1).** He put little emphasis on featuring science concepts in the engineering design process. He just provided the explanation below:

> **Deniz**: Solar eclipse viewers protect us from the Sun's harmful rays, so we must wear glasses **(researcher's pre-observation form, 1).**

Deniz did not benefit from science content to solve the engineering problem in his lesson. Lastly, after groups shared their designs with other students, Deniz did not allocate time for the re-designing part. He did not discuss the strengths and weaknesses of students' designs and asked students to revisit their solutions.

Regarding strategies for engagement with engineering concepts, Deniz used a contrived problem that was prepared for the purpose of the lesson only. He did not pay too much attention to using the engineering talk during the lesson, such as not integrating the "prototype" concept until the end of three hours of instruction **(researcher's pre-observation form, 1).**

After teaching, Deniz considered that using the 5E learning cycle was compatible with STEM education without giving content-specific details:

> It actually matched really well. It is pretty clear what we are going to do in each step. 5E learning cycle helped us organize the lesson and made things easier for the teacher. Guiding the groups in the Exploration phase was not difficult as I expected **(post-interview, 1).**

On the other hand, his consciousness started to increase with respect to engagement with engineering concepts while reflecting on the lesson:

> I gave examples of software and computer engineering. However, we should highlight this issue. The games that students play on the computer are developed by these types of engineering fields. I will recommend that Ada use these kinds of examples more frequently. Moreover, we should say engineers find solutions and develop products, such as energy-efficient buildings, computer games, etc. and relate these examples to our lesson **(post-interview, 1).**

Regarding design-centered teaching practices, Deniz touched on how one group ended up creating two different prototypes in his lesson:

> We need to be careful about the budget as a limitation. Generally, students did not take limitations into account. On the other hand, the groups tended to develop and test their prototypes by skipping the previous steps (of the engineering notebook). For instance, one group designed two different Solar eclipse viewers, one of them was 18.5 TL, and the other one was 21 TL. I tried to draw their attention to the fact that budget is a limitation, but I think it did not work **(post-interview, 1).**

Deniz could not be able to cover the re-designing part during the instruction; however, he reflected on his experience as a teacher and mentioned the points that should be improved in the revised lesson:

> We should extend the time for communicating the solutions. We should emphasize that the critical point is to design the most effective prototype with the lowest budget to find a solution to the problem. I did not underline this perspective in my lesson. Re-designing is also essential; maybe students will improve their designs and do a lower budget design **(post-interview, 1).**

In the reflection meetings, firstly, Defne talked about her observation regarding producing alternative solutions as part of the lesson. Deniz realized this issue and said he should not have said that sentence. The other main discussion was about the effectiveness of the material cards. Although the group members were seeking ways to make it more effective, Deniz said that the information cards did not work well. He added that he did not emphasize the Solar eclipse concept, and these cards should be removed from the lesson **(video-recorded reflection meetings; researcher's field notes, lesson study 1).** This situation demonstrated that Deniz experienced difficulties understanding the importance of providing scientific rationale for the design solution and conducting research to solve the problem.

In brief, Deniz's knowledge of instructional strategies showed the features of the PCK-A category at the beginning of the study. He preferred to use direct instruction as a teaching strategy, and no design-centered practices were found in his CoRe. It could be said that his level of knowledge of instructional strategies increased to the PCK-B category after completing lesson study 1. He started to talk about integrating the basic features of STEM education but with limitations and some problems. He could not clearly explain the specific reasons for choosing the 5E learning cycle in the STEM lesson plan. Moreover, he applied design-centered teaching practices to some extent, and still, he was having difficulty incorporating many of them. For instance, he tended to separate the science and engineering activities. Additionally, his knowledge of representations was changed minimally.

4.1.4.3.2. Lesson Study 2

Deniz was the observer teacher in lesson study 2; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz suggested using the 5E learning cycle again because he thought that students might have a misconception about the science concepts of the lesson, and using an unfamiliar strategy could be risky for the teacher. However, Defne convinced the other participants to use a new strategy. While planning the lesson, Deniz indicated that he did not possess enough knowledge to prepare a lesson using REACT, especially for Cooperating step **(researcher's field notes, planning meetings of lesson study 2).** Moreover, he was involved in the discussions concerning design-centered teaching practices and suggested using ready-made toy cars in the engineering design process, similar to his idea in lesson study 1. The exemplifying dialogues among the group members was given below:

> **Deniz**: I think we should use toy cars. Students can race their toy cars on the track and calculate the speed. Then, they can draw their graphs from the data.
> **Ada**: What about the skills we want them to gain?
> **Defne**: Then, how can we use the engineering design process? What will students do in proposing more than one solution according to what you have suggested? Or what about designing a race car by considering the criteria?
> **Deniz**: We can get different types of ready-made race cars, and students might choose among them.
> **Defne**: So, still, this does not fit our purposes.
> **Deniz**: Actually, you are right… I want to make things easier for students because we had a hard time making the wheels turn **(video-recording of planning meetings of lesson study 2).**

The above dialogue demonstrated that the discussions in the group contributed to Deniz's knowledge of instructional strategies with respect to design-centered teaching practices.

After planning meetings although Deniz increased his understanding of the phases of REACT after the planning meetings, he could not relate it to the key elements of STEM education. His reasons for choosing REACT were broad, and no topic-specific details were found in his statements.

Concerning design-centered teaching practices, he mentioned some of them. For example:

> Students are expected to generate solutions and choose; they develop prototypes to solve a problem. We can support this process by giving daily-life examples, such as whether the car has a speed or velocity indicator **(pre-interview, 2).**

As seen above, Deniz did not delve into the details; he just mentioned the steps of the engineering design process without relating them to the design challenge written in CoRe.

Deniz talked about science and engineering-specific details regarding the representations and activities. For instance, he indicated that the decision table in choosing the best solution part would help the student think from different perspectives and take criteria and limitations into account in the decision-making process **(pre-interview, 2).** He considered that using engineering-specific representations would be helpful in developing some skills, such as decision-making and critical thinking.

Concerning strategies for engagement with engineering concepts, he stressed the importance of promoting STEM careers as follows:

> While I was an engineering student, there was a car design competition between different universities. A group of engineering students, including mechanical, civil, and automotive branches, designed their cars as a group. Actually, we are doing a very similar process with middle school students. We can raise students' awareness of engineering as a profession. We should keep saying, "you are a group of young engineers to design a car with the highest speed that will race in Formula 1 **(pre-interview, 2).**

In the previous lesson plan, he started to talk about engineering careers; however, he elaborated on his understanding and suggested using visuals to get students' attention after the planning meetings.

Deniz observed Defne's lesson and noted that using REACT worked well in the STEM lesson plan. He paid attention to how the teacher utilized representations specific to engineering and mathematics and the daily-life examples provided by the teacher. He partially agreed that science concepts were discussed in the context of engineering. On the other hand, Deniz considered that the steps of the engineering design process were followed regularly, the engineering problem attracted students' attention, and the groups were guided effectively. Defne used engineering terminology in her instruction. Lastly, he wrote that the emphasis on engineering careers was adequate **(post-observation form, 2).**

After the implementation of the lesson, Deniz thought that REACT was appropriate to use in STEM lessons, but no specific details were encountered in his explanations. He had further suggestions about the Experiencing phase of the REACT:

> I think we should directly explain the speed concept in 10 minutes in the Application phase. We need to focus the students on the blackboard and explain the topic. Then, they should work on activity sheets. In this way, students will learn better, and classroom management problems will be eliminated, too **(post-interview, 2).**

He mentioned using direct instruction in Experiencing part of REACT, which demonstrated his limited knowledge regarding teaching strategy.

On the other hand, Deniz emphasized science-related representations and activities after observation of teaching as follows:

> We did not provide the speed formula to the students. We aimed to make students explore this concept through the activity sheets we prepared, but students had difficulty. I think we should provide the mathematical formulas and the triangle as well. We should also support the Application process with more daily-life examples. For instance, we can say that I can travel 400 km. in four hours, whereas the other might travel 100 km in that time. We can infer speed from these kinds of examples. The engineering design process is very effective, but students should know the theoretical part of the lesson before starting the engineering design process **(post-interview-2).**

As seen above, Deniz was in favor of enriching the instruction with real-world examples and using visual representations such as mathematical formulas and DST triangles, which were the limitations of the science curriculum, to help learners' understanding of the concepts. It could be said that his knowledge of curriculum and knowledge of instructional strategies interacted. On the other hand, above mentioned explanations included some problems regarding incorporating the engineering design process. For instance, he did not give weight to learning science concepts in the engineering design process and conducting research to learn the necessary knowledge for the design process. He thought that the science concept should be taught separately from the engineering design process after the implementation part of lesson study 2. It could be said that he experienced difficulties in integrating some basic features of STEM education.

In the reflection meetings, Deniz explained his suggestions about REACT in the post-interview. Below conversation was taken from the reflection meeting:

> **Deniz**: I think the teacher of the lesson should explain the speed concept at the beginning of the lesson.
> **Ece**: You mean direct instruction?
> **Deniz**: Yes, we should give mathematical formulas and explain the topic through it.
> **Defne**: But our purpose is to create an environment where students discover and explore concepts. I think what you have suggested contradicts with Experiencing step (of REACT). I agree that we should give mathematical formulas, but after students explore the concept independently.
> **Deniz**: Then, we should increase the number of daily-life examples and questions we will ask **(video-recorded reflection meetings, lesson study 2).**

As seen above, the reflection meetings contributed to Deniz's knowledge concerning teaching strategies. Moreover, Defne suggested similar ideas concerning science-specific representations as Deniz and the group revised the CoRe **(researcher's field notes, reflection meeting of lesson study 2).**

In summary, Deniz's knowledge of instructional strategies exhibited the features of the PCK-B category at the end of lesson study 2. He experienced some problems and talked about fewer design-centered teaching practices. For instance, conducting research to solve the problem, providing a scientific rationale for a design solution, and generating alternative solutions to the problem were not mentioned. Moreover, he had limited knowledge about the teaching strategy compatible with STEM. He could relate the basic features of the STEM education and REACT. Deniz elaborated on his understanding of representations specific to science. However, he could not be able to emphasize representations specific to mathematics and engineering at the end of lesson study 2. These features met with the PCK-B category with respect to knowledge of instructional strategies.

4.1.4.3.3. Lesson Study 3

Deniz was the teacher of the revised version of the lesson plan in lesson study 3; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

There were intense discussions about choosing the teaching strategy in the planning meetings. For example, Ada suggested the 5E learning cycle and problem-based learning, Defne suggested a 5E learning cycle, whereas Ece offered the 4E learning cycle. Except for those, Deniz put forward the idea that they did not have to use any particular teaching strategy; following the steps of the engineering design process would be sufficient. However, the group indicated that there should be teaching strategies that keep students engaged during the lesson to cover all objectives that wrote. The discussions ended by choosing 5E because of the familiarity with the strategy **(video-recorded planning meetings, lesson study 3).**

When Deniz was asked to explain his thoughts about the teaching strategies, he stated that:

> I suggested not to use a particular teaching strategy at the meeting. Nevertheless, my friends discussed that we should use the appropriate one. We preferred to use the 5E learning cycle as in the first lesson plan. The flow of the lesson was very good; we are good at using it. We combined the 5E learning cycle and STEM education effectively. For example, we used REACT in the previous plan and had difficult times because our knowledge about the strategy was not enough when we started to plan **(pre-interview, 3).**

Deniz was more knowledgeable about the 5E learning cycle than other strategies, which was mirrored in his preferences for choosing a strategy for the STEM lesson plan. On the other hand, he could not match the features of the 5E learning cycle and STEM education after the planning meetings. His descriptions were too general and only contained the name of the strategy. He did not provide how each step of the 5E learning cycle was appropriate for STEM lesson.

With respect to design-centered practices, he started to talk about the significance of conducting research to solve the problem:

> We might have used educational technologies (in researching the problem), but we do not have many opportunities to use them in our classroom environment.

> Therefore, we prepared material cards to investigate. Students will do research for their designs through these cards **(pre-interview, 3).**

Deniz's statements did not involve any topic-specific details; he just provided generic features of the engineering design process. On the other hand, he began to talk about featuring science concepts in the engineering design process for the first time in the study as follows:

> We will create the data collection table. All group data will be available on the board. We can discuss which thermos design will be the lowest temperature difference. We can benefit from daily-life applications of thermal insulation principles to discuss the concept. They will present their materials and discuss which one is more effective **(pre-interview, 3).**

As seen above, he developed his understanding of design-centered practices to some degree. Moreover, he touched upon representations and activities in science and other STEM disciplines with equal emphasis. For instance, he was aware that presenting engineering design challenge through animated video would attract students' attention to the lesson. Or using daily-life examples of thermal insulation such as sleeping bag, the cloth of astronauts, and decision table that shows negative and positive aspects of design to assist students' learning **(pre-interview, 3).**

Regarding strategies for engagement in engineering concepts, he underlined the importance of encouraging STEM careers similar to the previous cycles:

> We would use engineering-related visuals and discuss what kind of problems we would have in daily life if there were no engineers. We can emphasize aerospace engineering and mechanical engineering by using these visuals. We can also discuss how astronauts would go to space if engineers had not designed thermal-insulated suits for astronauts. When students hear of engineers, they might think of civil engineers, but we have engineers that design iPad in the visuals; for example, we should use them effectively **(pre-interview, 3).**

In the observation of the teaching phase, Deniz observed Ada's lesson and noted that all steps of 5E were implemented regularly. He found the number of daily-life examples and use of tables adequate. He noted that representations specific to engineering, such as animated video and visuals, worked very well. He also wrote that material cards were effective in conducting the research part and totally agreed that the use of engineering talks was sufficient. Deniz considered that the steps of the engineering design process were followed properly **(pre-observation form, 3).**

Deniz thought there was no need to change any part of the 5E learning cycle after teaching observation and said that he would implement it directly as Ada did **(post-interview, 3).** Deniz started to talk about using science concepts in the engineering design process in the pre-interview, and he elaborated his understanding by giving specific examples about this point:

> Students examined the material cards while choosing the appropriate materials for their thermos designs; they did not have difficulty. For example, one student wanted to use plastic wrap, and the other students warned him about the flammability of the material, and then they gave up using it. They discussed the advantages and disadvantages of the materials while creating their porotypes **(post-interview, 3).**

Although his awareness of some design-centered practices improved after teaching observation, he still had some problems. For example, he did not realize and talk about how Ada skipped the re-design part **(post-interview, 3).**

In the reflection meetings, Ada talked about the re-design part that should be incorporated into the lesson, and Deniz, the teacher of the revised lesson, did not indicate any idea. Deniz did not make any recommendations for revising the CoRe **(researcher's field notes, reflection meetings of lesson study 3).**

Deniz was the lead teacher of the revised version of the STEM lesson plan. Although the lesson was planned by using the 5E learning cycle, he utilized direct instruction at the beginning of the lesson and directly explained the concepts of insulation and how the heat is transferred in solid, liquid, and gases, supported with question and answers as seen in Figure 4.31. Too much instruction was given to the students at the beginning of the lesson. Then, he moved to the 5E learning cycles. It could be inferred that he gave students little chance to explore the concepts independently, contrary to the nature of 5E **(researcher's post-observation form, 3).**

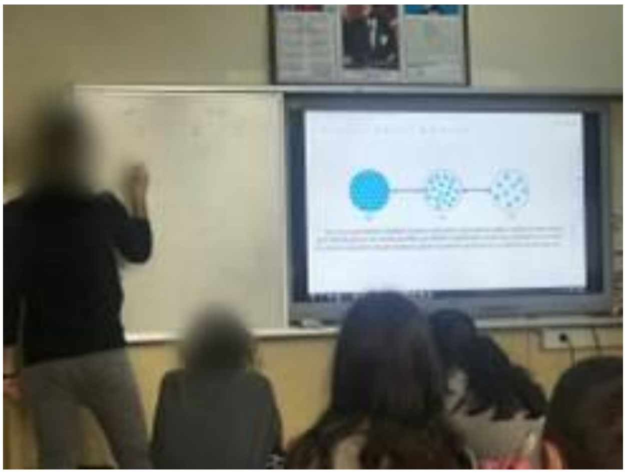

Figure 4. 31 Scene from Deniz's Classroom in Lesson Study 3

On the other hand, his instruction demonstrated some features of design-centered teaching. For example, he emphasized producing alternative solutions as opposed to his first STEM lesson as follows:

> **Deniz:** I know you want to create your thermos designs. However, first, you should think about the alternatives. At least two alternatives, three or more would be better **(researcher's post-observation form, 3).**

He also paid attention to determining the criteria and limitations in the engineering design challenge, managing the groups, and communicating their results and designs. However, he skipped the researching the problem part quickly since he explained it at the beginning of the lesson, did not use the budget as a limitation, and did not implement the re-design part **(researcher's post-observation form, 3).**

Deniz used activities and representations in science and other STEM disciplines and extended his understanding compared to the previous teaching of the STEM lesson plan. For instance, he utilized a poster of the engineering design process and went over the process step by step. He constructed a data collection table and compared students' designs, as seen in Figure 4.32 **(researcher's post-observation form, 3).**

Figure 4. 32 Scene from Deniz's Classroom while Comparing Designs

Additionally, he used engineering-related visuals to attract students' attention to the engineers' work. The below dialogue was taken from his classroom:

Deniz: What do you see in the first visual?
S1: There is something like a laptop.
Deniz: Yes, they are measuring something.
S2: Like a calculator.
S3: It is like an old, undeveloped version of the computer.
Deniz: Exactly. Calculators would be this big without engineers, so many people would work to calculate as you see in this visual.
S4: Even phones have calculators now.
Deniz: You are right. The problem was that calculators were too big, and engineers solved it. They designed smaller calculators and put them as an application on our mobile phones, as you have said **(researcher's post-observation form, 3).**

As seen above, he was able to utilize visual representations specific to engineering and assist students in developing career awareness in engineering. He put emphasis on the engineers' nature of work and used engineering terminology as a part of a lesson. On the other hand, the revised lesson plan contained an increased number of daily-life examples in science and engineering disciplines; however, Deniz skipped that part of the lesson **(researcher's post-observation form, 3).**

In conclusion, Deniz's instruction exhibited the features of the PCK-B category at the end of lesson study 3. He could not be able to list the reasons for choosing a particular strategy for STEM education and did not match the characteristics of STEM education and REACT. Moreover, instead of establishing more connections between science and engineering, he tended to separate the activities. He mentioned this situation in lesson study 2 while he was an observer teacher and then implemented it in his instruction in lesson study 3. On the other hand, he developed his understanding of design-centered teaching practices but with some limitations. For instance, he did not complete a full iteration of the engineering design process or did not give importance to conducting research to learn about the concepts, although they were discussed in the reflection meeting before teaching. Representations and activities were the most developed part of his knowledge of instructional strategies at the end of lesson study 3.

4.1.4.3.4. Lesson Study 4

Deniz was the observer teacher in lesson study 4; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

The discussions in the last planning meetings were centered on alternative teaching strategies. However, Deniz was in favor of using the 5E learning cycle as in the previous STEM lesson plans. He stated they were knowledgeable about the 5E learning cycle, which made the planning process more manageable. He mentioned how they experienced difficulty in planning the lesson with REACT in lesson study 2. On the other hand, the other group members discussed that they wanted to try a new and appropriate strategy. They reached a consensus about using problem-based learning, and Deniz did not object to their ideas **(researcher's field notes, planning meetings of lesson study 4).**

He was asked to explain his thoughts about using problem-based learning; he indicated that:

> We tend to use the 5E learning cycle; therefore, this plan will be different for me. We will see whether it will work or not; I am not sure. However, I suggested not using any particular teaching strategy in the previous meetings; I think we should only use an engineering notebook. However, the steps of problem-based learning and engineering notebook fit each other. The planning process went well. The Elaboration part of 5E was challenging for us. We did not think about this issue in this plan, which could be an advantage **(pre-interview, 4).**

Similar to the previous lesson study cycles, he did not provide an apparent reason for choosing a specific strategy for their STEM lesson plan. Regarding design-centered practices, Deniz stressed the importance of proposing alternative solutions to the problem and working in collaboration as follows:

> Students have difficulty in generating solutions. The teacher should create a productive discussion environment in which students need to develop high-order thinking skills such as critical thinking. They experience difficulty, but good designs emerge in the end. They need to complete this process to solve the problem. I think the most crucial part of the engineering design process is this part (proposing alternative solutions to the problem) **(pre-interview, 4).**

This step was problematic for Deniz's first STEM lesson teaching experience. It could be inferred that he developed his understanding; however, he did not touch upon some features of design-based teaching practices throughout lesson study 4, such as re-designing, learning from failure, balancing roles in the groups, and conducting research to solve the problem.

With respect to representations and activities, Deniz focused on science and engineering disciplines, but his explanations were unclear and rather general:

> We will understand what students know about the topic through the KWL chart. If there is a problem in their knowledge, we can focus on it later…The animated video about engineers will be effective in creating awareness about engineering careers and how engineers work **(pre-interview, 4).**

Regarding mathematics, he only stated that using different kinds of graph will be effective in their lesson plan. On the other hand, he had a more improved understanding of the strategies for engagement with engineering concepts. He stated that:

> Students know who the engineer is but do not have enough knowledge about their work. For example, I asked who constructed the bridges; they answered only "engineers". However, they did not say civil engineers. They also draw engineers working alone. In our lesson, we should emphasize that engineers from different fields work in groups to increase their career awareness **(pre-interview, 4).**

While observing Ece's lesson, Deniz noted that problem-based learning worked well. He paid specific attention to the representations specific to mathematics and engineering and wrote down that the daily-life problem attracted students' attention **(pre-observation form, 4).**

After observation of teaching, Deniz reflected on using problem-based learning as follows:

> I think problem-based learning might be used in STEM lessons. We have time management problems in the 5E learning cycle and REACT. Problem-based learning is very similar to the steps in an engineering notebook. We could have used this method more than once if we had had enough knowledge at the beginning of the study. We were undecided about using it because of our limited understanding and practice, but we enjoyed it very much and learned how to use it **(post-interview, 4).**

As seen above, Deniz became more knowledgeable about the alternative teaching strategies compatible with STEM education. However, he could not be able to extend his understanding of the specific reasons for using it in STEM lesson.

Regarding design-centered teaching practices, Deniz concentrated on researching the problem part with details for the first time in the study:

> Students learn new knowledge regarding sound; for instance, they have learned about the decibel scale and the properties of the material that could be used in their designs. The science magazine was effective in investigating the problem. If we had not prepared a science magazine, Ece would directly teach the lesson. If students learn by exploring, the learning is more permanent **(post-interview, 4).**

As seen above, Deniz talked about the activity specific to science and encouraged learners to investigate the problem. This point demonstrated that his understanding of design-centered practice was improved to some degree because he directly transmitted information to the students in his teaching experience in lesson study 3 rather than encouraging them to investigate. He also added that the number of daily life examples in science and engineering content should be increased in the lesson **(post-interview, 4).**

After completing four-lesson study cycles, he prepared an individual CoRe by selecting a 5E learning cycle. This situation showed that he had a tendency to use familiar strategies to plan a STEM lesson instead of using REACT or problem-based learning, or any other alternatives. He integrated design-centered teaching practices into his CoRe, but there were some missing and problematic parts. For instance, he could not use authentic problem. The contrived problem was created for the purpose of the lesson, and no criteria and limitations were included. He asked students to design a telescope to observe the stars. He did not implement the re-designing part, whether conceptually or physically. On the other hand, he used information cars to support students' exploration of the types of telescopes and light pollution. Deniz did not use representations specific to engineering, such as decision tables or visuals. He included daily-life examples specific to science. No emphasis on strategies for engagement with engineering concepts was found in his post-individual CoRe.

In summary, Deniz' explanations met the characteristics of the PCK-B category at the end of lesson study 4 concerning knowledge of instructional strategies. His understanding of choosing appropriate teaching strategies changed minimally throughout the study. He did not want to use a particular strategy or prefer to use the same strategy in STEM lesson plans. His reasons for selecting a teaching strategy did not involve the critical elements of STEM education. On the other hand, although he made progress in terms of design-centered teaching practices, some of the essential parts of them were still missing. His knowledge regarding representations and activities developed, but generally, his emphasis was on one discipline of STEM education.

4.1.4.4. Knowledge of Assessment

4.1.4.4.1. Lesson Study 1

Deniz was the teacher of the first version of the lesson plan in lesson study 1; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

The analysis of pre-individual CoRe exhibited that Deniz concreated on science content outcomes in parallel with the objectives of his CoRe. He used traditional assessment methods, such as open-ended and multiple-choice questions with summative purposes. It could be said that his knowledge of assessment concerning what to assess and how to assess was limited at the beginning of the study.

In the planning meetings, Deniz focused on assessing the engineering design process through the analytical rubric. He gave examples from his former experiences as an engineering student as follows:

> **Deniz:** I attended a competition in which teams from different universities developed their cars and tested them. They filled out a rubric after each test. We can think the same way.
> **Ada:** Yes, it makes sense. We can write the steps in an engineering notebook.
> **Defne:** Then, we can say that we use an analytic rubric. Or holistic? I think it is analytical; we have multiple things to consider **(video-recorded planning meetings of lesson study 1).**

As seen above, after Deniz's initial suggestions, the group decided to develop a rubric for assessing the engineering design process. The researcher asked whether the lesson plan was assessing students' prior knowledge, Deniz. A stated that they did not prepare anything to assess it. Instead, he mentioned how they were going to assess the whole lesson by using the rubric:

> It will be a comprehensive assessment. We can evaluate almost all phases of the lesson with this rubric. Every part of the engineering design process is present in the rubric **(pre-interview, 1).**

Deniz did not realize the discrepancy between the objectives of the lesson and what to assess after the planning meetings of lesson study 1 since they wrote only science-related objectives. He focused on only one discipline while talking about the parts of the lesson that was worth assessing.

He was the teacher of the first version of the lesson plan. He used informal questioning to assess students' prior knowledge in science and engineering, although it was not discussed in the planning meetings. For instance, he asked, "Do you remember how the Solar eclipse happened?" "do you know who the engineer is?" "do you know the meaning of criteria and limitations?" types of questions in his instruction for diagnostic purposes at the beginning of the lesson **(researcher's pre-observation form, 1).**

Moreover, Deniz applied some formative assessment methods. He walked around the groups and observed the learner's performance during the engineering design process. He tried to provide feedback to the groups by asking additional questions and providing some important points. For instance, one group did not consider the limitation of the budget while creating their prototypes. He realized and explained that they should not exceed their budget while designing Solar eclipse viewers and re-consider their solution. On the other hand, he did not use learners' budget calculations as an assessment, and the learner's products were not assessed during his instruction **(researcher's pre-observation form, 1).**

After teaching, Deniz still put greater importance on assessing the engineering design process and did not mention any other assessment method to be used in the lesson **(post-interview, 1)**. It could be inferred that his knowledge of assessment with respect to what to assess and how to assess remained unchanged and limited after teaching part of lesson study 1.

In the reflection meeting, Deniz did not make any other comments regarding the assessment; however, the group paid attention to the informal questions he asked during the lesson for diagnostic purposes and included them in CoRe **(researcher's field notes, reflection meetings of lesson study 1).**

In brief, the nature of Deniz's knowledge of assessment indicated the features of the PCK-A category before starting the study. He only concentrated on assessing the science content, and his repertoire of ways of assessing students' learners was restricted to traditional types of assessment. Deniz made a transition to the PCK-B level after completing lesson study 1. His focus was on assessing the engineering design process, and he ignored assessing science content outcomes, students' products, etc. Though he was able to suggest revisions in instruction based on the assessment, and he described some alternative assessment methods for formative purposes at the end of the lesson study 1.

4.1.4.4.2. Lesson Study 2

Deniz was the observer teacher in lesson study 2; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz suggested using a word association test to check students' misconceptions and understanding of the speed topic. The following dialogue was taken from the planning meetings:

> **Deniz**: We can use a word association test to assess students' understanding.
> **Ada**: It could be a good idea. We can understand whether they have the misconceptions we have been talking about.
> **Deniz**: Yes, we may apply it at the beginning of the lesson.
> **Defne**: Yes, after showing the video, we can ask some questions regarding the video. Then, we can apply it. Has anyone used it before?
> **Deniz:** I used it in one of my lesson plans. It is easy to prepare.

> **Defne:** How will we apply it? To the groups or individuals?
> **Ada:** Implementing it individually takes too much time. We should apply it to the groups **(video-recorded video meetings, lesson study 2).**

As seen from the excerpt, Deniz focused on assessing focusing on science content outcomes for diagnostic purposes. He also said that using concept cartoon towards to end of the lesson would be practical to understand whether the misconception that emerged at the beginning of the lesson was cleared or not **(pre-interview, 2).**

Deniz mentioned assessing engineering outcomes of the lesson and students' products; however, his descriptions were too broad, and little emphasis was given as follows:

> The rubric that we created was very comprehensive. We can assess every part of the lesson, the steps of the engineering design process…We have another rubric to assess students' designs. It is not about winning or losing the race. The process is important for us. Our perspective is not result-oriented; we are process-oriented in our lesson plan **(pre-interview, 2).**

Deniz was not clear about why they would assess students' products, and his explanations did not include any key elements specific to STEM education. The CoRe included some short-answered and multiple-choice questions to be used at the end of the lesson to assess mathematics objectives, but he did not concentrate on them. Regarding how to assess, he talked about rubrics and concept cartoon but did not provide particular examples for the items in these assessments **(pre-interview, 2).**

In the observation of the teaching part, Deniz realized that the teacher of the lesson asked informal questions to identify students' prior knowledge of science. He noted that the concept cartoon and rubric for assessing students' designs were not used due to the time limitation **(pre-observation form, 2).** Deniz did not write any comments about the use of word association test or giving assessment sheets as homework. While reflecting on the lesson, he asserted that the implementation time of the concept cartoon might be changed **(post-interview, 2).**

In the reflection meeting, the teacher of the lesson also offered to use concept cartoon earlier in the lesson, which Deniz agreed with her. He did not involve any other discussion regarding assessment **(researcher's field notes, reflection meetings of lesson study 2).** While observing the revised version of the lesson plan, he noticed how Ece used informal questioning to provide feedback to the students, different from his observations of the first version of CoRe **(post-observation form, 2).**

After completing lesson study 2, it could be inferred that Deniz's knowledge of assessment met the features of the PCK-B category. Although he began to consider assessing students' products and engineering design process, his focus was on assessing science content outcomes. Regarding how to assess, he started to mention different assessment methods, such as word association test and concept cartoons. However, these assessment methods were planned to check science content outcomes. He did not discuss how to assess students' products and mathematics content. He mainly mentioned assessment methods used for diagnostic purposes, and fewer details about formative and summative assessments were given. Lastly, he could not link how the chosen assessment methods were in line with the objectives of the lesson. In brief, Deniz's knowledge of assessment displayed the typical characteristics of the PCK-B category at the end of lesson study 2.

4.1.4.4.3. Lesson Study 3

Deniz was the teacher of the revised version of the lesson plan in lesson study 3; therefore, excerpts from pre and post-interviews, teaching segments, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, Deniz contributed to the discussions by suggesting there should be a self-assessment sheet at the end of the engineering notebook in which groups should evaluate the ongoing work in the groups. The group members accepted his idea; however, he did not contribute to the items. He did not involve discussions about assessing science and other STEM disciplines concepts in the discussion part **(researcher's field notes, planning meetings of lesson study 3).**

Deniz concentrated on assessing students' prior knowledge in science, science content outcomes, and engineering design process regarding what to assess components after planning meetings:

> The diagnostic tree and poster aim to check students' understanding of science content. Rubrics assess every piece of the lesson, especially the engineering design process **(pre-interview, 3).**

He added that they would assess students' prior knowledge in science through question and answer at the beginning of the lesson. It could be said that Deniz's explanations were too broad, and he was not sure about how to relate the objectives. He could not explicitly specify why they wanted to assess different parts of the STEM lesson. No specific examples regarding assessment methods were found in his explanations. Furthermore, he did not concentrate on assessing mathematic content outcomes. Although he suggested using a criteria list to assess students' products, he did not put emphasis on assessing this part of students' learning **(pre-interview, 3).**

Deniz observed the first version of the lesson. He mainly concentrated on assessing science content outcomes. For example, he wrote that the teacher used the diagnostic tree correctly and used question-answer to elicit students' prior knowledge of heat and temperature concepts. He added that the students' designs were assessed by interpreting the data collection table **(pre-observation form, 3).** He did not mention the criteria for assessing students' designs.

When he was asked about his thoughts on the assessment part of the lesson, he stated that: "the diagnostic tree is very appropriate to use. Ada talked over every item in the diagnostic tree" **(post-interview, 3).** As seen from the explanation, he only mentioned assessing science content outcomes and did not favor using varying formative assessment methods. He did not provide any other comments about the other disciplines of STEM when the researcher asked. Moreover, as a teacher of a revised version of the STEM lesson plan, Deniz did not make any suggestions about improving the assessment part **(researcher's field notes, reflection meetings of lesson study 3).** This situation demonstrated that his knowledge of assessment concerning revision based on assessment did not enhance at the end of the reflection meeting.

Deniz started the lesson by asking informal questions, such as "What is heat?, What is temperature?" types of questions. During the lesson, Deniz did not mention the criteria list to assess the effectiveness of the designs. The groups chose their best solution, constructed prototypes, and started collecting data. In the middle of the data collection process, he only said that:

> The thermos design with the least temperature change after taking multiple measurements will be the best design **(researcher's post-observation form, 3).**

Moreover, he could not spare enough time to implement the diagnostic tree, poster, and self-assessment sheet. He gave Draw and Engineer Test as homework to be collected in the next lesson **(researcher's post-observation form, 3).** As seen above, Deniz could not be able to complete the assessment part. In the reflection meeting, he said that he spent too much time with students' misconceptions about engineers and scientists and over-emphasized the STEM careers parts, which resulted in not being able to implement the assessment as written in CoRe **(video-recorded reflection meetings, lesson study 3).**

In brief, Deniz's knowledge of assessment remained unchanged after completing the steps of lesson study 3. Although he talked about assessing students' products and the engineering design process, no details were provided about how they aligned with the objective of the lesson and why there was a need to assess these parts of the lesson. His emphasis was more on science content. There was a variety of assessment methods written in CoRe, and he had difficulty developing an understanding of how to use them. He also could not implement them during the re-teaching phase. There was no coherence in the assessment of his explanations and teaching. These features met the PCK-B category with respect to knowledge of assessment.

4.1.4.4.4. Lesson Study 4

Deniz was the observer teacher in lesson study 4; therefore, excerpts from pre and post-interviews, observation forms, and planning and reflecting meetings were considered in this section.

In the planning meetings, the discussions were centered on assessing science content outcomes, students' products, mathematics content, and prior knowledge. Deniz did not involve in the discussions concerning what to assess **(researcher's field notes, planning meetings of lesson study 1).** On the other hand, he provided his point of view regarding how to assess students' learning. The exemplifying excerpt from planning meetings was provided below:

> **Ada:** We have some misconceptions regarding the sound concept. We can use the diagnostic tree again. It really worked well in the previous lesson plan. We can put some items by considering students' misconceptions.
> **Defne:** It could be. During the lesson, we can detect their misconceptions through question and answer. However, we need something different towards

> the end of the lesson to check their learning. The diagnostic tree could be one alternative. What about concept cartoon?
> **Deniz:** I think using these methods for assessment is unnecessary. If we ask good questions supported with daily-life examples, we can assess students' understanding **(video-recorded planning meetings, lesson study 4).**

As seen above, Deniz did not appreciate using a variety of assessment methods. He favored using informal questioning to assess students' learning at the end of the planning meetings of lesson study 4. However, the discussions in the group concentrated on different types of formative assessment methods.

After the planning meetings, his focus was on assessing the science content of the lesson. He expressed that:

> We choose Kahoot to attract students' attention at the end of the lesson. We used a multiple-choice format. We have questions about sound insulation, the materials used in insulation and comparing different environments. We will apply a word association test to check their misconceptions about the engineers' jobs…With the rubric, we have a chance to assess many parts of the lesson **(pre-interview, 4).**

Although he mentioned assessing engineering content, his statements were too generic and did not include alignment with the objectives. He provided more detail about assessing science content outcomes. Moreover, regarding how to assess component, he did not demonstrate any change in his understanding.

During observation of the lesson, Deniz noted that all objectives of the lesson were assessed as planned in CoRe. He also jotted down that students' music room designs were assessed, and he totally agreed that feedback was given to the students while implementing Kahoot **(pre-observation form, 4).** It could be said that he mostly paid attention to what had been discussed in the planning meetings. He did not give detailed explanations about the parts of the lesson that were worth assessing; he only indicated that the assessment methods and their content were appropriate to check students' understanding **(post-interview, 4).**

In his post-individual CoRe, he concentrated on science content and the engineering design process but not in an equal way. For instance, he planned to use two instruments, true and false, and a matching game to assess science content and give topic-specific details. On the other hand, he used a rubric to assess the engineering design process without giving details. He did not specifically develop a rubric for his STEM lesson, the rubric had generic items and it could be used in any STEM lesson. There was a discrepancy between the objective and the assessment (**post-individual CoRe).**

In summary, Deniz's focus was more on science content, and little emphasis was given to assessing the objectives of other STEM disciplines. His explanations consisted of examples and details for science content. He had difficulty explaining how the criteria list was related to assessing students' products or the rubric connected to engineering content. He did not touch on assessing mathematics content. Moreover, the diverseness of assessment methods was not observed in his explanations. He did not make any attempts to provide ways for revising the instruction based on the assessment. Therefore, his knowledge of assessment did not show change after completing lesson study 4 and showed the features of transitional PCK, which is the PCK-B category.

4.1.4.5. Summary of the Findings for Case 4

Deniz’s PCK for STEM enhanced to some extent after attending the four lesson study cycles. His improvement showed variances with respect to components of PCK for STEM. Table 4.5. summarizes Deniz’s PCK development throughout the study.

Table 4. 5

Deniz’s Development of PCK for STEM in Four Lesson Study Cycles

	Before the Study	**Lesson Study 1**	**Lesson Study 2**	**Lesson Study 3**	**Lesson Study 4**
Curriculum	PCK-A	PCK-B	PCK-B	PCK-B	PCK-B
Learners	PCK-A	PCK-B	PCK-B	**PCK-C**	**PCK-C**
Instructional Strategies	PCK-A	PCK-B	PCK-B	PCK-B	PCK-B
Assessment	PCK-A	PCK-B	PCK-B	PCK-B	PCK-B

As seen in Table 4.5., Deniz’s PCK for all components of PCK was in the PCK-A category at the beginning of the study. In other words, his PCK was related to teaching a science topic and general. During the first lesson study cycle, all components of PCK for Deniz switched from the PCK-A to the PCK-B category. Deniz started integrating some features of STEM education into his practice and understanding; however, the coherence among the STEM disciplines was insufficient. For instance, he did notice establishing objectives for other STEM disciplines rather than science, but he discussed integrating engineering while preparing CoRe. Alternatively, he started to apply design-centered teaching practices but with some limitations.

Furthermore, Deniz's PCK for STEM showed the typical characteristics of the PCK-B category for all components at the end of lesson study 2. His improvement was not significant, and he still had transitional PCK for STEM. In general, one discipline of STEM was given more weight in his statements. For instance, he concentrated more on the science discipline regarding misconceptions, while his focus was on the engineering discipline concerning difficulties in the knowledge of learners component. Deniz focused on one STEM discipline and superficially mentioned other STEM disciplines in all components of PCK for STEM at the end of lesson study 2.

As provided in Table 4.5, Deniz's PCK for STEM remained in the PCK-B category except for the knowledge of learners component at the end of lesson study 3. Improvement in the knowledge of learners component was not accompanied by the development of other PCK for STEM components in which Deniz was a teacher of the revised version of the STEM lesson plan. He made extensive progress with learners' misconceptions and difficulties. He put equal emphasis on learners' difficulties in science and other STEM disciplines. On the other hand, he concentrated more on science objectives, and the connection of STEM disciplines in his instruction was not coherent; he encountered some difficulties in establishing connections. He could not apply a variety of assessment methods after attending lesson study 3. A similar situation was observed in lesson study 4. Deniz's PCK displayed uneven development at the end of the study. Although he reflected the features of PCK for STEM with respect to knowledge of learners, he had transitional PCK regarding knowledge of curriculum, instructional strategies, and assessment. He showed intermediate development concerning these three components of PCK.

4.1.5. Cross-Case Analysis of Participant's PCK for STEM Development

This section compared and contrasted four cases according to each component of PCK for STEM development. The aim is to underline the differences and common points in terms of knowledge of curriculum, knowledge of learners, knowledge of instructional strategies, and knowledge of assessment. All components of PCK for STEM for each case showed the characteristics of the PCK-A category at the beginning of the study, and they moved to the PCK-B category after completing lesson study 1. It could be said that four cases demonstrated similar and simultaneous development patterns up to this point. Afterward, their level of development and development patterns showed variability. How each case progressed after lesson study 1 was given component by component below.

4.1.5.1. Knowledge of Curriculum

Defne and Ece, who were the teachers of lesson study 2, and Ada who was the observer teacher, switched from the PCK-B to the PCK-C after completing lesson study 2 with respect to knowledge of curriculum. In contrast, Deniz's knowledge of curriculum was transitional throughout the study as seen in Figure 4.33. In other words, Ada, Defne, and Ece could establish objectives for at least two STEM disciplines and relate the topics with other science topics and STEM disciplines, explain their reasons for selecting objectives, and enhance understanding of the scope of science, mathematics and technology, and design curricula. Deniz had some problems in setting objectives for other STEM disciplines, such as design process and mathematics, and relating topics to other science topics and STEM disciplines at the end of the study. It could be concluded that all cases showed noticeable improvement concerning knowledge of curriculum throughout the study; however, their levels of improvement differed.

4.1.5.2. Knowledge of Learners

All cases reached the PCK-C category at the end of the four lesson study cycles concerning the knowledge of learners (Figure 4.34). However, there were some minor differences in their development patterns. For instance, three cases (Ada, Defne, and Ece) switched from the PCK-B to the PCK-C category after completing lesson study 2, whereas one case (Deniz) showed remarkable improvement in his understanding of learners at the end of lesson study 3. Although each participant was at the same level after completing the study, the time of improvement slightly differed.

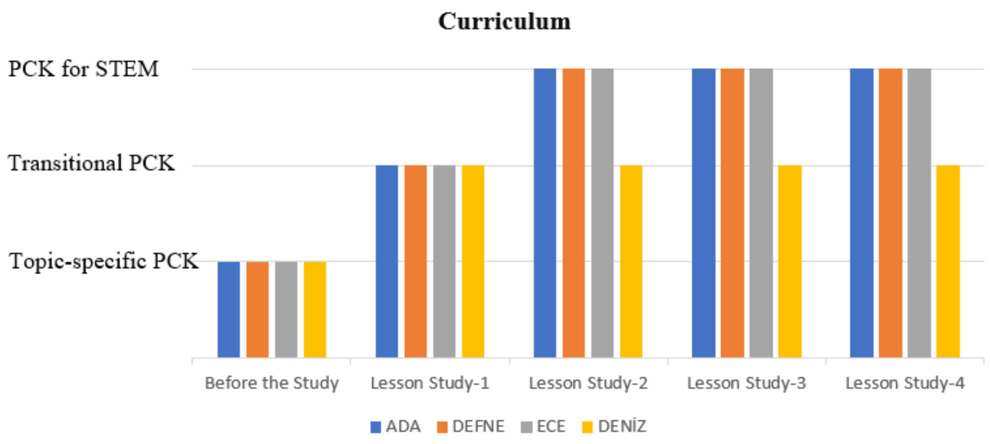

Figure 4. 33 The Comparison of Development Patterns of Knowledge of Curriculum regarding Each Case

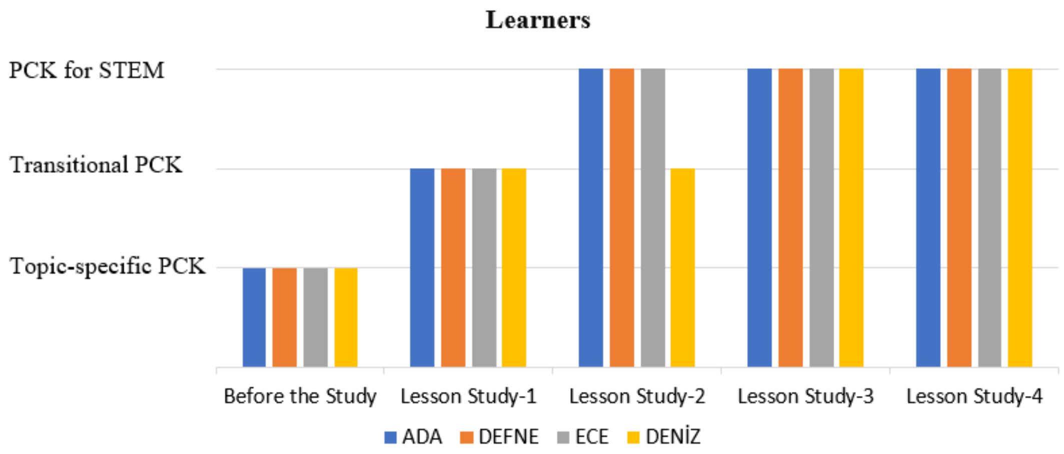

Figure 4. 34 The Comparison of Development Patterns of Knowledge of Learners regarding Each Case

4.1.5.3. Knowledge of Instructional Strategies

Three cases (Ada, Ece, and Defne) ended this process more or less at the same levels at the end of the study. Their PCK levels regarding knowledge of instructional strategies were more integrated and consisted of more coherence. They had rich repertories about the teaching strategies compatible with STEM and representations and activities in science and other STEM disciplines by giving detailed descriptions. The only difference is in these three cases' development patterns. Ada reflected the features of the PCK-C category at the end of lesson study 2, whereas Defne and Ece made progress in relation to knowledge of instructional strategies later than Ada. They reached the PCK-C category after completing lesson study 3. On the other hand, in one case, Deniz had less coherence between STEM disciplines at the end of the study as seen in Figure 4.35. He struggled to explain the preferences for choosing a particular teaching strategy in STEM lessons and did not touch on essential elements of STEM education. Different from the other participants, he had difficulty in applying design-centered teaching practices in his instruction, although the group prepared a common CoRe. It could be concluded that all cases except for Deniz had a strong PCK concerning knowledge of instructional strategies at the end of the study. Deniz demonstrated intermediate development and had transitional PCK with respect to knowledge of instructional strategies.

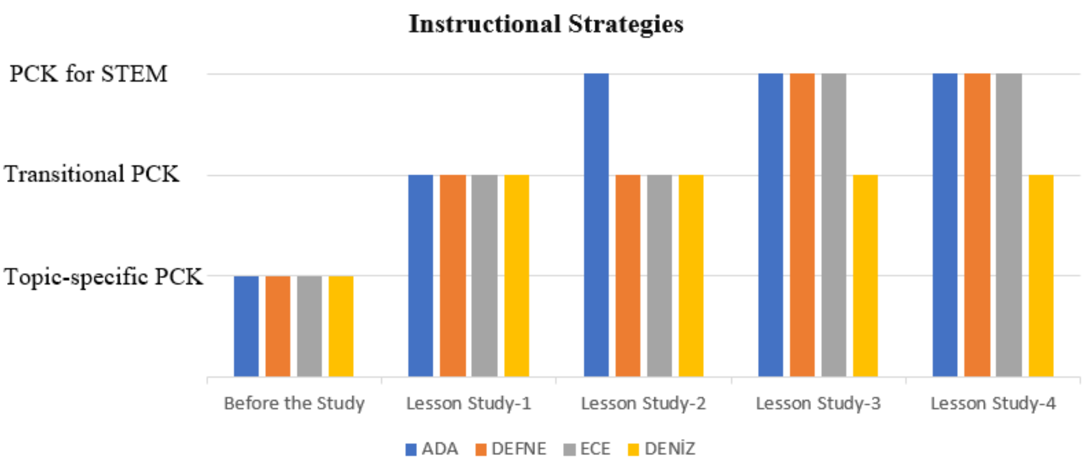

Figure 4. 35 The Comparison of Development Patterns of Knowledge of Instructional Strategies regarding Each Case

4.1.5.4. Knowledge of Assessment

Each case's PCK development pattern with respect to knowledge of assessment showed variances at the end of the study. For instance, two cases (Ada and Ece) were in PCK-C level when the study was completed. They were both conscious about assessing students' understanding of science content and in other STEM disciplines sufficiently and equally and adopted various assessment methods. However, Ada met the properties of the PCK-C category after completing lesson study 2, whereas Ece moved to the PCK-C level at the end of lesson study 3. The other two cases (Deniz and Defne) remained in the PCK-B category regarding knowledge of assessment after four-lesson study cycles (Figure 4.36). Their focus was more on science content regarding what to assess, and their explanations were too broad at the end of the study.

No evidence was found concerning how the objectives of the lesson aligned with the assessment and the importance of assessing learners' products in STEM lessons. All participants showed noticeable improvements at the end of the study; however, their development levels differed. It could be concluded that half of the cases were in the PCK-C category and half of the cases had transitional PCK with respect to knowledge of assessment.

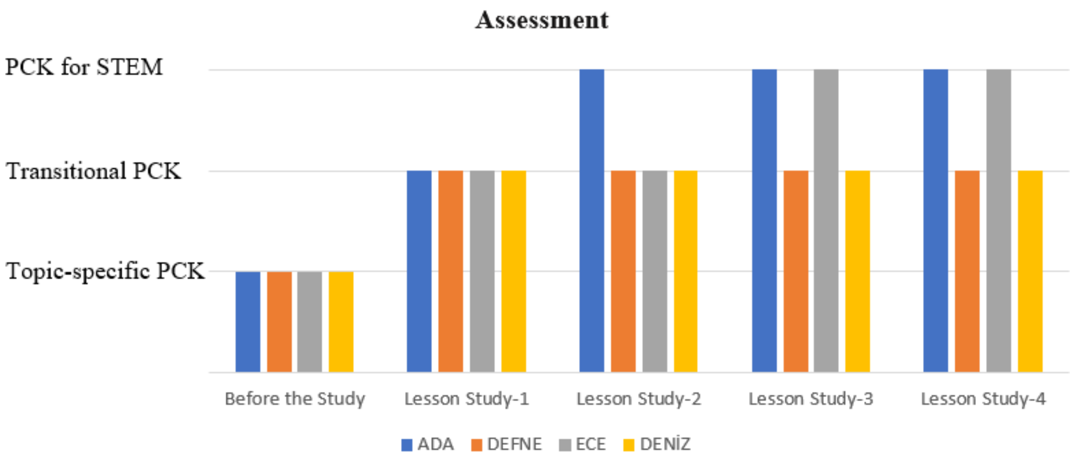

Figure 4. 36 The Comparison of Development Patterns of Knowledge of Assessment regarding Each Case

4.2. Results for Elements of the Lesson Study Contributing Preservice Teachers' PCK for STEM Development

This part aims to present how different elements of the lesson study contributed to participants' development of PCK for STEM according to each component. The findings related to the second research question were summarized in Table 4.6, and the details are presented below.

Table 4. 6

Elements of Lesson Study Contributing to Preservice Science Teachers' PCK for STEM

PCK Components/ Elements of Lesson Study	Planning	Teaching	Observing the Lesson	Reflecting
Curriculum	Ada Defne Ece Deniz	Ada Defne	-	Defne Ece
Learners	Ada Defne Ece Deniz	Ada Defne Ece Deniz	Ada Defne Ece Deniz	Ada Defne Ece Deniz
Instructional Strategies	Ada Defne Ece Deniz	Ada Defne Ece Deniz	Ada Defne Ece Deniz	Ada Defne Ece Deniz
Assessment	Ada Defne Ece Deniz	-	Ada Ece	Ada Defne Ece

4.2.1. Knowledge of Curriculum

The participants were not conscious of the scope of curricula from other STEM disciplines, such as mathematics and technology, and design at the beginning of the study **(pre-individual CoRes).** Moreover, they had a general understanding of the scope of the science curriculum and had difficulty relating the science topics to other science topics and other STEM disciplines **(pre-CoRe-1).** On the other hand, starting from the second CoRe, objectives for science and other STEM disciplines were established. All participants mentioned that the planning phase was the primary source of their PCK for STEM development with respect to knowledge of curriculum, as seen in Table 4.6. For instance, Ada stated:

> We decided the objectives of the lesson as a group and defended our perspectives in the meeting. We criticized all ideas about different objectives during the planning meetings and were open to criticism. For instance, I learned about mathematics objectives thanks to Defne. Her suggestion increased my awareness, and I started to examine the mathematics curriculum the way I examined the science curriculum **(Ada, post-interview, 2).**

Likewise, Defne highlighted that she elaborated on her understanding of the science objectives in the curriculum in the planning meetings:

> I was full of apprehension while choosing the objectives for our first collaborative CoRe. I was concerned about whether the scope of the objectives would match what we wanted to do in the STEM lesson. I examined students' books and science curriculum before coming to planning meetings. I made my suggestions and listened to my friends' ideas. We determined the objectives by criticizing each idea and discussing the reasons. For example, I gave up my idea about selecting objectives about planets because Ada put forward her idea and advocated that integrating the engineering design process would be more effective if we chose Solar eclipse topics. I had not considered the daily-life problem or testing prototype parts while suggesting my idea. Therefore, Ada changed my perspective in the (planning) meeting about choosing objective **(Defne, pre-interview, 1).**

On the other hand, Deniz indicated that planning meetings were also effective in terms of his knowledge about the scope of the science curriculum as follows:

> The science curriculum always seemed to me very complicated. I could not understand its structure. However, I am getting better at understanding it because, in the planning meetings, we discussed from several perspectives and examined the curriculum in detail, making connections with other topics. My friends' suggestions while choosing the objectives from the science curriculum were enlightening for me **(Deniz, pre-interview, 3).**

Unlike the above examples, Ece touched upon how the planning meetings were helpful for using the curricula from other STEM disciplines and relating the topics to other science topics. She indicated that:

> I realized we should examine the science curriculum in detail while designing a STEM lesson plan. Because STEM lesson plans are comprehensive, they could involve different science topics from different grades. For instance, I noticed that students should know about the friction topic to design the fastest car and choose the appropriate tires in the planning meetings. This led me to analyze the science curriculum and check whether students had learned about this objective in the previous grades. In this way, my knowledge increased **(Ece, pre-interview, 2) …** The planning meetings guided me to examine mathematics and technology and design curriculum. For instance, we wanted our students to design a sound-proof music room to find a solution to the problem. There was a related objective in Technology and Design curriculum. Moreover, we want them to calculate the budget, collect data, create graphs, and interpret them to decide whether their design would solve the problem. I learned about in which grade level these objectives were placed in the mathematics curriculum and the scope of the objectives after examining them with my friends **(Ece, pre-interview, 4).**

Similarly, Ada briefly touched on writing objectives for different disciplines in STEM lessons:

> We should consider the connection of the objectives within the science curriculum in STEM lessons. We should also do this for mathematics and technology and design curriculum. As a group, neither of us was conscious of these curricula, and the planning meetings helped us to examine them in detail. Moreover, CoRe was also helpful for me. The question in the CoRe increased my attention, and I started to focus on the order of the topics and their sequence **(Ada, pre-interview, 4).**

As seen above, Ada was one of the two participants talking about using CoRe in the planning phase of lesson study to enhance her PCK for STEM concerning knowledge of curriculum.

On the other hand, two of the four participants pointed out that the teaching phase of lesson study was influential in promoting their knowledge of curriculum. For example, Ada drew attention to the teaching parts by concentrating on how she related two science topics in her instruction:

> I realized that connecting science topics with other science topics was really important while teaching the lesson. For instance, I talked about eye health topic when I was trying to explain the harmful rays of the Sun. I added that they would learn about this topic in the following units, and I need to say that during teaching **(Ada, post-interview, 1).**

Although this point was not included in the first version of CoRe-1, Ada was able to establish a relationship with other science topics during teaching, demonstrating the influence of teaching on her development of knowledge of curriculum. Similarly, she remarked that observing peers was influential because she was able to recognize the importance of relating with sound insulation and sound propagation topics **(post-interview, 4).**

Lastly, two participants mentioned the significance of the reflection phase of lesson study in their progress with regard to the knowledge of curriculum at the end of the study. For example,

> In the first CoRe, we only wrote science objectives. We modified the science objective with my friends' suggestions. On the other hand, although we knew the importance of integrating engineering into the STEM lesson plan, we did not put it as a separate objective. I realized this discrepancy in the reflection meetings. I remembered the discussions between Ada and Ece while discussing revising the

> objectives. This discussion led me to examine mathematics and technology and design curriculum, and I suggested writing mathematics-related objectives in lesson study 2. I can see more clearly at the end of the study **(Defne, pre-interview, 4).**

In brief, all participants found the planning phase of the lesson study beneficial in terms of enhancing their knowledge of curriculum. Some of the participants addressed the teaching and reflection parts of lesson study and the use of CoRe as the contributing sources of their development of knowledge of curriculum, while one of them appreciated the importance of observation of teaching.

4.2.2. Knowledge of Learners

All participants mentioned that planning, teaching, observation of teaching, and reflecting on the lesson helped them to improve their knowledge of learners, as seen in Table 4.6. Moreover, three participants pointed out that using CoRe in lesson study cycles contributed to their knowledge regarding learners' misconceptions and difficulties.

In relation to the planning meetings, participants touched upon collaborative work was beneficial in considering the different perspectives about students. For instance, Ada stated:

> Everyone looks from a different point of view in the planning meetings, and another group member completes the missing part that I cannot think of. If we had prepared individually, we might not have been able to think so comprehensively. For instance, I could not consider students' difficulties in determining the unit of sound. One of my friends suggested this since students had similar difficulty in STEM lessons concentrating on speed. I like these types of discussions, and I believe these contributed to my development **(Ada, pre-interview, 4).**

Similarly, the other participant stressed how she started to think about science-related misconceptions through the discussions in the planning meetings:

> The planning part was very effective for me regarding students' misconceptions. For instance, Deniz observed the 5th grade lessons as a cooperating teacher and faced misconceptions about the heat. Then, we argued about it in the planning meetings, and I realized that I had never thought about this misconception before **(Ece, pre-interview, 3).**

Moreover, Ece mentioned that the planning meetings made her realize mathematics-related misconceptions in lesson study 4. She stated that her consciousness was increased about the misconceptions related to bar charts, and she paid specific attention to this issue while teaching the lesson about designing a sound-proof music room (**post-interview, 4).**

Three participants also mentioned that using CoRe in the planning phase of lesson study helped them to augment their knowledge of learners at the end of the study. For instance:

> Thanks to CoRe, my knowledge was enhanced about which concepts students might have misconceptions about or at which points of the lesson might be challenging for them. If I detect misconceptions in any of the STEM fields, I start to think about which strategies I can use to understand whether they are eliminated or not. The two questions in the CoRe helped me a lot to develop an awareness of students' misconceptions and difficulties in the planning meetings. I know that teachers should be prepared before the lesson about these issues **(Ece, pre-interview-4).**

With respect to the teaching part of the lesson study, participants talked about how they began to understand students' points of view in the learning process. After the teaching, they were able to consider alternative ways of identifying and overcoming students' difficulties and misconceptions. The exemplifying excerpts are provided below:

> We did not prepare our first STEM lesson plan according to the classroom environment. I mean, we did not think about the most basic questions that students could ask or what we would do if we faced misconceptions. However, as we teach and observe our friends' lessons, we now consider students' misconceptions and explanations about how we deal with them. The more we interact with the student, the more misconceptions we can detect **(Deniz, pre-interview, 4).**

Deniz stressed that teaching and observation of teaching were the two sources of knowledge development regarding learners. The CoRes prepared in lesson study 3 and lesson study 4 included many misconceptions and difficulties in science and other STEM disciplines in parallel with what Deniz stated.

In a similar vein, Defne expressed:

> We applied three STEM lessons, and the last one is also ready to implement. While preparing our STEM lessons, we now consider what students might think

> and at what points they might have difficulty. Implementing a STEM lesson with 6th grade students was very helpful at this point. I consider students' misconceptions in different parts of lesson and seek ways to detect and eliminate them. Actually, I think the engineering design process and lesson study have a lot in common. We plan, implement, reflect on the lesson, weighted our strengths and weakness in the plan, and revise and re-teach it, as in the engineering design process. This process influenced my understanding of students **(Defne, pre-interview, 4).**

Likewise, Ada explained her teaching experiences after she carried out her first STEM lesson plan, and she pointed out how she realized learners' difficulties in engineering discipline while implementing the lesson plan:

> I have not implemented a lesson plan in the classroom before. Therefore, I struggled in terms of which concepts students might experience difficulty with while preparing CoRe. I had lots of deficiencies before implementing the lesson. However, I started understanding students' points of view while teaching the lesson. I began to give feedback on their questions. I tried to present additional examples about the points that experienced difficulty. For instance, since I realized they had difficulty differentiating criteria and limitations, I provided telephone examples to make the concepts concrete **(Ada, post-interview, 2).**

As Ada indicated, participants started to pay more attention to learners' difficulties in science and other STEM disciplines after teaching and began to write them in CoRe **(CoRe-2, CoRe-3, and CoRe-4).**

Moreover, Defne mentioned the importance of teaching part of lesson study by focusing on the usefulness of CoRe:

> As a teacher of the lesson, CoRe gives me the message that "you should be ready for these misconceptions and difficulties before coming to the lesson". More importantly, we have experienced almost all the misconceptions and difficulties we wrote about there. It is good to see that the possible misconceptions discussed in the meetings actually emerged in the lesson… In the first STEM lesson plan, we had little interaction with the students and could not correctly predict their misconceptions and difficulties, but now we are getting better **(Defne pre-interview, 4).**

Additionally, participants emphasized the reflection part as one of the major sources to contribute their knowledge of learners. For instance, Defne explained that reflection was the valuable part of the lesson study that contributed to her knowledge development regarding learners as follows:

> While implementing the STEM lesson plan, we have been using observation form. We write our observations on specified points and make at least three

> suggestions for revision of the lesson. For me, it was helpful, especially in terms of difficulties and misconceptions of students. Reflecting on the lesson helped me to increase my self-confidence about teaching. In the second lesson study cycle, I implemented the first lesson plan. I had difficulties in correcting misconceptions about speed. Then, we discussed and modified the CoRe in the reflection meetings. Ece's lesson was more effective than the first version, and this part was the turning point for me. Now, I will be the teacher of the revised version of the lesson plan this time, and I feel confident about students' misconceptions and difficulties **(Defne, post-interview, 4).**

Ada mentioned similar things to Defne. She underlined that the revised version of CoRe-1 was richer than the first version of CoRe-1 in terms of learners' difficulties:

> I applied the revised version of CoRe in the first lesson study cycle. While Deniz was implementing the first version, I began to realize the flaws in our plan. I asked myself "whether the students understood the concept of criteria and limitations". I felt very comfortable while implementing the revised version of CoRe. After Deniz's lesson, I suggested many points about students' difficulties in the meetings, and I added an example to address these students' difficulties in my teaching **(Ada, pre-interview, 2).**

Furthermore, Ada provided more comprehensive understanding about the importance of reflection with respect to the knowledge of learners at the end of the study as follows:

> We prepare and implement STEM lessons, observe the students and reflect on them. Discussions about what we could change for the revised lesson plan were very fruitful during this process. For instance, my friend might observe different students than me and observe he is struggling. Then, she shares her observations in the reflection meetings. Arguing over these observations taught me a lot. I also took many observation notes while my friends implemented the lesson and shared them with the group. For instance, students had difficulty understanding the sound absorption principles in the last STEM lesson plan. None of us thought this concept would cause confusion. I have noted it and will share it with my friends in the reflection meeting so that we can revise the CoRe. I can say I learned the most in the reflection part **(Ada, post-interview, 4).**

As Ada stated above, this point was added to post-CoRe 4 after the reflection meeting. Similarly, Deniz shared a moment of how he changed his mind in the reflection meetings about the knowledge of learners at the end of the study:

> We had robust discussions about the difficulties throughout the process. While arguing over the implemented lesson, I noticed some points I had never considered. For instance, one group member said that you might have explained the student's questions through energy transformation (in the third STEM lesson plan). Then, I asked myself, "she is right; why could I not think of this way

> during teaching". If I had explained this way, I could handle with student's difficulty more effectively. Therefore, the reflection meetings were very constructive **(Deniz, pre-interview, 4).**

Ece explained her improvement in knowledge of learners' by addressing observation of the lesson combined with the reflection part at the end of the study:

> During the observation of the lesson, we realized the missing parts of the lesson. In the following meetings, we constantly revise CoRe and add and remove some misconceptions and difficulties. For instance, during observation, I could realize students' misconception that civil engineering is the only type of engineering. Later in the group discussion, I increased my awareness of this misconception while my friend shared her observation notes. In the same manner, I noted that in Ada's lesson, one student stated that "the heat cannot be measured," and she skipped this misconception. I shared my observation and feedback during the reflection meeting and I think it helped her improve her knowledge **(Ece, pre-interview, 4).**

In brief, participants mentioned that all elements of lesson study contributed to their development of PCK concerning the knowledge of learners. Furthermore, using CoRe in lesson study was also frequently mentioned by the participants in terms of the knowledge of learners. Participants advocated that they became aware of students' difficulties and misconceptions using CoRe as a lesson planning tool.

4.2.3. Knowledge of Instructional Strategies

All participants stressed that planning a collaborative lesson plan was effective in improving their knowledge of instructional strategies. To begin with, participants mentioned that the planning phase was influential in shaping their knowledge about alternative teaching strategies used in STEM lesson plans. For instance, Defne stated that:

> If we had not prepared the plan as a group, I could not have learned about problem-based learning. Maybe I would never use it in STEM lessons. I might search the internet and examine the course books to learn about problem-based learning. However, I have learned in a better way by discussing it with my friends and you. There were many ideas about the strategy, and we had a chance to criticize the advantages and disadvantages. We discussed how to integrate different disciplines into problem-based learning, especially the engineering design process **(Defne, pre-interview, 4).**

Similar to Defne, Ada pointed out the significance of collaborative work in planning meetings regarding choosing appropriate teaching strategies for STEM lessons at the end of the study:

> It is a good opportunity for us to learn more about problem-based learning in the planning meetings. This was our last lesson plan. We learn together by discussing. What Ece's suggested made sense to me, and we were able to use different teaching strategies thanks to this study, such as REACT and problem-based learning. We did not have a chance to prepare lesson plans using problem-based learning before because of the heavy load of teaching method courses. We cannot all know everything, but we can learn much from our peers. This study provided a learning environment for me. During this process, we discussed with my friends in the group; I mean, we learned by discussing. I learned a lot from my friends. I learned how STEM education and problem-based learning fit each other smoothly **(Ada, pre-interview, 4).**

In parallel with her statements, Ada used problem-based learning in her post-individual CoRe which was evidence for her enhanced understanding of using alternative teaching strategies compatible with STEM at the end of the study.

Deniz also shared his experiences with regard to teaching strategies and design-centered teaching practices and explained his progress through the planning meetings of lesson study:

> I like working in a group and cooperating with my peers. While I was preparing the lesson plan individually, there was a single point of view. It feels like what I am doing is right. On the other hand, while preparing a lesson plan with the group, there are multiple points of view, and I frequently say to myself that "what my friend has suggested is a better way to plan a lesson"… Moreover, I did not know anything about how the engineering design process might be used with students, but we discussed a lot about how to integrate it in the best way possible. Although we took the same courses (in undergraduate education), everybody contributed differently and learned from each other in the meetings **(Deniz, pre-interview, 4).**

Correspondingly, Ece talked about how the planning meetings were valuable in planning a lesson plan other than using the 5E learning cycle as follows:

> 5E is a method we know very well and use constantly. I thought we might experience difficulty when using REACT. I used it once last year, and it was difficult for me. Also, I could not get it right in my head what we could do at which step. Applying and Cooperating parts were incredibly challenging for me. For instance, I had not planned anything special for Cooperating part in my previous lesson plan; I just said, "there is a cooperating among students in the application part". However, I understand this is not the case; we need to think of

> specific things for this step; students should learn in collaboration with the activity **(Ece, pre-interview, 2).**

As seen in Table 4.6. all participants appreciated the planning phase of the lesson study in terms of their development of knowledge of instructional strategies. In the same manner, the teaching phase was found to be effective regarding knowledge of instructional strategies. Participants' focus was on design-centered teaching practices and strategies for engagement with engineering concepts in relation to the teaching part of the lesson study. For instance, when Deniz was asked to compare his development of knowledge of instructional strategies at the end of the study, he referred to teaching and observation of teaching in addition to planning and reflecting parts. He provided examples from different cycles of lesson study and explained that:

> I learned a lot about the engineering design process while implementing the lesson. For instance, in our first STEM lesson, we talked about students should generate as many solutions as possible (while solving the engineering problem); however, I could not reflect this discussion into practice. I can say that I learned from my mistakes during teaching and the criticism directed to me (in the reflection meeting)… As I observed in this last STEM lesson plan, using a science magazine was effective; students searched for the necessary information. I will share my thoughts in the reflection meeting that this was the best STEM lesson in terms of integrating the steps of the engineering design process **(Deniz, post-interview, 4).**

Similarly, Defne underlined that teaching was the contributing factor to her enhanced knowledge of design-centered teaching practices and representations after implementing the first version of the STEM lesson plan in lesson study 2:

> The teaching part made me notice the importance of completing the entire cycle of the engineering design process. I could not complete it in this lesson. If I had enough time, I could let students re-build their cars and underline speed concept more effectively. … I understand that using graphs was necessary for our lesson to visualize the concepts during my lesson and make a decision about the designs **(Defne, post-interview, 2).**

Additionally, participants generally emphasized how they had a chance to observe different teaching strategies in practice throughout the study. They emphasized that the teaching and observation parts of lesson study created a rich environment for them regarding teaching strategies:

> I started using the strategies more regularly and systematically because we had little teaching experience at the beginning. Moreover, observing my peers while

> implementing a specific teaching strategy was helpful for me. How they reflected what we prepared in the classroom, how they added or removed some components, or changed the flow of the lesson during instruction were really effective **(Ece, post-interview, 3).**

In a similar vein, Ada stressed teaching and observation of teaching parts as contributing factors to her advanced knowledge:

> Experiencing what I learned during my undergraduate education in the classroom environment helped me to consolidate what I learned and noticed the deficiencies in my knowledge regarding teaching strategies. I also learned to integrate mathematics and engineering into teaching strategies. The observation form you gave us was also helpful. The implementation of the lesson plan had a positive effect on my development. Moreover, while my friends were observing my lesson, I felt lucky. Their feedbacks were really essential for my development **(Ada, post-interview, 1).**

Defne mentioned that teaching part of lesson study enabled a chance to apply theoretical knowledge and strengthen her knowledge of instructional strategies:

> While planning a lesson plan with the 5E learning cycle in methods, we wrote that the "teacher will be the guide through the lesson". I really understood the meaning of the "guide" by teaching and observing my friends in this study. We want students to explore necessary scientific knowledge, develop prototypes and find a solution. Both the 5E learning cycle and STEM education require effective guidance in the classroom, and I mostly learned how to guide students at the end **(Defne, pre-interview, 4).**

Lastly, three participants mentioned that the reflection parts of the study were also helpful in improving their knowledge of instructional strategies. Defne pointed out that she felt more confident in teaching the revised version of the lesson plan as follows:

> We used several teaching strategies during this process. Although we had a strong background in the 5E learning cycle, we learned how to integrate STEM education into it. On the other hand, learning to use REACT and problem-based learning was one of the most significant advantages of this study. We also learned about the design process. The meeting after teaching helped me to go through the teaching process and improve my knowledge about using the strategy. For instance, I will teach the revised version of the STEM lesson. We used problem-based learning for the first time. I feel confident about using problem-based learning combined with STEM education because we already used it; I observed it and will discuss our observation. If any flaws are detected by any of my friends, we can revise (**Defne, post-interview, 4).**

The other participant mentioned her advanced design-centered teaching practices after the reflection meetings when asked at the end of the study:

> My friends mentioned the points that did not catch my attention during the lesson in these meetings. For instance, Ada said that the roles in group work should be carefully balanced during the design process in the previous lesson plan. I tried to involve girls, especially in the testing process, in my STEM lesson after these discussions **(Ece, post-interview, 4).**

In brief, all participants agreed that collaborative planning, teaching, and observation of teaching parts of lesson study were the main elements that contributed to their development of knowledge of instructional strategies. Only one participant did not refer to the influence of reflection meetings with respect to knowledge of instructional strategies at the end of the study.

4.2.4. Knowledge of Assessment

Participants concentrated on assessing only science content outcomes at the beginning of the study **(pre-individual CoRes).** As seen in Table 4.6. some elements of lesson study cycles contributed to their knowledge about what to assess, how to assess, and revision in instruction based on assessment.

All participants valued the planning part of the lesson study concerning their improvement in knowledge of assessment. For example, Ece talked about multiple perspectives in the planning meetings that shaped her knowledge of assessment as follows:

> We had difficulty in choosing the appropriate assessment tools. Working in the group was advantageous for us at this point. For instance, Deniz proposed using a rubric to assess students' performance, but I did not know anything about the items in the rubric. We discussed this as a group and decided to reflect the steps of the engineering design process into a rubric on a three-point scale. If I was working alone while preparing a STEM lesson plan, I would not prepare this rubric **(Ece, pre-interview, 1).**

Moreover, Ece approached from a different point of view and explained how the assessment methods they used became varied after the planning meetings in lesson study 3:

> We discussed several things regarding assessment in the planning meetings. For instance, we prepared a diagnostic tree. I had not used it before, and preparing it with my friends gave me confidence. During this process, we talked about the "Draw and Engineer Test", rubrics, and concept cartoons. If I individually planned CoRe, I would have difficulty in finding a suitable assessment method **(Ece, pre-interview-3).**

As Ece indicated above, CoRes designed in lesson study 3 and lesson study 4 included a variety of assessment methods and focused on assessing students' learning in different STEM disciplines.

Ada mentioned similar things regarding the importance of planning meetings on her development of knowledge of assessment:

> The discussion in the planning meetings throughout the study led me to conduct additional investigations. For instance, I suggested using the KWL chart, which my friend also liked. Preparing the questions in the KWL chart as a group made our work easier **(Ada, pre-interview, 4).**

Furthermore, participants frequently indicated the significance of reflection meetings on their progress regarding assessment, especially with regard to assessing engineering content and students' products in a STEM lesson. For instance:

> We created a rubric to assess learners' understanding during the design process. We collected engineering notebooks and scored learners' performance in the (reflection) meeting. Then, we discussed that some items were not adequate to assess students' performance and revised them. Moreover, we changed objectives after completing an assessment of the rubric. Similarly, we used the revised version of the rubric in the second CoRe and will assess engineering notebooks again in the upcoming meeting with my friends **(Defne, post-interview, 2).**

With respect to assessing students' products, Ece mentioned how their understanding was deepened through the observation of the lesson and reflecting on the lesson as follows:

> While observing Ada's lesson, I realized that more emphasis should be done on how we plan to assess students' thermos designs. Ada tried to explain a little. However, I will discuss in the reflection meeting that the criteria list should be presented at the beginning of the engineering design process **(post-interview, 3).**

Another participant emphasized how she was able to make revisions in instruction in the reflection meetings with the help of the observation protocol:

> I think the last three questions in the observation form (proposing at least three points for revising CoRe) were practical. They are about what we could change in CoRe to make students better understand the lesson. For instance, some assessment methods did not work well in the classroom as we planned, such as the concept cartoon about speed in the second lesson plan. We changed the time of the implementation in the reflection meeting. Therefore, reflection meetings were helpful in criticizing the plan and making the necessary revisions in the assessment **(Ada, pre-interview, 4).**

To conclude, the planning and reflection phases of the lesson study were considered major contributing elements in participants' development of PCK with respect to knowledge of assessment at the end of the study. None of the participants mentioned the teaching phase and the use of CoRe regarding their improvement of knowledge of assessment.

CHAPTER 5

DISCUSSION

In this chapter, firstly, the results regarding participants' PCK for STEM development were discussed according to the four components by comparing and contrasting PCK and STEM literature. Then, the results concerning the elements of the lesson study were discussed. Finally, implications for teacher education programs, teacher education research, and future studies were provided.

5.1. Discussion of the Results for PCK for STEM Development

The present study investigated how preservice science teachers' PCK for STEM develops in the context of lesson study. In parallel with this purpose, four lesson study cycles were carried out with four preservice science teachers. Participants collaboratively plan their STEM lessons in this process. The STEM lesson was implemented in a real classroom environment with 6^{th}-grade students. After teaching, the group reflected on the lesson by drawing upon their observations and experiences. The lesson plan was modified, and the re-teaching phase was completed. Each preservice teacher was supposed to teach one first version of the STEM lesson plan and one revised version of the STEM lesson plan throughout the study. The main results of the study showed that participants were not able to integrate the main elements of STEM education into their CoRe at the beginning of the study, and their PCK was topic-specific (PCK-A). However, all participants showed improvement in the level of their PCK for STEM at the end of the study, whether PCK-B (transitional PCK for STEM) or PCK-C (coherent PCK for STEM). Participants in the PCK-B category focused more on one STEM discipline, and the integration between the disciplines was not strong. On the other hand, participants in the PCK-C category equally concentrate on at least two STEM disciplines. These findings are compatible with Aydin-Gunbatar et al. (2020) study, which stated that all participating preservice chemistry teachers' PCK for STEM progressed due to the LESMER model enriched with experiencing STEM activities, studying with mentors and reflection; however, the level of improvement displayed differences among the participants. Similarly, Lau and Multani (2018) found that engaging in design challenges and reflection on the experiences contributed to the science and mathematics teachers' PCK for STEM development when they were subjected to teaching out-of-discipline content. Faikhamta et al. (2020) and Sarkim (2020) pointed out that long-term professional development programs in which teachers are actively involved have positively influenced shaping their PCK for STEM. In the current study, the preservice science teachers were actively involved in more than a semester-long lesson study cycles and improved their PCK for STEM; therefore, supported the findings of previous studies mentioned above. Moreover, participants spend considerable time with each other in the planning and reflecting phases of four lesson study cycles. For instance, the planning meetings generally lasted four to six hours, and reflection and re-reflection meetings lasted one hour in one lesson study cycle. The participants used the PCK language during these meetings. They had intense discussions regarding curriculum, learners, instructional strategies, and assessment through the prompts in CoRe for nearly six months which might be another significant factor that helped them increase their PCK for STEM in this study.

When the PCK for STEM components was considered, the findings revealed that the degree of development showed dissimilarity across the cases. For instance, after completing four-lesson study cycles, Ada and Ece reached the highest level of PCK concerning all components of PCK for STEM. On the other hand, Deniz's knowledge of learners met the characteristics of the PCK-C category, whereas other components of PCK for STEM progressed to the PCK-B category. Four preservice science teachers collaboratively planned the STEM lesson plans, followed the same plan, taught the same classes, and reflected on the lesson together. However, although there are some commonalities in their PCK, different PCK for STEM levels emerged from the data of the study. In addition, their development patterns varied, even if the participants finished the study with the same PCK for STEM levels according to its component. For example, Ada transitioned to PCK for STEM after completing lesson study 2 while Ece moved from PCK-B to PCK-C with respect to knowledge of assessment at the end of lesson study 3. It could be inferred that PCK for STEM is specific to each case, and the development pattern across the participants is unique. A similar situation has been observed in the literature; for instance, Belge-Can and Boz (2022) pointed out that two participating preservice chemistry teachers' PCK development patterns displayed differences in a two-year longitudinal PCK-based study although they attended the same courses in the teacher education program. This finding might be explained by the idiosyncratic nature of PCK (Gess-Newsome, 2015; Park & Oliver, 2008).

Furthermore, it could be highlighted that the constituent elements of PCK were not developed simultaneously within some participants in the present study. In other words, expanding knowledge in one category of PCK was not accompanied by an expansion in other PCK components. For example, Deniz's PCK for STEM regarding knowledge of learners reached the PCK-C level at the end of the lesson-study 3; however, his PCK concerning the other three PCK components reflected the features of the PCK-B category at the end of the study. The improvement in his knowledge of the learner component did not mean his overall PCK was developed. Therefore, PCK for STEM components developed unevenly for Deniz. Similar to Deniz, Defne demonstrated uneven development. While her knowledge of curriculum, knowledge of learners, and knowledge of instructional strategies improved to the PCK-C category, her knowledge of assessment reflected typical features of the PCK-B category at the end of the study. There are several PCK studies in the literature reported uneven development among the components (Adadan & Oner, 2014; Belge-Can & Boz, 2022; Brown et al., 2013; Ekiz-Kiran et al., 2021; Magnusson et al., 1999; Reynolds, 2020). Several factors might be influential at this point. For instance, preservice teachers' teaching efficacy, different orientations to teaching science, their personal characteristics, and the level of subject matter knowledge (Gess-Newsome, 2015; Park & Oliver, 2008) might be effective in the uneven development of PCK for STEM components. A detailed discussion regarding each PCK for the STEM component is given below.

5.1.1. Discussion of the Results for Knowledge of Curriculum

Concerning setting objectives for science and other STEM disciplines, participants were not fully aware of the scope of the science curriculum at the beginning of the study. Moreover, they had not examined the mathematics and technology and design curricula before the study and did not form objectives except science discipline in their pre-individual CoRes. The results of the study pointed out that all participants improved their knowledge of curriculum to some extent at the end of the four lesson study cycles. For example, participants mentioned integrating the engineering design process into their lesson in lesson study 1; however, they did not establish clear objectives related to engineering after the planning meetings. The reflection meetings could be considered a turning point where participants were involved in discussions about writing objectives from other STEM disciplines at the end of lesson study 1. Afterward, the participants agreed on writing science, mathematics, and engineering-related objectives starting from lesson study 2. Three participants were able to set objectives for science and other STEM disciplines with equal emphasis after completing four-lesson study cycles. This situation is consistent with Faikhamta et al.'s (2020) study stating that teachers concentered on writing science-related objectives at the beginning of PCK-based professional development on STEM education, but they were able to write objectives for the engineering design process, mathematics, and 21st century skills at the end of the professional development program. In addition, Aydin-Gunbatar et al. (2020) reported similar results. Preservice chemistry teachers wrote only chemistry-related objectives at the beginning of the STEM-based elective course; however, the majority of the participants were able to consider writing objectives for at least two STEM disciplines (i.e., engineering design process, mathematics) after a semester. It is evident that objectives should be derived from multiple disciplines and tied to the standards in STEM lessons (Bartels et al., 2019; Guzey et al., 2016). In the current study, participants extended their understanding of other curricula as the lesson study progressed, but they also reported difficulties in determining the relevant objectives for other STEM discipline objectives. Participants felt comfortable selecting and modifying science objectives towards the end of the study; however, writing objectives for mathematics according to the students' levels was challenging for them. This finding is in parallel with Srikoom et al.'s (2018) study pointing out that teachers tended to integrate familiar concepts from mathematics without examining the curriculum while planning STEM lessons. In our case, for example, Ada recommended writing mathematics-related objectives about four mathematical operations in the early stages of study and did not consider the mathematics curriculum while making this suggestion. However, she increased her awareness about the scope of the mathematics curriculum and recommended writing objectives from the mathematics curriculum and adapting them to the students' grade levels in lesson study 2. Additionally, establishing engineering objectives was also difficult for participants at the beginning of this study since there is no engineering curriculum from which the objectives were obtained. It is reasonable to note that as participants began to use the engineering design process correctly, it was reflected in the quality of engineering-related objectives. This point might be an indicator that subject matter knowledge is influential in shaping PCK, and previous research supported this finding (Carlsen & Daehler, 2019; Großschedl et al., 2015).

Moreover, the difficulties in setting objectives other than science content are most probably associated with the curriculum courses participants took in their undergraduate education. The courses in teacher education programs are influential in preservice teachers' knowledge of curriculum (Belge-Can & Boz, 2022; Subramaniam, 2022); however, participants of the study did not take any curriculum courses regarding mathematics and technology and design. They were not familiar with the scope of these curricula at the beginning of the study. Therefore, the experiences in lesson study cycles might have contributed to participants' understanding of setting objectives for out-of-discipline content in STEM education in the present study. In literature, several studies emphasized the importance of lesson study in promoting knowledge of curriculum. For instance, the intervention group performed better in understanding the scope and sequence of the physics curriculum compared to the control group in a lesson study conducted with preservice teachers in a field experience course (Juhler, 2016). Another study carried out by Boz and Belge-Can (2020) applied a microteaching lesson study with preservice chemistry teachers in which all participants' knowledge of curriculum regarding the objectives of solubility concepts was enhanced due to the lesson study. This point was contradictory to some degree with our findings because although all participants showed improvement with respect to setting objectives in STEM disciplines in the context of lesson study, their level of development differed. Ada, Ece, and Defne were able to set, modify and critique at least two STEM objectives. On the other hand, Deniz focused on science objectives, and he did not pay too much attention to setting objectives for engineering and mathematics most of the time, although he used the engineering design process and mathematics in his STEM lessons. It could be inferred that Deniz demonstrated intermediate improvement concerning the knowledge of curriculum. This difference might be explained by teaching out-of-discipline content in STEM education because his understanding of the science curriculum was also limited at the beginning of the study but developed after completing four lesson study cycles. This improvement was not accompanied by understanding of other disciplines' objectives, warnings, and limitations. Moreover, it is reported in the studies that improvement in knowledge of curriculum is person-specific knowledge (Aydin et al., 2013; Ekiz-Kiran et al., 2021); therefore, Deniz's development level might not be in the same manner as other participants concerning knowledge of curriculum.

Additionally, participants' knowledge was enhanced concerning relation to other science topics and STEM disciplines at the end of the study. They began to consider the link between the previous and the following science topics and provided examples in the teaching phase of lesson study. For instance, Defne was the teacher of lesson study 2, and she did not connect the speed concept with force and friction topics which students needed to consider while designing their car prototypes. Defne was also the teacher of lesson study 4, and she linked the sound insulation topic with sound propagation in the teaching phase, this time more apparently. Moreover, Ada did not relate the topic with other STEM disciplines in her first teaching experience in lesson study 1, but she related to one goal of the science curriculum with the engineering content through career awareness in lesson study 3. This provides evidence that teaching experience plays an important role in developing knowledge of curriculum in this study, in line with several studies (Davis, 2004; Friedrichsen et al., 2009). The present study provided augmented teaching experiences for preservice science teachers to implement STEM lessons supported with the observation by peers, thus, might have contributed to their knowledge of curriculum.

5.1.2. Discussion of the Results for Knowledge of Learners

All participants had a limited understanding of the learners before participating in the lesson study. Concerning misconceptions, preservice science teachers had difficulty stating and determining misconceptions in science prior to the study in parallel with the related literature (Barnett & Friedrichsen, 2015; Ekiz-Kiran et al., 2021; Juhler, 2016). Moreover, no misconceptions or difficulties regarding other STEM disciplines were found in their CoRes at the beginning of the study. All participants showed remarkable improvement and reached the highest PCK for STEM level concerning the knowledge of learners at the end of the study. As suggested by the relevant literature, knowledge of learners is one of the most easily improved components of PCK (Park & Oliver, 2008), and knowledge of learners is the only component that displayed more coherence between STEM disciplines that emerged from the data of this study. Preservice science teachers identified misconceptions, gave detailed explanations about the misconceptions in at least two STEM disciplines in a detailed way, provided ways to identify them, and talked about possible origins of these misconceptions by drawing upon their self-teaching experiences and relevant literature rather than their self-experiences as students. This finding is aligned with the research providing that teachers' understanding of balancing science and engineering content with respect to the knowledge of learners enhanced after the PCK-based STEM professional development program (Faikhamta et al., 2020). Participants' focus was on science-related misconceptions in the first lesson study cycle; however, as the lesson study cycles continued, they began to consider science, engineering, and mathematics-related misconceptions. For instance, participants used specific methods to elicit students' engineering-related misconceptions of engineering in lesson study 3 and lesson study 4. They accommodated the instruction by considering students' possible mathematics-related misconceptions. Participants equally focused on misconceptions in different STEM disciplines in parallel with Aydin-Gunbatar et al. (2020) study revealing that most participants described science, engineering, and mathematics-related alternative conceptions after attending STEM-based elective course including reflecting and studying mentors phases. Moreover, the number of science-related misconceptions participants stated was enhanced. Similar results were reported in the previous studies. For instance, Adadan and Oner (2014) studied with two preservice chemistry teachers, and both participants were able to list possible sources of students' misconceptions about the behavior of gases topic through CoRe, and the number of misconceptions increased due to PCK- based method course. Moreover, Ekiz-Kiran et al. (2021) concluded that all participating preservice teachers' understanding of misconceptions enhanced at the end of the PCK-based field experience course supported with CoRe and observation. Therefore, the elements of lesson study utilized in the present study might contribute to participants' development of knowledge learners with respect to misconceptions.

Concerning difficulties, preservice teachers were partially aware of students' difficulties in science and other STEM disciplines at the beginning of the study. It is reported in the literature that preservice teachers might not realize students' difficulties because of their limited teaching experiences (Brown et al., 2013; De Jong & Van Driel, 2004; Reynolds, 2020). Additionally, no difficulties regarding other STEM disciplines were observed prior to the study. Similar to the misconception sub-component, the current study greatly contributed to preservice teachers' understanding of learners' difficulties in at least two STEM disciplines. Participants concentrated more on engineering-related difficulties throughout lesson study 1; however, they began to pay attention to the science and mathematics-related difficulties over the course of the study and considered these points in the planning process. For instance, they determined that choosing the best solution challenged the students, and then they created decision diagrams to scaffold student learning. Similarly, they realized that creating and interpreting graphs from the collected data was difficult for students; for this reason, preservice teachers prepared additional examples in the planning phase. As evidenced in previous studies (Aydin-Gunbatar et al., 2020; Lertdechapat & Faikhamta, 2021), preservice teachers' knowledge of learners regarding difficulties in science and other STEM disciplines improved as a result of participating in long-term training, which is lesson study in this case.

Knowledge of learners is the only PCK for STEM component that all participants achieved PCK-C category in the current study. The development patterns concerning the knowledge of learners were nearly the same for all participants. Each participant was supposed to implement at least seven hours of STEM lessons in the present study and observed nearly 25 hours of STEM lessons. For instance, Defne and Ece were the teachers of the second lesson study cycle, and both of them moved to the PCK-C level at the end of this cycle concerning the knowledge of learners. In other words, lesson study 2 was a crucial turning point for Ece and Defne regarding the knowledge of learners, who were the teachers of the lesson. Similarly, Deniz was the teacher of the revised version of the STEM lesson plan in lesson study 3, and he moved to the highest level after the re-teaching phase. Therefore, teaching experiences supported with observing peers in the classroom environment might be the reason for improved knowledge regarding learners. In a study conducted by Brown et al. (2013), it was reported that gaining experiences in the classroom environment contributed to preservice teachers' knowledge of learners, as evidenced in our findings. On the other hand, the result of this study is contradicted by Boz and Belge-Can's study (2020), in which preservice teachers' knowledge regarding learners' difficulties about solubility concepts remained unchanged after attending lesson study. However, the researchers applied micro-teaching lesson study, and the preservice teachers could not implement the lesson plan in an actual classroom environment. Therefore, the differences between these results might be linked to the teaching experiences in a real classroom environment in which preservice science teachers are provided the opportunity to interact with students in this study.

Additionally, the previous researchers demonstrated a strong relationship between subject matter knowledge and the knowledge of learners (Abell, 2008; Magnusson et al., 1999). The development of participants' understanding of misconceptions and difficulties in engineering might be related to the improved subject matter knowledge in engineering. Although examining preservice teachers' subject matter knowledge is not the concern of the present study, their subject matter knowledge in the engineering and engineering design process might be enhanced as they engage in the steps of lesson study, such as planning, observing, and reflecting on teaching. Accordingly, they might have better identified and overcome engineering-related misconceptions and difficulties at the end of the four lesson study cycles. Furthermore, participants took Mathematics-1 and Mathematics-2 courses in teacher education programs, and these courses aimed to increase their subject matter knowledge. However, participants did not take any courses on teaching mathematics to elementary and middle school students. At this point, lesson study is effective in supporting preservice teachers' knowledge of learners (Juhler, 2016). The long-term and continuous experiences in lesson study cycles might influence participants to consider difficulties and misconceptions in mathematics in the current study. Moreover, participants' tacit knowledge concerning learners might be more apparent (Nilsson & Loughran, 2012) through using CoRe, observing several hours of STEM lessons, and enriching teaching experiences in the context of lesson study.

5.1.3. Discussion of the Results for Knowledge of Instructional Strategies

Before the study, participants were not knowledgeable about the teaching strategies compatible with STEM education because none preferred to use a particular teaching strategy in their pre-individual CoRes except Defne. The findings of the current study revealed that participants' understanding of alternative teaching strategies used in STEM education enhanced at various levels through participating in four lesson study cycles.

To begin with, participants agreed to use the 5E learning cycle by underlining that they had sufficient knowledge regarding this strategy in lesson study 1. The limited knowledge of other teaching strategies retained participants to use alternatives. Moreover, their explanations about the strategy were general, and they did not associate their reasons for choosing the 5E learning cycle with the basic features of STEM education in lesson study 1. On the other hand, participants selected the 5E learning cycle again in lesson study 3. Distinctly, they started to relate the main characteristics of STEM education to the steps of the 5E learning cycle, except for Deniz at the end of lesson study 3. Three participants were able to elucidate the reasons for choosing the 5E learning cycle to prepare a STEM lesson plan, which is one of the indicators of a more coherent PCK for STEM with respect to knowledge of instructional strategies. Additionally, preservice science teachers started to talk about alternative teaching strategies that could be used in STEM education as the lesson study cycles progressed, such as REACT and problem-based learning. Three participants were willing to use problem-based learning as an alternative teaching strategy in lesson study 4, explicitly matched the features of problem-based learning with STEM education, and prepared several activities to enhance students' learning since teachers with solid knowledge regarding various strategies scaffold students to learn better in STEM lessons (Srikoom et al., 2018). Boz and Belge-Can (2020) reported similar results that show preservice teachers' instructional strategy choices might change as they get more knowledgeable about the strategies in the micro-teaching lesson study. The participants of this study began to use alternative teaching strategies in STEM lessons at the end of the four lesson study cycles.

As indicated above, participants' PCK for STEM development levels showed differences concerning knowledge of instructional strategies. A similar situation was observed in Ekiz-Kiran et al. (2021) study in which three participants' knowledge of instructional strategies significantly developed, whereas one participant did not show great improvement in a PCK-based field experience course supported with CoRe and observation. In our case, Ada, Defne, and Ece were able to extend their repertoire in terms of teaching strategies and provided content-specific details rather than discipline-specific details while explaining their instructional preferences. Collaborative planning, enriched teaching experiences in a real classroom, observation, and reflection might have contributed to participants' progression regarding teaching strategies. On the other hand, Deniz was in favor of not using any particular strategies in general in the planning meetings. The other group members suggested alternatives and convinced him to use them in the planning meetings. Nevertheless, his explanations were too broad, and his teaching mostly did not involve many features of STEM education. What had been discussed in the planning meetings was not totally mirrored in Deniz's teaching because his understanding of STEM education as a new approach might "not strong enough yet to stimulate change in practice" (Barendsen & Henze, 2019, p. 1165). For instance, even if he carried out the STEM lesson plan prepared using the 5E learning cycle in lesson study 3, he tended to provide factual information regarding thermal insulation directly at the beginning of the lesson, contrary to the lesson plan. Then, he moved on to the steps of the 5E learning cycle and engineering design process. This finding is consistent with Brown et al.’s (2013) study stating that participating preservice teachers of the study tended to teach the content through "inform types of instruction near the beginning of lessons so they could transmit new terms and concepts to students" and then continue with laboratory, explore and practice activities (p. 148). This situation might be related to Deniz's teaching orientation. Examining the teaching orientations is not in the scope of the current study; however, knowledge of instructional strategies is reasonably related to orientation to the teaching science component (Magnusson et al., 1999). Deniz might have a didactic teaching orientation in the present study. His didactic orientation might behave as a filter and inhibit him from properly using the steps of the 5E learning cycle in the STEM lesson plan (Gess-Newsome, 2015).

With respect to design-centered teaching practices, participants did not integrate any design practices, such as proposing open-ended design challenge and proposing more than one solution to solve the problem into their pre-individual CoRes. Participants started integrating some design-centered practices while ignoring the others at the end of lesson study 1. For instance, they did not emphasize researching the problem or re-designing part. Furthermore, they could not discuss science concepts in the context of the engineering design process, possibly resulting in making an art and craft project in lesson study 1 (Guzey et al., 2019). As the lesson study cycles progressed, Ada was the only participant who had developed an understanding of design-centered teaching practices to the highest level after completing lesson study 2. She reached the PCK-C category sooner than the other participants regarding design-centered teaching practices. Crismond and Davis (2013) described the features of informed designers as "can learn and use science, technology, engineering, and mathematics (STEM) ideas and practices while doing design challenges" (p. 50). In the current case, Ada became the informed designer sooner than the others and touched on many design-centered teaching aspects, including featuring science concepts in the engineering design process and troubleshooting the designs at the end of lesson study 2. This situation might be linked to her prior experiences in the engineering design process-related project she had attended. Because in a study focusing on PCK for STEM, Faikhamta et al. (2020) observed that as the teachers' understanding is changed into "engineering design process is not just designing tools or artefacts, but it also involves defining problems, considering constraints and criteria, researching knowledge, designing and testing models and prototypes, evaluating and communicating solutions" (p. 13) after attending professional development program. Ada’s experiences in the previous project and the lesson study group might be contributed together to the improvement of her understanding of design-centered teaching practices sooner than her peers. Other participants might need a longer time to internalize the new approach and increase their knowledge of the engineering design process, and the way engineers work at this point. In this regard, lesson study 3 is a hallmark for Defne and Ece regarding knowledge of instructional strategies, and they began to utilize aspects of design-centered teaching practices. Many design-centered teaching practices were evident in their statements enriched with content-specific details, and the quality of integrating the engineering design process is increased during their teaching in lesson study 4. They were able to address criteria, and limitations, give importance to teamwork, manage and balance group work, communicate the results etc. These findings confirm the previous studies on PCK for STEM development which suggest long-term support is helpful for implementing the steps of the engineering design process properly and contribute to the preservice teachers' increased knowledge about the design process (Aydin-Gunbatar et al., 2020; Lertdechapat & Faikhamta, 2021). Moreover, using an engineering notebook is found to be effective with middle school students (Hertel et al., 2017). In the same manner, integrating engineering notebooks into CoRe might be another factor in fostering preservice science teachers' improved knowledge about design-centered teaching practices and using the steps of the engineering design process properly.

Another finding of the present study indicated that three participants (Ada, Ece, and Defne) utilized "explicit integration" of engineering into science at the end of the study (Guzey et al., 2019). They provided an environment in which students learned science concepts through the engineering design process in STEM lessons at the end of the study. On the other hand, Deniz struggled to apply complete design-centered teaching practices throughout the study, and his knowledge of these practices improved to some degree. His science and engineering integration can be categorized as an "add-on approach" in general (Guzey et al., 2019) because he tended to separate the science content and engineering design process in his teaching experiences both in lesson study 1 and lesson study 3. Moreover, some critical elements of the engineering design process were missing in his statements and teaching segments, and he could extend his knowledge to the PCK-B category, which refers to the transitional PCK at the end of the study. The literature signifies that not having adequate subject matter knowledge in engineering is one of the reasons why teachers experience difficulty in infusing engineering into their lessons (Hynes, 2012; Stohlmann et al., 2012). However, in our case, Deniz was a former engineering student and had some experience and knowledge regarding engineering. The difference in his knowledge of instructional strategies development patterns in the lesson study group could be explained by having strong subject matter knowledge does not imply developed PCK for STEM (Magnusson et al., 1999). In other words, subject matter knowledge is necessary for improving PCK; however, it is not ensured developed PCK. Deniz might have the necessary subject matter knowledge regarding engineering but could not make his knowledge accessible to the learners in terms of design-centered teaching practices (Shulman, 1987). He might require additional time and teaching experiences compared to the other preservice teachers to learn about teaching out-of-discipline content because PCK is unique to each teacher (Park & Oliver, 2008).

Concerning strategies for engagement with engineering concepts, as participants' knowledge about design-centered teaching practices elaborated, they utilized engineering talk more appropriately. They considered it an integral part of the lesson. For instance, the term "prototype" was not taught as a focus of the first STEM lesson plan but taught intentionally in the following STEM lesson plans. More time for discussions related to using engineering language was allocated, which is consistent with Guzey et al.'s (2019) study revealing that teachers' use of engineering language was improved over a three-year period while applying design-based lessons. Moreover, all participants paid more attention to the authentic context for the engineering design process at the end of the study. In the first lesson study cycle, although the engineering design challenge included a fictitious client, design criteria, and limitations as indicated in the relevant literature (Maiorca & Mohr-Schroeder, 2019; Wheeler et al., 2019), the client's need was not motivated students to solve the problem (i.e., designing a Solar eclipse viewer). The middle school students preferred to use only the given filters to observe the Solar eclipse and indicated they did not need to design viewers; just using filters was enough for them to observe the Solar eclipse in lesson study 1. Peterman et al. (2017) described that situation as "creating contrived problem only for the purposes of the lesson" in their study (p. 1918). The engineering design challenge was contrived and not engaged students in lesson study 1. However, other engineering design challenges in the current study consisted of "authentic problems of interest to scientists and/or engineers" (p. 1918), which is evidence for participants' increased understanding. Additionally, the representations and activities that participants used were limited in number and focused on only science discipline at the beginning of the study. Then, participants focused on engineering-related representations in lesson study 1, and they superficially used representations in other STEM disciplines. On the other hand, participants could use representation in science, engineering, and mathematics with equal emphasis during their teaching of STEM lesson plans in lesson study 3 and lesson study 4. For instance, Ada suggested integrating a "decision diagram" to facilitate students' choice of the best solution into the engineering notebook. Crismond and Adams (2012) explained that "informed designers" use several strategies, including decision diagrams, to implement engineering design effectively, which is in parallel with Ada's improved knowledge in the present study. Similarly, Ece enriched her instruction with daily-life examples about science and role play. Moreover, Deniz utilized the poster of the engineering design process and data collection tables in his instruction. These points are considered indicators of participants' advanced knowledge regarding representations in STEM lessons.

5.1.4. Discussion of the Results for Knowledge of Assessment

The findings revealed that all participants' knowledge of assessment for STEM progressed with varying levels at the end of the study. This is in line with other studies' results of knowledge assessment, which indicated that participants use a diversity of assessment methods and the dimensions of students' learning that are worth being assessed in STEM lessons were expanded through professional development programs (Lertdechapat & Faikhamta, 2021; Srikoom et al., 2018). Likewise, attending lesson study influences elaborating preservice teachers' understanding of the purposes of assessment and several methods that could be applied to assess students' learning (Juhler, 2016). In our case, Ada and Ece's knowledge required for what to assess, how to assess in STEM lessons, and how to make revisions based on assessment were improved to the PCK-C category, although Defne and Deniz's knowledge slightly improved to the PCK-B category in this respect. Studies focusing on PCK development of preservice teachers also reported that the development of the assessment component displays dissimilarity among the participants (Belge-Can & Boz, 2022; Ekiz-Kiran et al., 2021; Reynolds, 2020).

In terms of what to assess, all participants concentrated on assessing science content outcomes in parallel with the objectives they stated at the beginning of the study. In lesson study 3 and lesson study 4, Ada and Ece focused on assessing engineering, engineering design process, and mathematics in addition to the science content in a balanced way. On the other hand, two participants (Defne and Deniz) in the PCK-B category generally concentrated on one discipline of STEM, “engineering or science” while deciding the areas of STEM lessons worth assessing and superficially assessed the other disciplines' objectives at the end of the study. STEM education requires assessing multiple learning areas at the same time (Gao et al., 2020; Harwell et al., 2015); however, some participants of the study struggled to give equal emphasis on assessing objectives from multiple disciplines.

Concerning how to assess, the findings demonstrated that participants utilized more formative assessment and talked about various methods as the lesson study cycles continued. The number of assessment methods utilized and the time for implementing them changed for the participants throughout the study. For instance, preservice science teachers focused on using the only rubric to assess the engineering design process in lesson study 1. Starting from lesson study 2, they began to consider alternative assessment methods, such as concept cartoons, word association test, Draw-an-Engineer-Test, and peer evaluation. They started to implement assessment methods not only at the end of the lesson but also realized the significance of formative assessment and ongoing feedback to the groups during the STEM lessons. Nevertheless, there are some differences between participants' development levels with respect to how to assess. Defne and Deniz experienced difficulties applying assessment methods prepared in the planning meetings, and they skipped some of them during the teaching phase of lesson study. These two participants' post-individual CoRes also did not reflect a variety of assessment methods compared to what had been discussed throughout the study.

Additionally, Gao (2020) argues that assessing the students' products and the engineering design process in STEM education is critical. Defne and Deniz concreated more on assessing the engineering design process through a rubric, and assessing students' final products was missing in their statements and teaching phase of the lesson study. It could be referred that the alignment between objectives and which part of the lesson should be assessed is not coherent for Defne and Deniz, although the CoRes involved objectives regarding assessing the students' products starting from lesson study 2. Moreover, the emphasis on presenting criteria for successful design and assessing students’ products was unclear for these two participants. The findings of a study by Aydin-Gunbatar et al. (2020) demonstrated that most preservice teachers were able to consider assessing chemistry content, design process, and students’ products after attending STEM-based elective course designed through LESMER model. However, few of them still focused more on chemistry content outcomes in the STEM lessons model corresponds to the findings of this study.

One of the primary problems for assessment in STEM education is that "existing assessments tend to focus on knowledge in a single discipline” (NRC, 2014, p. 6).

Preservice teachers in the present study are trained to assess monodisciplinary objectives and learn about assessment instruments specific to science in the teacher education program. They are not familiar with assessing engineering or mathematics outcomes due to their background. Correspondingly, they might struggle to apply multidimensional assessment simultaneously in STEM lessons. Correia and Baptista (2022) pointed out that many preservice primary teachers had difficulty in assessing the different outcomes of STEM lesson after attending STEM-based science methods course. The possible reason for more improvement with respect to knowledge of assessment for Ada and Ece in this study might be associated with the number of assessment courses that participants took in the teacher education program. All participants had to complete the "Measurement and Assessment" course in their undergraduate education; however, Ada and Ece took "Evaluation of Classroom Learning" as an elective course. The content of this course focuses on formative assessment methods in science education. Ada and Ece might have a richer repertoire than the other two participants due to this extra course before starting the study. The present study does not aim to investigate participants' development of STEM understanding; however, as Ada and Ece's understanding of STEM enhanced, they might have chosen various assessment methods from their repertoire and adapted the assessment instrument to assess out-of-discipline objectives as the lesson study cycles proceeded. Their PCK for STEM becomes more coherent regarding knowledge of assessment than Defne and Deniz. Moreover, using assessment methods in practice is problematic for teachers (Friedrichsen et al., 2009), and Defne and Deniz might not translate their knowledge of assessment into practice when planning and implementing STEM lessons.

Furthermore, the connection between the knowledge of learners and knowledge of assessment is highlighted in many PCK studies (Henze et al., 2008; Park & Oliver, 2008). As the teachers' awareness of students' misconceptions and difficulties improves, they are inclined to assess students' learning better. The present study partially confirmed this situation. Ada and Ece's knowledge of learners developed to the PCK-C category, and it is reasonable to consider that they suggested diverse assessment methods to assess different parts of STEM lessons with the enhanced knowledge of learners. For instance, Ada recognized students' misconceptions about heat and temperature topics and recommended preparing a diagnostic tree consisting of items about possible misconceptions of students on this topic. Similarly, Ece was able to identify students' difficulties with the engineers' work and linked this difficulty to the use of the Draw-an-Engineer Test as an assessment method. On the other hand, Defne and Deniz's PCK development levels for knowledge of learners and knowledge of assessment were not progressed in parallel. Their knowledge of learners indicated more integration, whereas knowledge of assessment showed less coherence among STEM disciplines. In another saying, the improved knowledge of learners was not reflected in their understanding of assessment. The literature revealed that developing knowledge of assessment might take more time than developing other components (Henze et al., 2008). Combined with the challenges of assessment in STEM education due to its interdisciplinary nature and imprecise connection across disciplines (Gao et al., 2020), some participants might need additional time to augment their knowledge of assessment more. Moreover, Hanuscin et al. (2011) pointed out that teachers' knowledge of assessment for the nature of science was not significantly developed due to participating in the professional development program, and it was one of the PCK components that developed the least among others. The results of the present study supported these findings since two participants' knowledge of assessment in STEM lessons was still transitional and slightly developed through participating in four lesson study cycles.

5.2. Discussion of the Results for Elements of Lesson Study Influencing PCK for STEM

Lesson study is more than preparing a shared lesson plan (Fujii, 2014; Lewis, 2002). One of the essential features of lesson study is co-constructing the knowledge (Holden, 2022), and the interactions among the lesson study group expand teachers' horizons about the multiple ways of planning a lesson (Anfara et al., 2009). Preservice science teachers had limited knowledge regarding STEM education at the beginning of this study; however, as they engaged in the dialogues while planning STEM lessons, they discussed the possible ways of instruction to enhance students' learning which also influenced their PCK for STEM. Moreover, Lewis (2002) pointed out that "It is not so much what happens in the research lesson itself that makes it successful or unsuccessful. It is what you have learned working with your colleagues on the way there" (p. 34). The participants of the current study spent many hours together planning and reflecting on the STEM lessons and underlined the importance of learning from a peer throughout the process. Lesson study helps create a collaborative learning environment and allow to deepen preservice science teachers' knowledge of curriculum, learners, instructional strategies, and assessment in STEM lessons in this study, in accordance with Belge-Can (2019) and Juhler (2016) studies reporting that participating in lesson study shaped preservice teachers' PCK. There are several interacting elements of lesson study used in the present study, and how the different main elements contributed to participants' PCK for STEM is discussed below.

5.2.1. Collaborative Planning

In the present study, participants valued collaborative planning meetings with respect to each component of PCK for STEM. Desimone (2009) asserted that the collective participation of teachers in professional development programs is an effective way to increase their learning. The participants worked as a group throughout four lesson study cycles in the present study. Although the lesson plans were implemented individually, preservice science teachers planned STEM lessons and reflected on in after teaching as a group. These collaborative meetings provide an environment in which participants share their ideas freely, discuss the alternatives and critique their opinions. Participants reported that collaborative planning made the STEM lesson plan better compared to individually prepared ones. This point confirms the previous lesson study conducted by Bridges (2015) stating that science teachers felt more comfortable while implementing collaboratively planned lesson.

The participants of the study had little teaching experiences and the STEM education approach was new to them at the beginning of the study. It could be said that the collegial conversations in the planning meetings are a valuable element of lesson study that increases participants' PCK for STEM according to all components in the present study. For instance, Ada indicated that her awareness regarding establishing mathematics-related objectives was enhanced after planning meetings because she started to think from another perspective after Defne's suggestions. The other example was related to using teaching strategies compatible with STEM education. Participants had limited knowledge regarding the alternatives but emphasized that they learned about possible teaching strategies by learning from other group members. Defne said that "If we had not prepared the plan as a group, I could not have learned about problem-based learning. Maybe I would never use it in STEM lessons”. In parallel with the findings of the current study, a study by Carrier (2011) concluded that “one person’s idea sparked the ideas of another” in collaborative meetings and participating teachers utilized the 5E learning cycle at the end of the study (p. 152). Additionally, Ece mentioned her knowledge regarding students’ misconceptions enhanced because the peer in the group put forward a misconception that she cannot think of individually. The participants of the study involved in peer discussions by using PCK language thanks to CoRe in the planning meetings and dealt with setting objectives, learners’ difficulties and misconceptions, teaching strategies and assessment in STEM lessons. They frequently mentioned the contribution of other group members in terms of thinking of alternative routes in planning STEM lessons which informed their PCK for STEM. Consistent with previous research, preservice teachers learn a lot from alternative ideas from their colleagues in this collaborative working environment (Anfara et al., 2009). There are several studies in the literature reported the effect of collaborative planning on PCK development (Chassels & Melville, 2009; Coenders & Verhoef, 2019; Faikhamta et al. 2020; Lange et al., 2022; Lertdechapat & Faikhamta, 2021; Lewis et al., 2009; Marble, 2007) and the findings of the present study supported them.

The present study utilized CoRe as a lesson-planning tool. CoRe was prepared collaboratively in the planning meetings. Since the aim of the present study is to monitor preservice science teachers' PCK for STEM development, CoRe facilitates making PCK obvious and elucidating the reasons for their instructional choices, such as setting objectives for STEM lesson plans (Hume & Berry, 2011; Loughran et al., 2008). Carpendale and Hume (2019) refer to collaboratively prepared CoRe as "can be viewed as a manifestation of cPCK, can also create a platform for initiating and/or strengthening individual science teachers’ pPCK development for each of the participating teachers" (p. 227). In the current case, collaborative CoRe is used to support the development of each participant PCK for STEM, as the researchers suggested. Moreover, the literature reveals that the use of CoRe reinforces preservice teachers’ PCK development (Aydin et al., 2013; Hume & Berry, 2011; Juhler, 2016). Participants' explanations were too broad at the beginning of the study, and they had topic-specific PCK; however, as they got familiar with PCK construct through CoRe, they started to give detailed explanations about curriculum, learners, instructional strategies, and assessment in science and other STEM disciplines and transitioned to PCK-B or PCK-C category with the help of CoRe at the end of the study in parallel with the previous research findings.

Participants of the study addressed utilizing CoRe while talking about their development in terms of knowledge of learners and knowledge of curriculum. For instance, Ece indicated that the two prompts regarding learners' difficulties and misconceptions made her think about these points while designing lesson plans compared to the typical lesson plan format they used in their undergraduate education. Similarly, Defne described the role of CoRe as “you should be ready for these misconceptions and difficulties before coming to the lesson”. The findings of the study revealed that participants considered how to deal with learners’ difficulties and misconceptions and took precautions before they emerged as the lesson study cycles progressed, thanks to using CoRe in the planning process. Similarly, Ekiz-Kiran et al. (2021) concluded that all participating preservice teachers developed their understanding of learners by not only teaching the content but also thinking of misconceptions and difficulties in the planning phase after CoRe was integrated into the field experience course. The blending of CoRe and lesson study underpins the development of PCK and focuses all PCK in a balanced way (Juhler, 2016). Therefore, this study provides evidence to use CoRe in lesson study to enhance PCK for STEM.

5.2.2. Teaching and Observing the Lesson

The present study provided enriched teaching experiences for preservice science teachers to implement STEM lesson plans. Each participant carried out three or four lesson hours of STEM lesson plans twice throughout the study. They indicated that these teaching experiences are especially effective in terms of developing their knowledge of curriculum, knowledge of learners, and knowledge of instructional strategies. For example, Deniz summarized the importance of the teaching phase in his development of knowledge of learners as follows: "The more we interact with the student, the more misconceptions we can detect". The literature revealed that teaching experience plays a vital role in terms of the improvement of preservice teachers’ knowledge of learners (Aydin et al., 2013; Brown et al., 2013; Lange et al., 2022; Reynolds, 2020), which is consistent with the findings of this study. On the other hand, Bahcivan (2017) found that preservice teachers' knowledge of learners demonstrated subtle development in micro-teaching lesson study and the researcher attributed this situation to implementing the lesson plan with peers. Therefore, it is reasonable to note that the improvement of the participant's knowledge of learners in this study is most probably related to teaching experiences in a real classroom environment.

Moreover, two participants appreciated the role of teaching in terms of making the connection between other science topics in previous grades and following grades. This finding supported the study conducted by Sickel (2012), which concluded that as novice teachers gain experience, they are more likely to make connections between the topics in the same grade. Davis (2004) also pointed out that teaching experience is an essential source of development of knowledge of curriculum. Regarding knowledge of instructional strategies, all participants emphasized that they experienced the teaching strategies in practice and learned to use design-centered teaching practices properly during the teaching phase of lesson study. Several studies indicate the effectiveness of teaching experience on knowledge of instructional strategies (Aydin et al., 2013; Brown et al., 2013; Ekiz-Kiran et al., 2021), which is in line with the findings of the present study. Therefore, providing increased teaching experiences in an actual classroom environment through the lesson study might have contributed to the participants' progression of PCK for STEM in the current study.

Additionally, participants frequently mentioned the importance of observing peers during the teaching phase of lesson study on their knowledge development which is in parallel with Huang et al. (2022) study concluding that participating teachers valued the importance of observation in understanding how to integrate the engineering design process. The lesson study group consisted of four preservice science teachers in the present study, and three were in the role of observer teachers during the implementation of STEM lessons. It means participants observed nearly 25 hours of STEM lessons throughout the study. Observations provide opportunities for "capturing teachers' knowledge-in-action" (Barendsen & Henze, 2019, p. 1144) and participants tried to catch PCK for STEM in practice in the current study. They filled out the PCK for STEM-based observation form and wrote suggestions for the observed lesson to be discussed in the reflection phase. Thanks to the observation form, participants observed the PCK for STEM components in a well-established way in the teaching phase Grossman (1990) advocated that observation is a valuable source of PCK development combined with teaching experiences. Additionally, observation of teaching is an important element of lesson study that fosters PCK development (Coenders & Verhoef, 2019), and as evidenced in the present study, teaching and observation of teaching helped participants integrate the features of STEM education coherently.

All participants underlined that observing their peers was influential in shaping their knowledge of learners and knowledge of instructional strategies. Moreover, two of them valued the importance of observation in their improvement of knowledge of assessment, whereas none referred to knowledge of curriculum. This might be explained by the tacit nature of PCK, in this case, knowledge of curriculum (Loughran et al., 2004; Nilsson & Loughran, 2012) and the difficulties of catching PCK in practice (Park & Oliver, 2008). The participants of the present study had limited experiences regarding PCK; thus, they may not capture instances regarding knowledge of curriculum during observing of peers. Aydin et al. (2013) also concluded that observing peers were beneficial in promoting preservice chemistry teachers' knowledge of learners, knowledge of instructional strategies, and knowledge of assessment in a practicum course, whereas no direct influence on knowledge of curriculum was reported.

5.2.3. Reflecting on the Lesson

Reflecting on the lesson is one of the essential elements of lesson study (Dudley, 2015; Marble, 2007), and it is applied in the context of the present study. Lee and Tan (2020) labeled this process as “collaborative improvement” and stated that “teachers’ progressive building-upon of one another’s observations and ideas to improve a lesson while discussing observations and sharing possible speculations underlying the observations" (p. 9). In our case, the participants of the study came together and discussed the lesson as a group with the help of the observation forms after the teaching and re-teaching phases of the lesson study. The reflection meetings began with sharing the experiences of the teacher and continued with observer teachers' ideas and suggestions. What worked and did not work in the lesson was discussed using PCK language through CoRe. The CoRe was subjected to revisions in these meetings. The participants established new objectives, added difficulties and misconceptions that they noticed during teaching, modified the steps of teaching strategies or altered the flow of the lesson, and changed the time of or the way of assessment in the STEM lesson plans, which are typical points considered in collaborative reflection meetings in lesson study (Lewis et al., 2009; Xu & Pedder, 2015). Previous PCK studies highlight that reflection on teaching is one of the major sources of PCK development (Carlson et al., 2019; Henze & Barendsen, 2019; Park & Oliver, 2008). In a similar way, most of the participants of this study appreciated the value of reflection in all components of PCK for STEM. To be more specific, Defne was the teacher of the revised version of the STEM lesson plan in lesson study 4, where the group used problem-based learning for the first time. Defne stated that she got more knowledgeable about the teaching strategy after thinking critically about the lesson and revising it based on their observations. She felt confident in applying the revised version of the plan.

The participants had a basic understanding concerning STEM education at the beginning of the study; however, they were involved in a continuous reflection in lesson study cycles and re-consider their experiences and observations. Therefore, reflection seems to be a powerful factor contributing to participants' PCK for STEM development in the present study since four components were reviewed, criticized, and revised in the reflection meetings. This is compatible with the research advocating that reflecting on experiences and observations is effective for developing participants' STEM understanding and expanding their PCK for STEM (Aydin-Gunbatar et al., 2021; Faikhamta et al., 2020; Lau & Multani, 2018; Lertdechapat & Faikhamta, 2021).

5.3. Implications

The present study has some implications for teacher education programs and teacher education research. To begin with, all preservice science teachers attending the study demonstrated improvement to some degree in their PCK for STEM, which points out the need for long-term intervention. The literature reported that preservice teachers have weak PCK for STEM (Lertdechapat & Faikhamta, 2021); however, this knowledge base develops significantly when they are assisted continuously through collaborative planning, enriched teaching experiences, observing peers, and reflecting on the whole process. As a result, all PCK for STEM components for every participant showed improvement at the end of this study. Because preservice teachers need to become more familiar with the engineering design process, these activities that target developing PCK for STEM should be centered around the engineering design process (Benuzzi, 2015). Therefore, we suggest that preservice science teachers should be provided long-term and ongoing support and the focus should be on the engineering and engineering design process to augment their PCK for STEM based on the findings of the present study.

In this direction, lesson study seems promising for teacher education programs. The findings revealed that the combination of different elements of lesson study worked well to promote preservice science teachers' PCK for STEM. This study incorporated the lesson study into the Practice in Science Teaching-1 course. Since one of the essential components of lesson study is teaching, it is believed that field experience and practice teaching courses where preservice science teachers provided opportunities for teaching in a real classroom environment would be feasible to integrate lesson study in teacher education programs. The findings also showed that more than one complete lesson study cycle is needed for participants' knowledge development. PCK enhanced gradually; for instance, there is less coherence between STEM disciplines at the end of lesson study 1; however, most of the participants' PCK for STEM was more integrated at the end of lesson study 3. Thus, multiple cycles should be preferred when implementing lesson study with preservice science teachers. In this way, preservice science teachers’ PCK for STEM development might be observed step-by-step. Completing an entire cycle of lesson study takes time; therefore, we suggest focusing on one topic from each unit for one lesson study cycle while designing STEM lesson plans. On the other hand, the focus should be on students’ learning in lesson study; however, since preservice science teachers have little teaching experience in the classroom, this point might be challenging for them and might turn into a limitation of using lesson study in teacher education programs. Therefore, we might wish to bring CoRe and lesson study together to improve preservice science teachers' PCK for STEM in future studies and help them to focus on student learning. The CoRe makes preservice science teachers consider different parts of the lesson while planning, such as learners' misconceptions, difficulties, and the relation of topics with other science topics and STEM disciplines. However, preservice science teachers might not be familiar with the construction of CoRe, and this situation might be an obstacle to developing PCK. Thus, the CoRe should be introduced first to preservice science teachers to overcome this limitation and the prompts and its role in shaping PCK should be explained clearly.

The other important factor of lesson study that emerged in the present study is collaborative planning. Participants appreciated the value of collaborative planning compared to individual planning. They learned from each other, and constructive feedback from peers helped them to strengthen their PCK for STEM. Therefore, collaborative planning might be applied in different courses in teacher education programs in addition to field experience and practice teaching courses. Additionally, the lesson study is combined with CoRe in the current study.

Furthermore, the findings showed that the participants value reflecting on the lesson in terms of promoting their PCK for STEM. The reflection should be integrated into the courses in teacher education programs, such as Methods of Science Teaching, Assessment in Learning, and PCK language should be used explicitly while reflecting on the teaching, microteaching, and activities conducted throughout the course.

Additionally, the participants had weak subject matter knowledge regarding engineering prior to the study. Since solid subject matter knowledge is necessary for developing PCK (Shulman, 1987), a course focusing on engineering and the engineering design process at the introductory level might be suggested in teacher education programs. Moreover, the findings revealed that preservice science teachers experience difficulty in writing objectives from other STEM disciplines, determining learners' difficulties and misconceptions except for science, and deciding which part of the lesson is worth assessing in integrated lessons. Hence, the courses such as Curriculum Development, Assessment in Science, and Misconceptions in Science might give a place to interdisciplinary teaching and underline the connection between science, mathematics, and engineering.

5.4. Recommendations

The study has some recommendations for future research. Firstly, the study was grounded on Magnusson et al.’s (1999) PCK model, a commonly used framework in science education (Henze & Barendsen, 2019). Distinctively, it was adapted to the PCK for STEM in the present study. The PCK components were re-defined (see Table

2.1), and the coding scheme (see Table 3.11) was created by drawing upon the PCK for the STEM framework and the data of the study. Therefore, the modified PCK framework and coding scheme are considered valuable for future PCK for STEM studies. The present study did not include orientations to the teaching component; thus, future studies might include this component while using PCK for STEM framework.

Secondly, PCK for STEM development levels was categorized into three with the help of Aydin-Gunbatar et al. (2020) study. The features of PCK for STEM components according to each developmental level were described, and future studies might benefit from this categorization to track participants’ PCK for STEM development. Additionally, observation protocol developed in the present study might also be used in future PCK for STEM studies. Preservice teachers might not be familiar with PCK; therefore, structured and PCK-based observation protocols might help them to decide what should be observed throughout the lesson and contribute to the enhancement of PCK for STEM, as evidenced in the findings of the present study.

Another recommendation would be related to examining participants’ STEM understanding. The study did not concentrate on how preservice science teachers' understanding of STEM changed throughout the study. Therefore, future studies might consider studying the connection between preservice teachers' understanding of STEM and how it is reflected in their development of PCK for STEM. Additionally, future studies might focus on subject matter knowledge in STEM disciplines and examine how subject matter knowledge influences PCK for STEM.

Regarding the implementation process, the lesson study group comprises only preservice science teachers in the current study. Further studies might include preservice teachers from different departments (i.e., mathematics education, computer education, and instructional technology) in parallel with the interdisciplinary nature of STEM education. The similar study might be conducted with in-service teachers. Moreover, the cooperating teacher was not involved actively in the lesson study process in our case because she did not have any experience related to STEM education. Her involvement was restricted to reflecting on the subject matter knowledge in science, classroom management, and student-teacher dialogues after the teaching phase. However, we recommend involving cooperating teachers who are knowledgeable about STEM education in the lesson study group in future studies, as underpinned in Fernandez’s (2010) and Juhler’s (2016) studies. The cooperating teacher might participate in planning meetings and other steps of the lesson study cycle and might be in the role of mentor to preservice science teachers.

Lastly, lesson study aims to maximize students learning (Dudley, 2015; Leavy & Hourigan, 2016) and no data were collected from students in the classroom. Although students' artefacts, such as the engineering notebook and budget sheet, were gathered after the teaching phase, they were used to revise the lesson without being subjected to data analysis. Additional student data might be obtained, and preservice teachers’ PCK for STEM development and students’ learning might be compared in future studies.

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APPENDICES

A. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
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06 AĞUSTOS 2021

Konu : Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi : İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Prof. Dr. Jale ÇAKIROĞLU

Danışmanlığını yaptığınız Fulden GÜLER NALBANTOĞLU'nun "Fen Bilimleri Öğretmen Adaylarının STEM (Fen, Teknoloji, Mühendislik, Matematik) Pedagojik Alan Bilgilerinin Gelişiminin Ders İmecesi Kapsamında İncelenmesi" başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **331-ODTU-2021** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

Prof.Dr. Mine MISIRLISOY
İAEK Başkan

B. APPROVAL OF EGE UNIVERSITY HUMAN SUBJECTS ETHICS COMMITTEE

T.C.
EGE ÜNİVERSİTESİ REKTÖRLÜĞÜ
Eğitim Fakültesi Dekanlığı
Matematik ve Fen Bilimleri Eğitimi Bölüm Başkanlığı

Sayı : E-41384124-302.08.01-342556
Konu : Araştırma İzni (Fulden GÜLER NALBANTOĞLU)

EĞİTİM FAKÜLTESİ DEKANLIĞINA

İlgi : 29.09.2021 tarihli ve 338280 sayılı yazı.

İlgi yazınız gereği, Orta Doğu Teknik Üniversitesi İlköğretim Anabilim Dalı doktora programı öğrencisi Fulden Güler NALBANTOĞLU'nun, Prof. Dr. Jale ÇAKIROĞLU danışmanlığında yürütmekte olduğu **"Fen Bilimleri Öğretmen Adaylarının STEM (Fen, Teknoloji, Mühendislik, Matematik) Pedagojik Alan Bilgilerinin Gelişiminin Ders İmecesi Kapsamında İncelenmesi"** başlıklı tez çalışmasını Bölümümüz Fen Bilgisi Öğretmenliği Lisans Programı Öğrencilerine uygulamak isteği uygun bulunmuştur

Bilgilerinize arz ederim.

Prof. Dr. Hülya YILMAZ
Bölüm Başkanı

C. APPROVAL OF MINISTRY OF NATIONAL EDUCATION ETHICS COMMITTEE

T.C.
İZMİR VALİLİĞİ
İl Millî Eğitim Müdürlüğü

Sayı : E-12018877-604.01.02-31997845 15.09.2021
Konu : Araştırma İzni
Fulden Güler NALBANTOĞLU

DAĞITIM YERLERİNE

İlgi :a) MEB Yenilik ve Eğitim Teknolojileri Genel Müdürlüğünün 21.01.2020 tarihli ve 81576613-10.06.02-E.1563890 sayılı yazısı (Genelge 2020/2).
b) Ortadoğu Teknik Üniversitesi Rektörlüğünün 20.08.2021 tarihli ve 227 sayılı yazısı.
c) Valilik Makamının 14.09.2021 tarihli ve 12018877-604.01.02-31890548 sayılı onayı.

Ortadoğu Teknik Üniversitesi İlköğretim Anabilim Dalı Doktora programı öğrencisi Fulden Güler NALBANTOĞLU, Prof. Dr. Jale ÇAKIROĞLU' nun danışmanlığında yürütmekte olduğu "Fen Bilimleri Öğretmen Adaylarının STEM (Fen, Teknoloji, Mühendislik, Matematik) Pedagojik Alan Bilgilerinin Gelişiminin Ders İmecesi Kapsamında Değerlendirilmesi" konulu tez çalışmasını Müdürlüğümüz Bayraklı ilçesine bağlı Kaymakam Özgür Kurak Ortaokulunda uygulama isteği Valilik Makamının ilgi (c) Onayı ile uygun görülmüştür.

Söz konusu ölçeklerin Bayraklı ilçesi Kaymakam Özgür Kurak Ortaokulunda 2021-2022 eğitim öğretim yılında, eğitim öğretimin başlamasıyla eğitim öğretimi aksatmayacak ve eğitim kurumu yöneticilerinin uygun gördüğü şekilde, araştırma yapılmadan önce araştırmanın yapılacağı okullar tarafından "Milli Eğitim Bakanlığına Bağlı Her Tür Okul ve Kurumlarda Yapılmasına İzin Verilen Araştırma Uygulamasında, Olabilecek Zararları Karşılama Taahhüdü" adlı ek' in araştırmacı tarafından doldurulması gerekmektedir.

Bilgilerinizi ve gereğini arz/rica ederim.

İlker ERARSLAN
Müdür a.
Müdür Yardımcısı

D. INTERVIEW QUESTIONS

DERS PLANI UYGULAMADAN ÖNCE SORULACAK SORULAR

DERSİN AMACI
1. Hazırladığınız STEM ders planında …. konusunu öğretirken öğretmenin sahip olması gereken alan bilgileri nelerdir? Bu konudaki alan bilginize ne kadar güveniyorsunuz? 2. Hazırladığınız bu planın neden bir STEM ders planı olduğunu düşünüyorsunuz? Bu planı STEM ders planı yapan nedir? 3. STEM ders planını hazırlarken hangi noktalara ağırlık verdiniz?
ÖĞRETİM PROGRAMI BİLGİSİ
4. STEM ders planı hazırlarken hangi kazanım (lar)ı seçtiniz? Neden bu kazanımları seçtiğinizi açıklayabilir misiniz? 5. STEM ders planını hazırlarken var olan kazanımlarda bir değişiklik yaptınız mı? a. Eğer yaptıysanız, hangi değişiklikleri yaptınız ve neden? b. STEM ders planı hazırlarken yeni kazanımlar eklediniz mi? Eğer eklediyseniz bu kazanımları nasıl yazdınız? 6. STEM ders planına göre öğrencilerinizin öğrenmesi gereken en önemli kavramlar/noktalar nelerdir? Bu noktaları/kavramları nasıl belirlediniz? 7. STEM ders planı hazırlarken öğretim programı ve kazanımları kullanma konusundaki gelişiminiz hakkında ne düşünüyorsunuz? a. Gelişiminize katkıda bulunan ne oldu? 8. Hazırladığınız STEM ders planında herhangi bir kaynağa ihtiyaç duydunuz mu? Neden bu kaynakları kullandınız? 9. Seçtiğiniz fen kazanımının diğer STEM disiplinleri ilişkisini nasıl kurdunuz? Örnek vererek açıklayabilir misiniz?
ÖĞRETİM STRATEJİLERİ BİLGİSİ
10. STEM yaklaşımını dersinize entegre etmek için hangi stratejileri seçtiniz? a. Lütfen bu stratejinin nasıl işe yaradığını açıklayın. b. STEM dersini öğretimi için neden bunun en iyi/daha iyi bir strateji olduğunu düşünüyorsunuz? c. STEM ders planını hazırlarken bu stratejileri kullanmanın herhangi bir dezavantajı olduğunu düşünüyor musunuz? 11. Hazırladığınız STEM ders planında ne tür örnekler, etkinlikler ve grafikler/çizimler/analojiler/modeller kullandınız? Seçtiğiniz gösterimler ve etkinlikler öğrencilerin konuyu kavramasına nasıl yardımcı olacak?

12. Hazırladığınız STEM ders planında Mühendislik Defteri'ni nasıl geliştirdiniz? Neler eklediniz? Mühendislik Defteri'ni ders esnasında nasıl kullanacaksınız?
13. STEM ders planını hazırlarken başka hangi öğretim stratejisini kullanabilirdiniz? Neden?

ÖĞRENCİ ANLAMA BİLGİSİ

14. Bu STEM dersinde öğrencilerin konuyu öğrenmesi için fen içeriği ve diğer STEM disiplinleri ile ilgili hangi ön bilgilere sahip olması gerekir?
15. Öğrencilerin fen içeriği ve diğer STEM disiplinleri ile ilgili sahip olması beklenen kavram yanılgıları nelerdir? Bu kavram yanılgılarına sahip olduğunu nereden biliyorsunuz?
    a. Öğrencilerin neden bu kavram yanılgısına sahip olduğunu düşünüyorsunuz?
    b. Bu kavram yanılgılarını nasıl belirlersiniz?
    c. Eğer öğrencilerin kavram yanılgıları varsa bunları düzeltmek için planınız nedir? Neden bu yöntemi kullandınız?
16. Hazırladığınız STEM dersine göre öğrencilerinizin fen ve diğer STEM disiplinleri ile ilgili zorluk yaşamasını beklediğiniz konular/kavramlar nelerdir?
    a. Bu konuyu öğrenmenin öğrenciler için neden zor olduğunu düşünüyorsunuz?
    b. STEM ders planı hazırlarken bu zorlukları nasıl göz önünde bulundurdunuz?

DEĞERLENDİRME BİLGİSİ

17. Öğrencilerin ön bilgilerini değerlendirdiniz mi? Evet ise; Neden?
18. STEM ders planınızı değerlendirmek için ne planladınız? Hangi teknikleri kullandınız?
    a. STEM dersini değerlendirmek için neden bu değerlendirme teknik(ler)ini seçtiniz?
19. Değerlendirme teknikleri seçtiğiniz kazanımlarla nasıl uyuşuyor?
    a. fen kazanımları açısından?
    b. diğer disiplinlerin kazanımları açısından? (matematik, teknoloji, mühendislik)
    c. 21. yüzyıl becerileri açısından?
20. Öğrencilerin ürün tasarımlarını nasıl değerlendirmeyi planlıyorsunuz?
21. Hazırladığınız plana göre öğrencilerinizin konuyu anlayıp anlamadığını dersin hangi aşama(lar)ında ölçüyorsunuz? Neden bu aşamaları tercih ettiniz?

DERS İMECESİ SÜRECİ
22. Ders imecesi sürecinde araştırma dersi (STEM dersi) planlamakla ilgili daha fazla ayrıntı verebilir misiniz? a. Planlama aşamasında etkili olan olumlu ve olumsuz faktörler nelerdi? b. Ders imecesinin STEM ders planı hazırlamanıza katkısı nedir? c. Ders imecesi sırasında STEM disiplinlerinin entegrasyonu hakkında ne öğrendiniz? Lütfen açıklayınız. 23. STEM ders planını uygulama konusunda ne ölçüde kendinize güveniyorsunuz? Lütfen kendinize 1 ile 10 arasında bir puan verin. Neden kendiniz için X puan verdiniz? a. Ders imecesi sürecinin kendinize verdiğiniz puana etkisinin ne olduğunu düşünüyorsunuz?

DERS PLANI UYGULADIKTAN SONRA SORULACAK SORULAR

(DERSİ ANLATAN KİŞİYE)

1. STEM dersinin uygulama sürecini nasıl değerlendirirsiniz? Lütfen 1 ile 10 arasında bir puan verin. Neden kendiniz için X puan verdiniz?
2. Planlanan ders ile uygulamaya konulan ders arasında herhangi bir fark var mıydı? Eğer varsa,
   a. bu farklılıklar nelerdir?
   b. size göre planlanan ders ile uygulanan ders arasında neden bazı farklılıklar vardı?
3. Uyguladığınız STEM dersini nasıl geliştirebilirsiniz? Hangi kısım (lar)ı ve neden?
4. STEM ders planınızı uygularken öğretmen olarak karşılaştığınız zorluklar nelerdi?
   a. Beklenmedik bir şeyle karşılaştınız mı?
5. STEM dersinin hangi bölümünde / bölümlerinde öğrenciler zorluk yaşadı?
   a. Öğrencilerin zorluk yaşadığını nasıl fark ettiniz?
   b. Bu zorluklarla nasıl başa çıktınız?
6. STEM dersinde fen içeriği ve diğer disiplinler ile ilgili bir kavram yanılgısı tespit ettiniz mi? Cevabınız evet ise;
   a. Nasıl tespit ettiniz?
   b. Tespit ettiğiniz kavram yanılgısını giderdiniz mi?
      - Eğer cevabınız evet ise; nasıl giderdiniz?
      - Eğer cevabınız hayır ise; neden gideremediniz?
7. STEM dersinde kullanılan öğretim stratejisi hakkında ne düşünüyorsunuz? Seçilen strateji öğrencilere rehberlik etmek için uygun muydu? Nasıl daha iyi uygulanabilirdi?
8. STEM ders planındaki kazanımlar öğrencilerin konuyu anlaması için uygun muydu? Uygun olmadığını düşünüyorsanız; revizyon aşaması için kazanımlarda nasıl bir değişiklik yapılmasını önermeyi planlıyorsunuz?
9. Derste kullanılan değerlendirme tekniği hakkında ne düşünüyorsunuz? Derste kapsanan STEM ile ilgili kazanımları değerlendirmek için uygun muydu? Açıklayabilir misiniz?
   a. STEM ders planını revizyon dersi aşamasına hazırlarken değerlendirme sonuçlarını nasıl kullanabilirsiniz?
10. Size göre ders imecesinin faydaları ve zorlukları nelerdir?
11. Ders imecesi döngülerine katıldıktan sonra STEM ders planı uygulamaya yönelik güveniniz nasıl gelişti?
12. Ders imecesi döngüsündeki hangi deneyimleriniz gelecekte STEM yaklaşımını kullanabilecek bir öğretmen olmanıza yardım etti? Nasıl?

DERS PLANI UYGULADIKTAN SONRA SORULACAK SORULAR

(DERSİ DİNLEYEN KİŞİLERE)

1. STEM dersinin uygulama sürecini nasıl değerlendirirsiniz? Lütfen 1 ile 10 arasında bir puan verin. Neden X puan verdiniz?
2. STEM dersi uygulama süreciyle ilgili grup toplantısında tartışmak istediğiniz noktalar nelerdir?
    a. Dersi anlatan öğretmenin fen bilgisi ve diğer disiplinler hakkındaki bilgisi hakkında ne düşünüyorsunuz? Bu süreci yönlendirmek için sahip olduğu bilgilerin yeterli olduğunu düşünüyor musunuz?
    b. Derste kullanılan öğretim stratejisi hakkında ne düşünüyorsunuz? Seçilen strateji öğrencilere rehberlik etmek için uygun muydu? Nasıl daha iyi uygulanabilirdi?
    c. Derste kullanılan değerlendirme tekniği hakkında ne düşünüyorsunuz? Derste kapsanan STEM ile ilgili kazanımları değerlendirmek uygun muydu?
3. STEM dersinde öğrenciler hangi konu/kavramlarla ilgili zorluk yaşadılar?
    a. Dersi anlatan öğretmen bu zorluklarla nasıl başa çıktı?
    b. STEM ders planını revizyon dersi aşamasına hazırlamak için gözlemlediğiniz bu zorlukları nasıl en aza indirmeyi planlıyorsunuz?
4. Dersi anlatan öğretmen STEM dersi sırasında herhangi bir kavram yanılgısı tespit etti mi? Eğer cevabınız evetse;
    a. Nasıl tespit etti?
    b. Kavram yanılgılarını giderdi mi? Evet ise; nasıl giderdi?
    c. STEM ders planını revizyon dersi aşamasına hazırlamak için gözlemlediğiniz bu kavram yanılgılarını nasıl kullanmayı planlıyorsunuz?
5. STEM ders planındaki kazanımlar öğrencilerin konuyu anlaması için uygun muydu? Uygun olmadığını düşünüyorsanız; revizyon aşaması için kazanımlarda nasıl bir değişiklik yapılmasını önermeyi planlıyorsunuz?
6. STEM dersinde yaptığınız değerlendirme size ne anlatıyor? STEM ders planını revizyon dersi aşamasına hazırlarken değerlendirme sonuçlarını nasıl kullanabilirsiniz?
    a. Hangi kısım(lar)ını ve neden?
7. Size göre ders imecesinin faydaları ve zorlukları nelerdir?
8. Ders imecesi döngülerine katıldıktan sonra STEM ders planı uygulamaya yönelik güveniniz nasıl gelişti?
9. Ders imecesi döngüsündeki hangi deneyimleriniz gelecekte STEM yaklaşımını kullanabilecek bir öğretmen olmanıza yardım etti? Nasıl?

E. CoRe (CONTENT REPRESENTATION)

STEM DERS PLANI X			
Sınıf Seviyesi:	**Kazanımlar:**		
Konu:	**Konu ile ilgili ana kavramlar-1**	**Konu ile ilgili ana kavramlar-2**	**Konu ile ilgili ana kavramlar-3**
1. Öğrencilerinizin konu ile ilgili hangi ana kavramları öğrenmesini planlıyorsunuz?			
2. Öğrencilerinizden bu kavram ile ilgili neleri öğrenmesi ve hangi becerileri kazanmasını bekliyorsunuz?			
3. Öğrencilerinizin bu kavramı bilmesi neden önemlidir?			
4. Öğretmen olarak bu konu hakkında neler bilmelisiniz? Lütfen spesifik örneklerle açıklayınız.			
5. Bu kavramı öğrenirken öğrencileriniz hangi zorluklarla karşılaşabilir?			
6. Bu kavram hakkında öğrencilerinizin sahip olabileceği yanlış kavramalar nelerdir?			
7. Öğrencilerinizin bu kavramı öğrenmesine yardımcı olmak için hangi öğretim yöntem/tekniklerini ve aktiviteleri kullanacaksınız?			
8. Öğrencilerinizin bu kavramı anlayıp anlamadığını nasıl değerlendireceksiniz?			

F. OBSERVATION PROTOCOL

STEM DERS GÖZLEM FORMU

Dersi gözlemleyen 3 öğretmen adayı ve araştırmacı tarafından doldurulacaktır.

1. Her bir bölüm için Evet/Hayır/Kısmen seçeneklerinden birini seçin. Seçiminizi ilgili bölümde ayrıntılı olarak açıklayın

Öğrencileri Anlama

	Dersi anlatan öğretmen:	**Evet**	**Hayır**	**Kısmen**	**Neden "Evet, Hayır veya Kısmen" seçtiğinizi temel alan açıklamalar**
1.	STEM dersinde öğrencilerin ön bilgilerini kontrol etti mi?				Nasıl kontrol etti:
2.	STEM dersinde öğrencilerin güçlük yaşadığı noktaları belirledi mi?				Karşılaşılan zorluklar:
3.	STEM dersinde öğrencilerin sahip olduğu kavram yanılgılarını belirledi mi?				Belirlenen kavram yanılgıları:
4.	STEM dersinde öğrencilerin kavram yanılgılarını ortadan kaldırdı mı?				

Öğretim Stratejileri

	Dersi anlatan öğretmen:	**Evet**	**Hayır**	**Kısmen**	**Neden "Evet, Hayır veya Kısmen" seçtiğinizi temel alan açıklamalar**
1.	ders esnasında öğrencilerin zorlandığı noktalarda planladığınız dersin akışında bir değişiklik yaptı mı?				
2.	STEM ders planında yazılmış fen öğretimi stratejilerini uygun bir şekilde kullandı mı?				
3.	STEM dersini uygularken konuya özgü etkinlikler kullandı mı? (simülasyon, animasyon, video, deney vs.)				Kullanılan Etkinlikler:
4.	STEM dersinde öğrencilerin kavramları daha iyi anlaması için konuya özgü grafikler, çizimler, analojiler, modeller kullandı mı?				
6.	ders esnasında "Mühendislik Defteri"'nin adımlarını düzgün şekilde uyguladı mı?				
7.	öğrencilerin fen ile ilgili kavramları mühendislik bağlamında tartışmasını sağladı mı?				

Öğretim Programı

	Dersi anlatan öğretmen:	**Evet**	**Hayır**	**Kısmen**	**Neden "Evet, Hayır veya Kısmen" seçtiğinizi temel alan açıklamalar**
1.	STEM ders planında belirtilen tüm kazanımları zamanında tamamladı mı?				
2.	ilgili fen konuları ve üniteleri arasında bağlantı kurdu mu?				
3.	fen konusunu STEM disiplinleri ile ilişkilendirdi mi?				
4.	STEM dersinde uygun kaynakları (kitap, internet, etkinlik kağıtları vb.) ve materyalleri (modeller vb.) kullandı mı?				
5.	dersin her bölümüne (giriş, gelişme ve sonuç) uygun bir zaman ayırdı mı?				
6.	STEM ders planında kavramları öğretmek için yaptığınız sıralamada bir değişiklik yaptı mı?				

Değerlendirme

	Dersi anlatan öğretmen:	**Evet**	**Hayır**	**Kısmen**	**Neden "Evet, Hayır veya Kısmen" seçtiğinizi temel alan açıklamalar**
1.	STEM dersinin tüm kazanımlarını değerlendirdi mi?				
2.	Dersin kazanımları doğrultusunda geleneksel değerlendirme yöntemleri (doğru yanlış, çoktan seçmeli, boşluk doldurma gibi) kullandı mı?				
3.	Dersin kazanımları doğrultusunda alternatif değerlendirme yöntemleri (kavram haritaları, posterler, rubrikler vb.) kullandı mı?				
4.	mühendislik tasarım sürecinin ürününü değerlendirdi mi?				
5.	öğrencilerin seviyelerine uygun değerlendirme yöntemlerini kullandı mı?				

STEM Entegrasyonu

	Dersi anlatan öğretmen:	**Evet**	**Hayır**	**Kısmen**	**Neden "Evet, Hayır veya Kısmen" seçtiğinizi temel alan açıklamalar**
1.	STEM dersi sırasında kriter, sınırlama, prototip vb. mühendislik terminolojilerini kullandı mı?				
2.	ders sırasında mühendislik tasarım sürecinin adımlarını düzgün bir şekilde uyguladı mı?				
3.	STEM ders planında belirtilen 21. yüzyıl becerilerine (problem çözme, iş birliği, yaratıcılık vb.) göre bir öğrenme ortamı oluşturdu mu?				Hangi 21. Yy becerileri kullanıldı:
4.	derste STEM ile ilgili kariyerlerle bağlantı yaptı mı?				
5.	öğrencilere küçük gruplar halinde çalışma ve grup iletişimini teşvik etme fırsatı verdi mi?				
6.	kız ve erkek öğrencilere derse aktif olarak katılmaları için eşit fırsat sağladı mı?				
7.	STEM dersini başlatmak için gerçek hayat problemi mi seçti mi?				

2. Ek Notlar:

3. Ders sonrası yapılacak grup toplantısında tartışmak istediğim ana noktalar:

a.

b.

c.

G. CURRICULUM VITAE

Personal Information

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Education

Ph.D.	Elementary Education Middle East Technical University, Ankara	2023
M.S.	Curriculum and Instruction Middle East Technical University, Ankara	2015
B.S.	Elementary Science Education Middle East Technical University, Ankara	2012

Work Experience

Research Assistant	Faculty of Education Science and Math Education Department Ege University, Izmir	2013-present

Projects

- **Researcher:** Flipping Learning Internationally in a Post Pandemic Era (FLIPP), Erasmus + KA2 Project (Project No: 2022-1-TR01-KA220-SCH-000089088), 2022-2024.
- **Educator:** Aliağa Bilim Şenliği: Sanayinin Kalbinde Bilim, TÜBİTAK 4007 (Project No: 119B224), 2021.
- **Researcher:** Middle School Students' Perceptions of Scientists and Engineers and Their Interest Towards STEM Careers, BAP (Scientific Research Project), (Project No: GAP-501-2018-3014), 2018-2019.
- **Educator:** 3. Uluslararası Mersin Bilim Şenliği. TÜBİTAK 4007 (Project No: 118B791), 2018.
- **Researcher:** Investigation of Pre-Service Teachers and Elementary Students' Sustainability Consciousness, BAP (Scientific Research Project), (Project No: BAP-05-06-2017-001), 2017.

- **Educator:** Ailemle Bilime Yolculuk. TUBİTAK 4007 (Project No: 117B214), 2017.
- **Educator:** Bilim-Tasarım-Teknoloji Hikayeleri 4: Sucul Ekosistemleri Yaşatalım, TÜBITAK 4004 (The Scientific and Technological Research Council of Turkey) Project, (Project No: 213B712), 2014.

Journal Papers

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Pekmez, E., Yilmaz, H., Alacam-Aksit. C. A., & **Guler, F.** (2018). An application of a module on the development of science-technology-design process skills for primary school students. *Ege Eğitim Dergisi, 19*(1), 135-160.

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Book Chapters

Guler-Nalbantoglu, F. (2022). Sanat eğitimi kapsamında doğadan esinlenen tasarımlar: Fen öğretiminde biyomimikri uygulamaları. In A. Oğuz-Namdar (Eds.), *Teknoloji destekli drama yöntemi ile sanat eğitimi uygulamaları* (pp. 277-295). Nobel Yayıncılık.

Namdar, B. & **Guler-Nalbantoglu, F.** (2022). Sosyobilimsel konulara giriş. In B. Namdar (Eds.), *Çağdaş yaklaşımlarla etkinlik destekli sosyobilimsel konuların öğretimi* (pp. 1-19). Nobel Yayıncılık.

Namdar, B. & **Guler-Nalbantoglu, F.** (2021). Teknoloji destekli öğretim. In K. Bilican & B. Şenler (Eds.), *İlkokulda fen öğretimi* (pp. 237-266). Vizetek.

Conference Papers

Guler-Nalbantoglu, F., Cakiroglu, J. & Yilmaz-Tuzun, O. (2022). Development of pre-service science teachers' PCK for STEM in the context of lesson study. European Conference on Educational Research (ECER), Yerevan, Armenia.

Guler-Nalbantoglu, F., Cetinkaya-Aydin, G., Cakiroglu, J. & Oztekin, C. (2021). Middle school students' perceptions of scientists and engineers and their interest towards STEM careers. European Conference on Educational Research (ECER), Online.

Guler, F. & Cakıroglu, J. (2018). PCK mapping of three experienced science teachers in refraction of light topic. European Conference on Educational Research (ECER), Bolzano, Italy.

Guler, F., Sen, M. Ozdemir, M. & Oztekin, C. (2018). Adaptation and validation of the sustainability consciousness questionnaire for teacher candidates. European Conference on Educational Research (ECER), Bolzano, Italy.

Sen, M., **Guler, F.** Ozdemir, M. & Oztekin, C. (2018). Uncovering teacher candidates' sustainability consciousness level. European Conference on Educational Research (ECER), Bolzano, Italy.

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Guler, F., Yigit-Koyunkaya, M. & Yilmaz, H. (2016). Öğretmenlerin STEM eğitimine dair farkındalıklarının artmasını amaçlayan bir STEM eğitim modelinin tanıtılması. 12th National Science and Mathematics Education Conference, Trabzon, Turkey.

Guler, F., Ozdemir, M., Asinmaz, A. & Oztekin, C. (2016). Çevre çizimlerinde sürdürebilir kalkınma izleri: "Resmim eskiden var olan doğayı yok etmemizi ve günümüzdeki kentleşmeyi anlatıyor". 12th National Science and Mathematics Education Conference, Trabzon, Turkey.

Guler, F. & Aksu, M. (2016). Pre-service science teachers' perceptions related to their pedagogical knowledge. European Conference on Educational Research (ECER), Dublin, Ireland.

Calik, B. & **Guler, F.** (2016). Comparison study of teacher education systems in Turkey & Poland. *3rd International Eurasian Educational Research Congress,* Muğla, Turkey.

Yigit-Koyunkaya, M., Yilmaz, H. & **Guler, F.** (2015). Where are we after 4 years STEM education experiences? 2nd International Conference on New Trends in Education: STEM Education: Establishing A Bridge Across Contexts, Istanbul, Turkey.

Yilmaz, H., Yigit-Koyunkaya, M., **Guler, F.** & Buyukaltay, D. (2015). Journey to the science world with STEM activities. 2nd International Conference on Education in Mathematics, Science, & Technology, Antalya, Turkey.

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H. TURKISH SUMMARY/TÜRKÇE ÖZ

Fen Bilgisi Öğretmen Adaylarının STEM Eğitimine ilişkin Pedagojik Alan Bilgisi Gelişimlerinin Ders İmecesi Kapsamında İncelenmesi

Giriş

Fen eğitiminde tek disiplinli bakış açısından, çok disiplinli bakış açısına geçiş son yıllarda belirgin hale gelmiştir (Johnson vd., 2016). Kohler ve arkadaşları (2016) "geleneksel yöntemlerin, öğrencileri küresel problemlere hazırlamadığını" iddia etmektedir (s. 13). Bu kapsamda yayınlanan rapor ve çalışmalarda Fen, Teknoloji, Mühendislik ve Matematik (STEM) disiplinlerinin entegre edilmesine güçlü bir vurgu yapılmaktadır (Akgunduz vd., 2015; Aydin-Gunbatar & Tabar, 2019; Moore vd., 2020; Rinke vd., 2016; Thibaut vd., 2019). Türkiye'de de Milli Eğitim Bakanlığı (MEB) fen bilimleri dersi öğretim programını revize etmiş ve mühendislik tasarım uygulamalarını öğretim programına dahil etmiştir (MEB, 2018a). Ancak, şu anda uygulanmakta olan öğretim programında mühendislik tasarım sürecine net bir vurgu yapılmamaktadır.

Öğretmenler STEM eğitiminin sınıflarda uygulanmasında kilit rol oynamaktadır; bu anlamda öğretmen kalitesini iyileştirmek oldukça önemlidir (Margot & Kettler, 2019; Sullivan & Bers, 2018). Öğretmenlerin güçlü STEM içerik bilgisine sahip olmaları ve STEM'i sınıfta nasıl uygulayacaklarını bilmeleri beklenmekle birlikte (Johnson vd., 2016) STEM eğitimini entegre etmek için yeterli pedagojik alan bilgisi (PAB) 'ne sahip olması da gerekmektedir (Honey vd., 2014; Saxton vd., 2014). Benzer şekilde, öğretmen adaylarının da STEM eğitimini sınıflarda etkili bir şekilde kullanmaları için nasıl destekleneceği ve eğitileceği açık değildir (Rinke vd., 2016). Öğretmen adayları, öğretmen eğitimi programlarında fen, matematik, öğretim teknolojileri gibi dersleri ayrı dersler olarak almakta ve disiplinlerarası kavramların öğretiminde zorluk yaşamaktadırlar (Yip & Chan, 2019). Ayrıca, yapılan araştırmalar, öğretmen adaylarının STEM eğitiminin uygulanacağı sınıflar için yeteri kadar hazır olmadıklarını da rapor etmektedir (Bartels vd., 2019; Fan & Yu, 2019; Radloff & Guzey, 2017). Fen bilgisi öğretmen adaylarının STEM'e ilişkin PAB'larının geliştirilmesi, ileride STEM eğitimini sınıflarında etkili bir şekilde uygulayabilmeleri açısından büyük önem taşımaktadır. Bu çalışmada fen bilgisi öğretmen adaylarının STEM'e ilişkin PAB'larının ders imecesi kapsamında gelişiminin incelenmesi hedeflenmiştir. Çalışmada yer alan araştırma soruları şu şekildedir:

1. Fen bilgisi öğretmen adaylarının STEM'e ilişkin pedagojik alan bilgileri ders imecesi kapsamında nasıl gelişir?
    a. Fen bilgisi öğretmen adaylarının öğretim programı bilgileri ders imecesi kapsamında nasıl gelişir?
    b. Fen bilgisi öğretmen adaylarının öğrencileri anlama bilgileri ders imecesi kapsamında nasıl gelişir?
    c. Fen bilgisi öğretmen adaylarının öğretim yöntemleri bilgileri ders imecesi kapsamında nasıl gelişir?
    d. Fen bilgisi öğretmen adaylarının değerlendirme bilgileri ders imecesi kapsamında nasıl gelişir?
2. Ders imecesi döngüsündeki hangi bileşenler fen bilgisi öğretmen adaylarının STEM'e yönelik PAB'larına katkıda bulunur?

STEM'e ilişkin PAB çalışmalarında araştırmacılardan bazıları PAB modellerine yeni boyutlar eklerken (Allen vd., 2016; Saxton vd., 2014), çok azı alanyazında var olan belirli PAB modellerinden yararlanmıştır (Aydin-Gunbatar vd., 2020; Srikoom vd., 2018). Bu çalışma, fen eğitimi alanında yaygın bir şekilde kullanılan Magnusson ve arkadaşlarının (1999) PAB modelini, STEM için PAB'a uyarlanmış ve dört boyutu STEM eğitimini temel özelliklerini dikkate alarak yeniden tanımlamıştır. Bu nedenle, bu çalışmanın belirli bir PAB modelini kullanması açısından alanyazın için önemli olabileceği düşünülmektedir.

Öğretmen eğitim programındaki dersler, öğretmen adaylarının PAB gelişiminin en önemli kaynaklarındandır (Evens vd., 2015; Hume & Berry, 2011). Nilsson ve Loughran (2012) ise öğretmen adaylarının PAB gelişimi için çeşitli yolların uygulanmasını önermişlerdir. Bu noktada ders imecesinin, öğretmen adayları için teori ve pratiği ilişkilendirmek için uygun bir bağlam sağlayabileceği (Dudley, 2015; Fernandez, 2005) ve PAB'larını geliştirebileceği düşünülmektedir (Juhler, 2016; Sims & Walsh, 2009). Bu çalışmanın önemli katkılarından biri, ders imecesini fen bilgisi öğretmenliği eğitim programlarına entegre etmek ve fen bilgisi öğretmen adaylarının STEM için PAB'larını geliştirmek için anlamlı deneyimler sunmaktır. Ayrıca, Park (2019) etkili öğretim için PAB gelişimine katkıda bulunan faktörlerin bir araya getirilmesinin altını çizmektedir. Bu çalışmada ders imecesi yoluyla, iş birliği içinde ders planlama (Coenders & Verhoef, 2019; Faikhamta vd., 2020), sınıf ortamında öğretim yapma (Akerson vd., 2017; Lau & Multani, 2018; Sickel, 2012), öğretimin gözlemi (Barendsen & Henze, 2019; Ekiz-Kiran vd., 2021) ve öğretim üzerine yansıtma (Akerson vd., 2017; Carlson vd., 2019; Henze & Barendsen, 2019; Nilsson & Karlsson, 2019) gibi PAB gelişimini destekleyen faktörler birlikle uygulanmıştır. Bu nedenle, çalışmanın PAB gelişimi ile ilgili alanyazına katkıda bulunacağını düşünülmektedir. Son olarak alanyazın, öğretmen adaylarının PAB'larını güçlendirmek için içerik gösterimi kullanılmasının önemini vurgulamaktadır (Aydin vd., 2013; Carpendale & Hume, 2019; Ekiz-Kiran vd., 2021; Hume & Berry, 2011; Nilsson & Loughran, 2012). Ancak ders imecesi ve içerik gösterimini birlikte kullanan çalışmaların sayısı sınırlıdır (Juhler, 2016; Pongsanon vd., 2011). Bu açıdan söz konusu çalışmanın içerik gösteriminin ders imecesi ile birlikte kullanımı ile ilgili alanyazında bulunan boşluğa katkı sağlayacağı düşünülmektedir.

STEM Eğitimi

Alanyazında STEM eğitimi ile ilgili birçok tanım bulunmaktadır (Bybee, 2013; Herschbach, 2011; Martin-Paez vd., 2019; Moore vd., 2020). STEM eğitimi öğrenciler, öğretmenler, program geliştirme uzmanları, politika belirleyiciler gibi farklı paydaşları içerdiği için ortak bir tanım yapılması oldukça zordur (English, 2016; Honey vd., 2014). Fakat alanyazında bulunan çalışmalar incelendiğinde farklı STEM eğitimi yaklaşımlarının bazı ortak özelliklerinin olduğu görülmüştür. Öncelikle, öğrenciler verilen mühendislik problemini çözmek için fen ve matematik ile ilgili bilgi ve becerilerden yararlanırlar (Dare vd., 2018; Guzey vd., 2014; Kennedy & Odell, 2014). STEM eğitiminin diğer temel özelliklerinden birisi de mühendislik tasarım sürecini içermesidir (Fan vd., 2021; Guzey vd., 2016). Mühendislik tasarım süreci farklı disiplinleri bir araya getiren katalizör olarak düşünülmektedir (Kelley &

Knowles, 2016). İyi tasarlanmış ve günlük hayatla ilişkilendirilmiş bir mühendislik tasarım süreci, öğrencilerin verilen problemleri kriterleri ve sınırlılıkları göz önünde bulundurarak çözmelerini sağlar (Guzey vd., 2016). Ayrıca, öğrencilere hatalarından öğrenmeleri için ortam oluşturur (Maiorca & Mohr-Schroeder, 2020) ve motive edici ve gerçekçi bir bağlam sunar (Bryan vd., 2015). STEM eğitiminin bir diğer önemli özelliği ise takım çalışmasını ve iş birliği içinde çalışmayı teşvik etmesidir (English & King, 2019). Öğrenciler hem bireysel sorumluluklar alıp hem de grup içindeki tartışmalara katılarak fikirlerini paylaşır, eleştirir ve problemi çözmek için müzakere eder (Capobianco & Rupp, 2014). STEM eğitimi ayrıca 21. Yüzyıl becerilerinin geliştirilmesi de hedefler (Thibaut vd., 2018). Probleme dayalı, projeye tabanlı ve sorgulamaya dayalı yaklaşımların kullanılması (Breiner vd., 2012; Chan vd., 2019a) ve değerlendirmenin alternatif yöntemlerle fen, matematik, mühendislik tasarım süreci, öğrenci ürünleri gibi farklı alanları kapsaması da STEM eğitiminin diğer temel özellikleri olarak sıralanmaktadır (Harwell vd., 2015). STEM eğitimi, farklı yaklaşımlar ve temel özellikler göz önünde bulundurularak bu çalışmada şu şekilde kavramsallaştırılmıştır: 1) fenin ana disiplin olması ve diğer disiplinlerin fen içine entegre edilmesi, 2) gerçek hayat problemlerinin (örneğin, en süratli araba tasarlamak, termos tasarlamak) mühendislik tasarım süreciyle çözülmesi, (3) fen ve/veya matematik disiplinlerinin mühendislik problemini çözmesi için kullanılması, (4) teknolojinin "öğretim teknolojileri" olarak ele alınması.

Mühendislik Tasarım Süreci

Mühendislik tasarım süreci tekrarlanan bir yapıya sahiptir (Crismond, 2013). Mühendislik tasarım sürecinin farklı modelleri arasında, bu çalışmada Massachusetts Eğitim Departmanı (2006) tarafından önerilen sekiz aşamalı mühendislik tasarım süreci kullanılmıştır. Mühendislik tasarım süreci problemi ve problemdeki kriter ve sınırlılıklar belirlenmesi ile başlar. Daha sonra öğrencilerin problem hakkında ve önceki çözümler ile ilgili araştırma yapmaları beklenir. Bu araştırmaların ışığında problemi çözmek için alternatif çözüm yollarının belirlenip daha sonra bunların arasından kriter ve sınırlılığı en iyi karşılayan çözüm yolunun seçilmesi gerekir. Öğrencilerin burada çözüm yolunun güçlü ve zayıf yönlerini belirlemeleri ve bir karar vermeleri gerekir. Bir sonraki aşamada öğrenciler seçtikleri çözüm yolu için prototip oluştururlar ve bu prototipin çalışıp çalışmadığını belirlemek için çeşitli denemeler yapıp veri toplarlar. Daha sonra gruplar, seçtikleri çözüm yolunun başta verilen mühendislik problemini nasıl çözdüğünü sunarlar. Son aşama olan yeniden tasarım aşamasında ise, öğrencilerden tasarımlarının güçlü ve iyileştirmeye açık yönlerini belirlemeleri istenir. Bu aşamada öğrenciler tasarımlarını güçlendirdikten sonra tekrar test etme sürecine girerler (Crismond, 2013; Hynes vd., 2011).

Pedagojik Alan Bilgisi

Bu çalışmada kavramsal çerçeve olarak pedagojik alan bilgisi kullanılmıştır. Shulman tarafından PAB "öğretim yaparken konunun daha anlaşılır olması için kullanılan gösterim ve biçimlendirmeler" olarak tanımlanmıştır (1986, s. 9). Shulman tarafından öne sürüldükten sonra birçok araştırmacı farklı PAB modelleri geliştirmiştir (Carlson & Daehler, 2019; Grosman, 1990; Park & Oliver, 2008). Bu çalışmada Magnusson vd. (1999) tarafından önerilen PAB modeli kullanılmış ve STEM eğitimin temel özellikleri baz alınarak revize edilmiştir. Bu modelde beş boyut bulunmaktadır: fen öğretim yönelimleri, öğretim programı bilgisi, öğrencileri anlama bilgisi, öğretim yöntemleri bilgisi ve değerlendirme bilgisi. Fen öğretim yönelimleri boyutu bu çalışma kapsamına dahil edilmemiştir. Friedrichsen vd. (2011) bu boyutun tanımlanmasında bazı sorunlar olduğunu bildirmiş ve bu sorunların ölçmeye yansıdığını da vurgulamıştır. Ayrıca PAB gelişimi ile ilgili yapılan birçok çalışma da bu boyutu benzer sebeplerle çalışmaya dahil etmemiştir (Aydin-Gunbatar vd., 2020; Juhler, 2016). Bu bağlamda STEM'e ilişkin PAB boyutları şu şekilde yeniden tanımlanmıştır: (1) öğretim programı bilgisi: öğretmenlerin STEM derslerinde kazanım belirleme (fen bilimleri öğretim programı ve diğer STEM disiplinleri için; örneğin, fen içeriği ve mühendislik tasarım süreci için kazanımlar yazma) ve fen kazanımlarını diğer STEM disiplinleriyle ilişkilendirme konusundaki bilgisi, (2) öğrencileri anlama bilgisi: öğretmenlerin, öğrencilerin mühendislik tasarım süreci ve fen ve matematik ile ilgili kavramlarda sahip olabileceği kavram yanılgıları ve yaşayabileceği zorluklar hakkındaki bilgisi, (3) öğretim yöntemleri bilgisi: öğretmenlerin STEM eğitimi ile uyumlu öğretim yöntemlerini kullanma (örneğin, 5E öğrenme döngüsü, probleme dayalı öğrenme), tasarım merkezli öğretim uygulamalarını uygulama ve STEM derslerinde gösterim ve etkinlikleri kullanma hakkındaki bilgisi, (4) değerlendirme bilgisi: öğretmenlerin STEM dersinin hangi bölümünün değerlendirilmeye değer olması gerektiği (örneğin, fen içeriği, mühendislik tasarım süreci ve ürünü, 21. yüzyıl becerileri vb.) ve uygun değerlendirme yöntemini kullanma (dereceli puanlama anahtarı, akran değerlendirmesi, poster sunumu vb.) ile ilgili bilgisi.

Ders İmecesi

Ders imecesi, Japonya'da sıklıkla kullanılan bir profesyonel gelişim programıdır (Dudley, 2015; Lewis, 2002) ve "öğretme ve öğrenmenin kalitesini artırmak amacıyla, bireyler yerine bir grup öğretmen tarafından grup olarak yürütülen sınıf pedagojisinin sistematik bir araştırması" olarak tanımlanır (Tsui & Law, 2007, s. 1294). Ders imecesi öğretmenlere "öğrencilerin gözünden öğretimi görme" fırsatını sunar (Lewis, 2002, s. 21).

Ders imecesi döngüseldir ve üç temel aşamadan oluşmaktadır: planlama, öğretim ve yansıtma. Yeniden öğretim ve yeniden yansıtma aşamaları ise isteğe bağlı olarak gerçekleştirilir (Dudley, 2015; Lewis vd., 2009). Bu çalışmada beş aşamanın tümü de takip edilmiştir. Planlama aşamasında, ders imecesi grubundaki dört ila altı öğretmen genellikle dersin hedeflerini belirlemek için bir araya gelir. "Araştırma dersi" olarak adlandırılan ders planlarını ortaklaşa planlamaya başlarlar. Ders imecesi grubundaki öğretmenler planlama toplantılarında fikir ve önerilerini paylaşırlar. Bu süreçte çeşitli toplantılar yapılır. Öğretmenler, öğrencilerin zorluklarını ve kavram yanılgılarını göz önünde bulundurarak planlama aşamasında öğrencileri araştırma dersine nasıl dahil edeceklerini kapsamlı bir şekilde tartışır (Takahashi & Yoshida, 2004). Örneğin, öğrencilerin zorlandıkları bir konunun öğretimi veya öğretim programında yeni bir yaklaşımın uygulanması ile ilgili ders planlayabilirler (Bridges, 2015). Öğretim aşamasında ise gruptaki öğretmenlerden biri ortak hazırlanan ders planını uygularken, uygun olan öğretmenler dersi gözlemler ve veri toplar (Coenders & Verhoef, 2019; Dudley, 2015). Ders imecesinin üçüncü ana aşaması öğretim üzerine yansıtmadır. Ders imecesi grubu, öğretim aşamasının hemen ardından toplanır. Uygulanan araştırma dersi, toplanan veriler ve deneyimler dikkate alınarak değerlendirilir. Genellikle dersin öğretmeni deneyimlerini paylaşmaya başlar ve ardından diğer grup üyeleri katkıda bulunur. Derste nelerin işe yaradığı ve daha iyi bir ders için neler yapılabileceği bu aşamada belirlenir. Bu tartışmalara dayanarak, öğretmenler dersin kazanımlarına ulaşmak için öğretim yöntemleri, değerlendirme vb. gibi yerlerde değişiklikler yaparlar. Yeniden öğretim aşamasında, gruptaki başka bir öğretmen revize edilmiş ders planını başka bir sınıfa uygularken diğer öğretmenler gözlemci olarak ders katılırlar. Bu aşamayı yeniden yansıtma aşaması takip eder ve ders imecesi grubu tekrar toplanarak ders planındaki değişikliklerin işe yarayıp yaramadığını ile ilgili tartışmalar yaparak ders planını bir kere daha revize ederler.

Yöntem

Çalışma Deseni

Araştırmacılar bilimsel çalışmalarda bütüncül bir bakış açısı ile "ne derece" sorusunun yerine "nasıl" sorusunun cevabını bulmak isteyebilirler (Fraenkel vd., 2012). Bu bağlamda nitel araştırmacılar doğal ortamdan veri toplamayı ve olayların insanlar tarafından nasıl algılandığı ile ilgilenirler (Denzin & Lincoln, 2011). Bu çalışmanın amacı fen bilgisi öğretmen adaylarının STEM eğitimine ilişkin pedagojik alan bilgilerinin ders imecesi kapsamında nasıl değiştiğini incelemek olduğu için nitel araştırma deseni kullanılmıştır. Nitel araştırma yöntemlerinden ise çoklu durum çalışması seçilmiştir (Creswell, 2013). Bu çalışmada, her bir öğretmen adayı bir durumu oluşturmuş ve ders imecesi süreci dört durum ile tekrarlanmıştır. Her bir duruma yönelik tanımlamalar dört ders imecesi kapsamında detaylı bir şekilde verilmiş ve daha sonra durumlar arasında her bir PAB boyutu ele alınarak karşılaştırma yapılmış, PAB gelişim örüntüleri arasındaki benzerlik ve farklılıklar ortaya konmuştur.

Katılımcılar

Katılımcılar amaçlı örnekleme yöntemi ile seçilmiştir (Patton, 2002). Katılımcılar belirlenmeden önce bazı seçilim kriterleri belirlenmiştir. Bu kriterler: (1) katılımcıların 4. sınıfta olması, alan bilgisi, pedagojik alan bilgisi ile ilgili derslerinin çoğunu tamamlamış olması, (2) Öğretmenlik Uygulaması-1 dersine kayıtlı olmaları, (3) gönüllü olmaları, (4) ekip çalışmasına yatkın olmaları. Ders imecesi araştırmalarında grupların en az üç, en fazla altı kişiden oluşması beklenmektedir (Lewis vd., 2006). Üç katılımcı ile çalışmak veri kaybı açısından riskli olacağından, dört fen bilgisi öğretmen adayı ile çalışılmasına karar verilmiştir. Katılımcıların gerçek isimleri yerine takma isimler kullanılmıştır: Ada, Defne, Ece ve Deniz. Katılımcıların üçü kadın, biri erkektir (Deniz). Katılımcıların genel not ortalamaları birbirine yakındır. Deniz daha önce mühendislik fakültesinde bir dönem okumuş, Ada ise fen eğitiminde güncel eğilimler isimli projeye katılmış ve bu proje kapsamında mühendislik tasarım süreci ile ilgili bir etkinliğe dahil olmuştur. Diğer katılımcılar daha önce herhangi bir STEM eğitimine katılmamışlardır.

Veri Toplama Süreci

Ana çalışma öncesinde pilot çalışma yapılmıştır. Pilot çalışmanın yapıldığı süreçte Covid-19 pandemi tedbirleri sebebiyle üniversite ve ortaokul öğrencileri çevrimiçi eğitim sürecinde oldukları için katılımcılar tarafından hazırlanan STEM ders planları çevrimiçi ortamda fen bilgisi öğretmen adaylarına uygulanmıştır. Pilot çalışma kapsamında iki ders imecesi uygulanmış ve bu sürecin sonucunda hazırlanan STEM ders planı formatının yerine içerik gösterimi kullanılmasına karar verilmiştir. Görüşme soruları ve gözlem protokolünde bazı maddelerde katılımcıların yönlendirmeleri ile değişiklikler yapılmıştır.

Ana çalışmada, dört ders imecesi döngüsü kapsamında hazırlanan STEM ders planları, öğretmen adayları tarafından 6. sınıf öğrencilerine uygulanmıştır. Uygulama tarihleri ve seçilen konular Tablo 1'de verilmiştir. Fen bilimleri öğretim programında bulunan her üniteden bir STEM ders planı hazırlanmış ve veri toplama süreci yaklaşık olarak altı ay sürmüştür.

Veri Toplama Araçları

Bu çalışmada, katılımcıların STEM'e ilişkin PAB gelişimlerini incelemek amacıyla dört farklı veri toplama aracı kullanılmıştır. Hangi veri toplama aracının hangi araştırma sorusunu yanıtlamak için kullanıldığı Tablo 2'de sunulmuştur.

Tablo 1

Ders İmecesi Döngülerine ait Detaylı Bilgiler

Ders İmecesi Döngüleri	**Tarih Aralığı**	**Seçilen Konu ve İlgili Mühendislik Tasarım Süreci Etkinliği**
Döngü-1	06.10.2021-11.11.2021	Güneş Tutulması ve Güneş Tutulmasını İzlemek için Gözlük Tasarımı
Döngü-2	16.11.2021-22.12.2021	Sürat ve Yarış Arabası Tasarımı
Döngü-3	23.12.2021-24.01.2022	Isı Yalıtımı ve Termos Tasarımı
Döngü-4	01.02.2022-18.03.2022	Ses Yalıtımı ve Ses Yalıtımlı Müzik Odası Tasarımı

İlk olarak, Magnusson vd. (1999) PAB modeli bileşenleri merkeze alınarak hazırlanan ve uzman görüşleri alınan görüşme soruları kullanılmıştır. Ön görüşme soruları ders imecesinin planlama aşaması sonrasında, son görüşme soruları ise öğretim aşamasından sonra bireysel olarak uygulanmıştır. İkinci veri toplama aracı olarak Aydin vd. (2013) tarafından öğretmen adayları ile kullanılması için revize edilen içerik gösterimi kullanılmıştır. İçerik gösterimin yatay ekseninde öğretilmesi planlanan kavramlar, dikey eksenlerde ise öğretimi etkileyebilecek kavram yanılgıları, değerlendirme gibi maddeler bulunmaktadır. Katılımcılar planlama toplantılarında içerik gösterimini kullanarak dört ortak STEM ders planı hazırlamışladır. Ayrıca, her katılımcıdan çalışmanın başında ve sonunda iki tane bireysel içerik gösterimi hazırlamaları istenmiştir. İçerik gösteriminde bulunan maddeler araştırmacı tarafından planlama ve yansıtma aşamalarındaki tartışmaları yönlendirmek için kullanılmıştır. Öğrenciler içerik gösterimini hazırlarken, sekiz basamaklı mühendislik tasarım sürecine dayalı olarak hazırlanan mühendislik defterini içerik gösteriminin öğretim yöntemleri kısmına entegre etmişlerdir. Üçüncü veri toplama aracı olarak araştırmacı tarafından geliştirilen ve PAB modeline dayalı olarak hazırlanan ve STEM eğitiminin temel özellikleri ile zenginleştirilmiş gözlem protokolü kullanılmıştır. Bu gözlem protokolü, her ders uygulamasında dersi gözlemleyen üç öğretmen adayı ve araştırmacı tarafından doldurulmuştur. Araştırmacı bu protokolü son görüşme sorularını düzenleme ve yansıtma toplantılarında ders planını revize ederken tartışmaları yönetmek için kullanmıştır. Son olarak, planlama ve yansıtma toplantıları video ile kaydedilmiş ve veri üçgenleme için kullanılmıştır.

Tablo 2

Araştırma Soruları ve Veri Toplama Araçları

Araştırma Soruları	Veri Toplama Araçları
3. Fen bilgisi öğretmen adaylarının STEM'e ilişkin PAB'ları ders imecesi kapsamında nasıl gelişmiştir?	Görüşme soruları İçerik gösterimi Gözlem protokolü Video kayıtları
4. Ders imecesinin hangi bileşenleri fen bilimler öğretmen adaylarının STEM'e ilişkin PAB gelişimine katkıda bulunmuştur?	Görüşme soruları İçerik gösterimi

Verilerin Analizi

Birinci araştırma sorusunun analizlerinde önce revize edilmiş Magnusson vd. (1999) PAB modeli baz alınarak geçici bir veri kodlama tablosu oluşturulmuştur. Üç görüşme ve iki içerik gözlemi iki farklı araştırmacı tarafından bağımsız olarak kodlanmıştır. Daha sonra araştırmacılar bir araya gelmiş ve kodlardaki farklılıkları tartışarak veri kodlama tablosunu güncellemiştir. Bu aşamada yeni kodlar ortaya çıkmıştır. Güncellenen veri kodlama tablosu kullanılarak bir görüşme daha ayrı olarak kodlanmış ve veri kodlama tablosunun son hali verilmiştir.

Bir sonraki aşamada bu kodlar kullanılarak katılımcıların STEM'e ilişkin PAB gelişim düzeyleri üç kategori olarak belirlenmiş (fene özgü PAB, geçiş PAB'ı ve STEM'e ilişkin PAB) ve bu kategoriler belirlenirken, Aydin-Gunbatar ve arkadaşlarının (2020) oluşturduğu PAB gelişim düzeylerinden yararlanılmıştır. İlk kategori PAB-A olarak belirlenmiş ve bu kategorideki katılımcıların fene özgü PAB'a sahip olduğu görülmüştür. Örneğin, STEM ders planı hazırlarken sadece fen ile ilgili kazanımların yazılması. İkinci kategori PAB-B (geçiş PAB'ı) olarak etiketlenmiş ve bu kategorideki katılımcıların STEM eğitimi ile ilgili temel özellikleri entegre etmeye başladıkları fakat STEM eğitimin tüm özellikleri yansıtamadıkları görülmüştür. Örnek olarak, katılımcıların öğrencilerin fen ile ilgili kavram yanılgılarını detaylı bir şekilde ele alırken diğer STEM disiplinleri ile ilgili kavram yanılgılarına yüzeysel olarak odaklandıkları görülmüştür. Son kategori PAB-C olarak belirlenmiş ve bu kategori STEM eğimini temel özelliklerinin dengeli bir şekilde entegre edildiğini göstermektedir. Bu düzeydeki katılımcıların hem fen kazanımlarını hem öğrenci ürünlerini hem de diğer STEM disiplinlerine yönelik kazanımları tam ve dengeli bir şekilde değerlendirmeleri örnek olarak verilebilir.

İkinci araştırma sorusu analiz edilirken ders imecesinin bileşenleri belirlenmiş ve katılımcıların yapılan görüşmelerde STEM'e ilişkin PAB gelişimleri hakkında konuşurken bu bileşenlerin hangilerine değindikleri belirlenmiştir. Katılımcıların verdikleri cevaplar içerik gösterimleri ile desteklenmiştir. Örneğin, bir katılımcı derse gözlemci olarak katılmasının öğrencileri anlama bilgisine olan katkısından bahsetmiş ve mühendislik ile ilgili öğrencilerin yaşadıkları zorluklar hakkında bilgisinin arttığını söylemiştir. Daha sonra bu durumun içerik gösterimlerinin revize edilmiş halinde olup olmadığı karşılaştırılmıştır.

Bulgular

Araştırma Sorusu 1: Fen Bilgisi Öğretmen Adaylarının STEM'e ilişkin PAB'larının Gelişimi

Durum 1: Ada

Çalışmanın başında Ada, STEM ders planı hazırlarken sadece fen kazanımları yazmıştır. Fen bilgisi öğretim programından kazanım seçerken içinde "proje tasarlar" ifadesinin olduğu kazanımlardan seçtiğini belirtmiştir **(bireysel içerik gösterimi-1).** Bu sebeple çalışmanın en başında öğretim programı bilgisinin PAB-A kategorisindedir. Ders imecesi 1'in planlama toplantılarında Ada aktif bir şekilde görev almış ve seçtikleri kazanımın mühendislik tasarım süreci ile uyumlu olması gerektiğini belirtmiştir. Fakat fen dışındaki bir disiplin için kazanım yazılmasını önermemiştir **(ön görüşme-1).** Ders imecesi 1'in sonunda Ada'nın öğretim programları bilgisi PAB-B kategorisine yükseltmiştir. Ders imecesi 2 sırasında gözlemci öğretmen olan Ada, görüşmelerde STEM ders planında matematik ve mühendislik ile ilgili kazanımlar yazmanın öneminden bahsetmeye başlamıştır.

Ayrıca, bir önceki STEM ders planında "yazdığımız kazanım ve yaptığımız değerlendirme arasında uyumsuzluğu" fark ettiğini söylemiştir **(ön görüşme-2).** Ders imcesi-2 sonunda Ada, STEM ders planında fen, matematik ve mühendislik tasarım süreci ile ilgili kazanım yazmaya eşit önem vermiştir ve öğretim programı bilgisi PAB-C kategorisine yükselmiştir. Ders imecesi 3 ve ders imecesi 4 sırasında Ada hem fen ile ilgili kazanım yazılmasını önermiş, hem de matematik programından öğrenci düzeyine uygun kazanımlar seçerek bunların nedenlerini detaylı bir şekilde vermiştir **(araştırmacı gözlem notları).** Bu bulgular, Ada'nın öğretim programı ile ilgili STEM'e ilişkin PAB (PAB-C) kategorisinin özelliklerini karşıladığını göstermektedir.

Öğrencileri Anlama Bilgisi

Ders imecesi 1'den önce hazırladığı içerik gösteriminde Ada sadece fen ile ilgili kavram yanılgıları ve zorluklara sınırlı bir şekilde yer vermiş olup, diğer STEM disiplinlerine odaklanmamıştır **(bireysel içerik gösterimi-1).** Ders imecesi 1 sırasında da içerik gösterimine fen ile ilgili kavram yanılgıları yazılmasını önermiş ve bu kavram yanılgılarına kendisinin de sahip olduğunu belirtmiştir **(ders imecesi 1, planlama video kayıtları).** Öğrencilerin yaşadığı zorluklarla ilgili yapılan tartışmalarda ise hem fen hem de mühendislik ile ilgili zorluklara değinmiştir. Örneğin, öğrencilerin kriterleri karşılayan birden fazla çözüm önerisi üretme ya da tasarımlarının sınırlılıklar dahilinde yapılması gibi konularda zorluk çekeceklerini düşündüğünü belirmiştir **(ön görüşm**e-2). Ada ders imecesi 1 döngüsüne başlamadan önce fene özgü PAB (PAB-A) kategorisinin özelliklerini taşırken, ders imecesi 1 sonunda geçiş PAB'ı (PAB) kategorine yükselmiştir çünkü kavram yanılgılarının ve öğrencilerin yaşadıkları zorluklar konusunda odağı bir STEM disiplininde olup diğer disiplinlere yüzeysel olarak değinmiştir.

Ders imecesi 2 sırasında Ada hem fen ile ilgili hem de mühendislik ve matematikle ilgili zorluk ve kavram yanılgılarına eşit bir şekilde değinmeye başlamıştır **(ders imecesi 2, planlama video kayıtları ve ön görüşme-2).** Örneğin, her veri tipi için tek bir çeşit grafik vardır gibi matematik ile ilgili olası kavram yanılgılarından bahsetmiştir **(ön görüşme-2).** Ada'nın öğrencileri anlama bilgisi ders imecesi 2 sonunda STEM'e ilişkin PAB (PAB-C) kategorisinin özelliklerini taşımaktadır. En az iki STEM disiplini ile ilgili kavram yanılgıları ve zorluklara eşit bir şekilde değinmiş, bunların olası nedenleri, tespiti ve giderilmesi için önerilerde bulunmuştur. Ders imecesi 3 ve ders imecesi 4 sırasında öğrencileri anlama bilgisi konusunda Ada, PAB-C kategorisinin özelliklerini göstermiştir. Örnek olarak, bir önceki STEM ders planı uygulamasında öğrencilerin sadece tek bir doğru mühendislik tasarım süreci olduğunu düşündüklerini fark etmiş ve üçüncü STEM ders planı hazırlarken bu kavram yanılgısını dikkate alarak dersi planlamaları gerektiğini belirtmiştir (**ders imecesi 3, planlama video kayıtları).**

Öğretim Yöntemleri Bilgisi

Ders imecesi döngülerine başlamadan önce Ada hazırladığı bireysel içerik gösteriminde STEM ile uyumlu herhangi bir öğretim yöntemi kullanmamıştır. Hazırladığı içerik gösterimi STEM eğitimimin temel özelliklerini ve tasarım süreci içermemektedir **(bireysel içerik gösterimi).** Ders imecesi 1 sırasında Ada, 5E öğrenme döngüsü kullanılmasını önermiş çünkü bu öğretim yöntemi ile ilgili bilgisine güvendiğini ve alışık olduğunu söylemiştir. Fakat neden özellikle bu öğretim yönteminin STEM dersinde kullanıldığı ile ilgili detaylı açıklamalar yapmamıştır (**ön görüşme-1).** Planlama toplantısında tasarım merkezli öğretim uygulamaları ile yaptığı önerilerle ön plana çıkmış ve arkadaşlarını ikna etmiştir. Örneğin, Deniz Güneş tutulmasını izlemek için gözlük tasarlarken hazır çerçeveler verilmesi gerektiğini savunmuş fakat Ada eğer hazır çerçeve verirlerse öğrencilerin sadece o çerçeveye filtre koyacağını, bunun da mühendislik tasarım problemini çözme, kriterleri sağlama, birden fazla çözüm yolu üretme gibi noktalarla uyuşmadığını belirtmiştir (**ders imecesi 1, planlama video kayıtları).** Dersin öğretimi aşamasında ise Ada tasarım merkezli öğretim uygulamalarını kısmen uygulamıştır. Örnek olarak, fen kavramlarının mühendislik tasarım süreci bağlamında tartışılması, yeniden tasarım gibi konulara öğretim sırasında önem vermemiştir **(araştırmacı gözlem protokolü).** Dolayısıyla, Ada'nın öğretim yöntemleri ile ilgili PAB'ı çalışmanın başında PAB-A kategorisine aitken, ders imecesi 1'in sonunda PAB-B kategorisine yükseltmiştir. Ders imecesi 2 döngüsünde Ada farklı bir öğretim yöntemi kullanılmasına destek vermiş ve grup arkadaşları ile REACT kullanımına karar vermişlerdir (**ders imecesi 2, planlama video kayıtları).** Fakat neden bu öğretim yönteminin STEM eğitimi ile uyumlu olduğu konusundaki açıklamaları yetersiz kalırken **(ön görüşme-2)** dersin öğretiminden sonra yapılan görüşmede REACT ile ilgili açıklamalarında STEM eğitiminin temel özelliklerinden bahsetmiştir **(son görüşme-2).** Ayrıca, tasarım merkezli öğretim uygulamaları ile ilgili anlayışı gelişmiştir. Örnek olarak, kız öğrencilerin sadece planlama aşamasında değil, test etme sürecinde de grup içinde aktif rol almaları gerektiğini, yeniden tasarım aşamasında araçların olumlu ve olumsuz yönlerinin tartışılıp, iyileştirilecek noktaların belirlenmesi gibi uygulamalara detaylı bir şekilde değinmiştir **(son görüşme-2).** Bu özellikler, Ada'nın ders imecesi 2 sonrasında STEM'e ilişkin PAB (PAB-C) kategorisinin özelliklerini taşıdığını göstermektedir. Ada ders imecesi 3 ve ders imecesi 4 sürecinde de PAB-C kategorisi ile uyumlu gelişim göstermiştir.

Değerlendirme Bilgisi

Ada'nın çalışmanın başında hazırladığı bireysel içerik gösteriminde fen kazanımları rubrik yardımı ile değerlendirilmiştir **(bireysel içerik gösterimi-1).** Ders imecesi 1'de Ada grup tartışmalarında sadece mühendislik tasarım sürecinin değerlendirilmesine odaklanmıştır **(ön görüşme-1).** Ders imecesinin başında Ada, PAB-A kategorisinde bulunurken, ders imecesi 1 tamamlandıktan sonra PAB-B kategorisine geçmiştir çünkü STEM ders planının sadece mühendislik ile ilgili kısımlarının değerlendirilmesine dikkat etmiştir. Ayrıca, önerdiği değerlendirme yöntemlerinde bir çeşitlilik bulunmamaktadır. Ders imecesi 2 döngüsünde Ada fen kazanımlarının yanı sıra matematik ve mühendislik tasarım sürecinin değerlendirilmesi gerektiğine dikkat çekmiştir **(ön görüşme-2).** Örnek olarak, öğrenci ürünlerinin değerlendirmek için kriter listesi ya da matematik kazanımlarını değerlendirmek için çoktan seçmeli sorular konulması konusunda fikirlerini arkadaşlarıyla paylaşmıştır **(ders imecesi 2, planlama video kayıtları).** Değerlendirme için kavram haritası, kriter listesi gibi çeşitli yöntemler önermiştir. Bu özellikler, Ada'nın STEM'e ilişkin PAB (PAB-C) kategorisine geçiş yaptığını göstermektedir. Ders imecesi 3 ve ders imecesi 4 sürecinde de Ada hem fen kazanımlarına hem de matematik, mühendislik kazanımlarına ve öğrenci ürünlerini değerlendirmeye eşit bir şekilde önem vermiştir. Sonuç olarak, çalışmanın sonunda Ada'nın değerlendirme bilgisi tutarlı ve STEM dersinin farklı kısımlarına dengeli bir şekilde odaklanmaktadır.

Durum 2: Defne

Öğretim Programı Bilgisi

Defne, çalışmanın başında hazırladığı STEM ders planında sadece fen ile ilgili kazanımlar yazmış ve içinde "genetik mühendisliği" geçen kazanımı fen öğretim programından seçmiştir **(bireysel içerik gösterimi).** Ders imecesi 1 aşamasındaki odağı yine fen kazanımları üzerindedir. Örneğin, STEM ders planlarında mühendislik tasarım sürecinin kullanımını tartışmakla birlikte mühendislik ile ilgili kazanım yazılmasını önermemiştir **(ön görüşme-1).** Bu durumlar, çalışmanın başında Defne'nin öğretim programı konunda PAB-A kategorisinde olduğunu gösterirken, ders imecesi 1 tamamlandığında PAB-B kategorisine geçiş yaptığını göstermektedir. Ders imecesi 2'nin planlama toplantılarında Defne, STEM ders planı hazırlarken matematik ile ilgili de bir kazanım yazılmasını önermiştir **(ders imecesi 2, planlama video kayıtları).** Defne matematik öğretim programının kapsamına hakim olmaya ve STEM ders planında farklı kazanımlar yazılmasına ağırlık vermeye başlamıştır. Dolayısıyla, ders imecesi 2 tamamlandığında Defne'nin öğretim programı bilgisinin PAB-C, yani STEM'e ilişkin PAB seviyesine yükseldiği görülmüştür. Ders imecesi 3 ve ders imecesi 4 aşamalarında da Defne'nin fen, matematik, teknoloji ve tasarım dersi öğretim programlarının kapsamına dair bilgilerinin arttığı, STEM ders planı için farklı disiplinlere ait kazanım yazarken, hepsine dengeli bir şekilde önem verdiği gözlemlenmiştir.

Öğrencileri Anlama Bilgisi

Ders imecesine başlamadan önce Defne içerik gösteriminde herhangi bir kavram yanılgısı belirtmemiştir. Öğrencilerin yaşadıkları zorluklarla ilgili olarak ise "öğrenciler genetik ve biyoteknoloji ile ilgili kavramları anlamakta zorlanır" şeklinde genel bir ifade kullanmıştır **(bireysel içerik gösterimi).** Ders imecesi 1 sırasında yalnızca fen ile ilgili kavram yanılgılarına odaklanmış ve öğrencilerin genel olarak mühendislik tasarım süreci ile ilgili yaşayabileceği zorluklara odaklanmıştır **(son görüşme-1).** Bu bağlamda, Defne çalışmanın başında PAB-A kategorisinin özelliklerini gösterirken, ders imecesi 1 sonunda öğrencilerin sahip olduğu kavram yanılgıları ve yaşadıkları zorluluklarla ilgili bir disipline odaklanmış olduğu için PAB-B kategorisine geçiş yapmıştır. Ders imecesi 2 esnasında Defne daha aktif bir rol almış ve fen ile ilgili kavram yanılgıların tespit edilmesi için kelime ilişkilendirme testi, kavram haritası gibi araçların kullanılmasını tercih etmiştir. Ayrıca, matematik ile ilgili "her veri seti için tek tip grafik çizilir" kavram yanılgısının içerik gösterimine eklenmesini önermiştir **(ders imecesi 2, planlama video kayıtları).** Öğrencilerin grafik çizme ve farklı çözüm yolları önerme konusunda zorlanacaklarını da belirtmiştir **(ön görüşme-2)** ve dersin öğretimi sırasında bu noktaların üzerinde durarak öğrencilerin yaşadıkları zorluklara en aza indirmeye çalışmıştır **(araştırmacı gözlem notları).** Özetle, Defne'nin öğrencilerin kavram yanılgıları ve zorluklarla ilgili bilgileri ders imecesi 2'yi tamamladıktan sonra gelişmiştir. Öğrencilerin fen, mühendislik ve matematik alanlarındaki güçlüklerinin farkına varmış ve dengeli bir şekilde bunları ele almıştır. Bu özellikler, STEM için PAB (PAB-C) seviyesini karşılamaktadır. Defne'nin öğrencileri anlama konusundaki bilgisi ders imecesi 3 ve ders imecesi 4 sırasında da PAB-C özelliklerini karşılamaktadır.

Öğretim Yöntemleri Bilgisi

Defne, bireysel hazırladığı ilk STEM ders planında argümantasyon yöntemini kullanmış fakat STEM eğitiminin temel özelliklerini içerik gösterimine entegre edememiştir **(bireysel içerik gösterimi).** Ders imecesi 1 sırasında 5E öğrenme döngüsü hakkındaki bilgilerine güvendiği için STEM ders planında bu yöntemin kullanılmasını tercih etmiştir. Fakat bu yöntemin neden STEM ders planında kullanılmaya uygun olduğu konusunda yeterli açıklamalar yapamamıştır **(ön görüşme-1).** Diğer yandan tasarım merkezli öğretim uygulamalarının bazılarının üzerinde durmaya başlamasına rağmen (probleme farklı çözüm yollarını önerilmesi gibi) tasarımların test edilmesi, tasarımdaki iyileştirecek noktaların belirlenmesi gibi noktalara çok yüzeysel olarak değinmiştir **(son görüşme-1).** Bu sebeple Defne ders imecesi 1 döngüsüne başlamadan önce PAB-A kategorisindeyken, ders imecesi 1 tamamlandığında PAB-B kategorisindedir. Benzer şekilde ders imecesi 2 sırasında da PAB-B özelliklerini göstermektedir. Örneğin, ders planında neden REACT yöntemini kullandıklarını açıklarken STEM eğitiminin temel özelliklerinden bahsetmemiştir **(ön görüşme-2).** Ayrıca, ders öğretimi sırasında mühendislik tasarım sürecinin bazı basamaklarını atlayarak uygulamıştır (örneğin bazı gruplarda sürat kavramını mühendislik tasarım süreci kapsamında tartışmamış ve kavramsal olarak yeniden tasarım yapmalarına olanak sağlamamıştır) **(araştırmacı gözlem notları).** Ders imecesi 3 ve ders imecesi 4 tamamlandıktan sonra Defne öğretim yöntemleri konusunda STEM'e ilişkin PAB (PAB-C) özelliklerini göstermiştir. Ders imecesi 4 yeniden öğretim aşamasında tasarım merkezli öğretim uygulamalarını düzgün bir şekilde uygulamıştır. Öğrencilerin hazırlanan ses dergisini kullanarak mühendislik problemini çözmelerine, ses yalıtımı ile ilgili araştırma yapmalarına rehberlik etmesi buna örnek olarak verilebilir. Sonuç olarak, çalışmanın sonunda Defne'nin öğretim yöntemlerine ilişkin bilgisi PAB-C kategorisinin özelliklerini taşımaktadır.

Değerlendirme Bilgisi

Ders imecesi döngülerine başlamadan önce hazırladığı içerik gösteriminde Defne fen kazanımlarını değerlendirmek için öğrencilerin bir poster hazırlamasını istemiş ve bu posteri bir rubrik ile değerlendirmiştir **(bireysel içerik gösterimi).** Defne'nin değerlendirmeye yönelik bilgisi çalışmanın başında PAB-A kategorisinin özelliklerini gösterirken, çalışmayı PAB-B kategorisinde tamamlamıştır. Değerlendirme konusunda Defne, STEM ders planlarının farklı alanlarını değerlendirmeye eşit bir şekilde odaklanmamıştır. Örnek olarak, ders imecesi 1 sırasında sadece mühendislik tasarım sürecinin rubrik ile değerlendirilmesine önem vermiştir **(ön görüşme-1).** Diğer ders imecelerindeki odak noktası fen kazanımlarını değerlendirmek üzerinde kalırken, matematik ya da mühendislik tasarım süreci ile ilgili yazılan kazanımların değerlendirilmesine yüzeysel bir şekilde değinmiştir. Ayrıca, tasarım sürecinde oluşan öğrenci ürünlerinin değerlendirilmesi konusundaki bilgisi de yüzeysel olarak kaldığı için çalışmanın sonunda değerlendirme bilgisi PAB-B kategorisinin özelliklerini taşımaktadır.

Durum 3: Ece

Öğretim Programı Bilgisi

Çalışmanın başında Ece, bireysel STEM ders planı için "elektrik enerjisinin ısı, ışık veya hareket enerjisine dönüşümü temel alan bir model tasarlar" kazanımını belirlemiş ve kazanımdaki tasarım ifadesinden dolayı seçtiğini ifade etmiştir **(bireysel içerik gösterimi ve ön görüşme 1).** Ders imecesi 1 sırasında gezegenlerin özellikleri ile ilgili kazanım seçmelerini önermiş fakat daha sonra bu kazanım ile mühendislik tasarım aşamasının test etme aşamasının çok zor olacağını belirterek vazgeçmiştir. Bunun yanında matematik ya da mühendislik ile ilgili kazanımlar yazılmasına değinmemiştir (**ders imecesi 1, planlama video kayıtları).** Dolayısıyla Ece, ders imecesi 1 sonunda PAB-B kategorisine ulaşmıştır. Ders imecesi 2 sırasında ise matematik, fen ve mühendislik tasarım süreci ile ilgili kazanım yazılmasına eşit şekilde önem vermeye başlamış ve matematik ve teknoloji-tasarım dersi öğretim programlarının kapsamları ve kazanımları ile ilgili bilgisi de artmaya başlamıştır. Daha sonra ders imecesi 3 ve ders imecesi 4 döngülerinde de benzer gelişimi göstermiştir. Örnek olarak, bir STEM ders planı hazırlamak için sadece "tasarlar" gibi kazanımlara gerek olmadığını, "ısı yalıtım malzemesinin özelliklerini belirler" gibi kazanımlarla da STEM ders planı hazırlayabileceğini belirtmiştir.

Öğrencileri Anlama Bilgisi

Ders imece döngülerine başlamadan önce Ece içerik gösteriminde fen ile ilgili bir kavram yanılgısı yazmış ve öğrencilerin değişkenleri belirleme ile ilgili zorluk yaşayacaklarını belirtmiştir. Bu sebeple, çalışmanın en başında fene özgü PAB'a sahiptir (PAB-A). Ders imecesi 1 sırasında Ece fen ile ilgili kavram yanılgıları üzerinde yoğunlaşırken, öğrencilerin yaşayabileceği zorluklar hakkında konuşurken, fen ile ilgili zorlukları ihmal edip mühendislik tasarım süreci ile ilgili yaşayabilecekleri zorluklara yoğunlaşmıştır **(ön görüşme-1).** Ece bir STEM disiplinine daha fazla odaklanıp, diğerlerine yüzeysel olarak değindiği için öğrencileri anlama bilgisi ders imecesi 1 sonunda PAB-B kategorisinin özelliklerini taşımaktadır. Ders imecesi 2 sırasında Ece öğrencilerin fen ile ilgili yaşadıkları kavram yanılgılılarının olası nedenlerini detaylı bir şekilde tartışmaya başlamıştır **(ön görüşme-2).** Planlama toplantılarında matematik ile ilgili kavram yanılgıları hakkında tartışmalar olmasına rağmen, Ece görüşmelerde bu kısımdan bahsetmemiştir. Fakat dersin yeniden öğretiminden sorumlu olan Ece, öğrencilerin grafik çizme ile ilgili kavram yanılgısı yaşadığını fark etmiş ve açıklama ve örnek verme yoluyla bu kavram yanılgısını gidermeye çalışmıştır **(araştırmacı gözlem notları).** Özetle, Ece'nin öğrenciler hakkındaki bilgisi, ders imecesi 2'yi tamamladıktan sonra PAB-C kategorisine yükselmiştir. Ece'nin fen ve diğer STEM disiplinlerindeki kavram yanılgılarını ve zorlukları dengeli bir şekilde tespit etme ve ele alma anlayışını gelişmiştir. Ders imecesi 3 ve ders imecesi 4 sırasında da Ece'nin öğrencileri anlama bilgisi PAB-C kategorisindedir.

Öğretim Yöntemleri Bilgisi

Ece ders imecesi döngülerine başlamadan önce hazırladığı STEM ders planında herhangi bir öğretim yöntemi kullanmamış ve tasarım merkezli öğretim uygulamalarına yer vermemiştir **(bireysel içerik gösterimi).** Ders imecesi 1 sırasında 5E öğrenme döngüsü seçmesinin nedeni olarak bu yönteme aşina olmasını göstermiştir. Tasarım merkezli öğretim uygulamaları ile ilgili bilgisi bir noktaya kadar gelişmiş olmasına rağmen, en iyi çözümü seçme, test etme gibi aşamaları göz ardı etmiştir **(son görüşme-1).** Benzer şekilde, Ece ders imecesi 2'de STEM dersinde neden REACT yöntemini seçtikleri ile ilgili genel açıklamalar yapmış ve dersin öğretimi sırasında tasarım merkezli öğretim uygulamalarının bazılarına önem vermemiştir **(araştırmacı gözlem notları).** Bu özelliklerden dolayı Ece'nin öğretim yöntemleri bilgisi PAB-B kategorisindedir. Diğer yandan Ece, ders imecesi 3 ve ders imecesi 4 sırasında PAB-C kategorisinin özelliklerini göstermeye başlamıştır. Örneğin, ders imecesi 4 planlama toplantılarında probleme dayalı öğrenme yöntemini kullanmalarını önermiş ve bu yöntemin mühendislik tasarım süreci ile uyumundan bahsetmiştir (**ders imecesi 4, planlama video kayıtları).** Ayrıca, ders imecesi 4 öğretim sırasında tasarım merkezli öğretim uygulamalarını eksiksiz ve düzgün bir şekilde uygulamıştır **(araştırmacı gözlem notları).**

Değerlendirme Bilgisi

Hazırladığı bireysel içerik gösteriminde Ece fen kazanımları rubrik ve akran değerlendirme formu kullanarak değerlendirmiştir (PAB-A). Ders imecesi 1 sırasında ise STEM ders planının mühendislik tasarım süreci ile ilgili kısmının değerlendirmesine odaklanmış **(ön görüşme-1)** ve ders imecesi 2 öğretim sırasında ise fen kazanımlarının değerlendirilmesine önem vermiş, öğrenci ürünlerinin ve matematik kazanımlarının değerlendirilmesine odaklanmamıştır. Bu özellikler değerlendirme bilgisi ile ilgili PAB-B kategorisinin özelliklerini karşılamaktadır. Ders imecesi 3 ve ders imecesi 4 sırasında Ece, PAB-C kategorisine yükselmiştir. Örnek olarak, öğrencilerin ses yalıtımlı müzik odası tasarımlarını değerlendirmek için bir kriter listesi oluşturmaları fikrini öne sürmüş **(ders imecesi 4, planlama video kayıtları)** ve dersin öğretimi sırasında STEM dersinin farklı alanlarının değerlendirilmesine eşit bir şekilde önem vermiştir **(araştırmacı gözlem notları).**

Durum 4: Deniz

Öğretim Programı

Deniz bireysel içerik gösteriminde sadece fen kazanımları yazmış ve kazanım seçerken alan bilgisinin zayıf olduğu ve gelişmek istediği bir kazanımı seçtiğini belirtmiştir **(ön görüşme-1).** Ders imecesi 1 sırasında Deniz mühendislik tasarım sürecinin entegrasyonundan bahsetmesine rağmen, fen dışında bir kazanım yazılmasını önermemiştir **(ön görüşme-1).** Bu özellikler Deniz'in çalışmanın başında PAB-A kategorisinde olduğunu, ders imecesi 1 tamamlandığında ise PAB-B kategorisine geçiş yaptığını göstermektedir. Deniz, ders imecesi 2, ders imecesi 3 ve ders imecesi 4'te de öğretim programı bilgisi PAB-B kategorisinin özelliklerini göstermiştir. Örneğin, fen bilimleri öğretim programının kapsamı hakkında bilgisi artmasına rağmen, matematik ve mühendislik tasarım süreci ile ilgili kazanım yazma ile ilgili önerilerde bulunmamış ve açıklamaları fen kazanımlarının üzerinde yoğunlaşmıştır **(ders imecesi 4, planlama video kayıtları)**

Öğrencileri Anlama Bilgisi

Ders imecesi döngülerine başlamadan önce Deniz, STEM ders planı hazırlarken sadece fen ile ilgili kavram yanılgısı ve zorlukları yazmıştır **(bireysel içerik gösterimi).** Ders imecesi 1 sırasında öğrencilerin Güneş tutulması sırasında Güneş, Dünya ve Ay'ın konumu ile ilgili kavram yanılgısına sahip olabileceğini belirtmesine rağmen **(ön görüşme-1),** dersin öğretimi sırasında ortaya çıkan bu kavram yanılgısını belirleyememiş ve giderememiştir. Diğer yandan, öğretim sırasında içerik gösteriminde yazmayan ve öğrencilerin zorlandığı bazı mühendislik tasarım süreci ile ilgili noktaları fark etmiştir **(araştırmacı gözlem notları).** Deniz, farklı STEM disiplinlerine eşit önem vermemiştir, dolayısıyla ders imecesi 1 sonunda öğrencileri anlama konusunda PAB-A kategorisinden PAB-B kategorisine geçiş yaptığını göstermektedir.

Diğer yandan Deniz, ders imecesi 3 ve ders imecesi 4 sırasında PAB-C kategorisine yükselmiştir. Örneğin, ders imecesi 3'ün yeniden öğretim aşamasında fen ile ilgili kavram yanılgılarının yanında mühendislerin ve bilim insanlarının yaptığı işler ile ilgili ders sırasında ortaya çıkan kavram yanılgısını belirleyebilmiş ve açıklama yoluyla gidermeye çalışmıştır **(araştırmacı gözlem notları).** Çalışmanın sonunda, Deniz en az iki farklı STEM disiplini ile ilgili kavram yanılgıları ve zorlukları dengeli bir şekilde ele alabilmektedir.

Öğretim Yöntemleri Bilgisi

Deniz çalışmaya başlamadan önce hazırladığı STEM ders planında doğrudan anlatım yöntemini tercih etmiştir **(bireysel içerik gösterimi).** Genel olarak Deniz, tüm ders imece döngüleri sırasında belirli bir öğretim yöntemi kullanmak istememiş fakat daha sonra arkadaşlarının öğretim yöntemi seçme konusundaki fikirlerine katılmıştır **(araştırmacı gözlem notları).** Yapılan görüşmelerde neden 5E ya da probleme dayalı öğrenmenin STEM ders planlarında kullanılabileceğine dair oldukça genel açıklamalar yapmıştır **(ön görüşme-3, ön görüşme-4).** Bunun yansıra Deniz, ders imecesi 1 öğretim aşamasında tasarım merkezli öğretim uygulamalarını bazı eksikliklerle uygulamıştır (örneğin, alternatif çözüm yolları üretme, Güneş tutulması kavramının mühendislik tasarım sürecindeki Güneş tutulması için gözlük tasarlama etkinliği kapsamında tartışılması gibi noktalara değinmemiştir). Benzer şekilde ders imecesi 3 yeniden öğretim aşamasında da yeniden-tasarım aşamasını uygulayamamış, fen kavramlarını mühendislik tasarım sürecinden ayrı olarak dersin başında ele almıştır **(araştırmacı gözlem notları).** Özetle, çalışmanın sonunda Deniz, STEM eğitimi ile uyumlu öğretim yöntemlerini kullanmak konusunda sınırlı bir anlayışa sahip olduğu ve tasarım merkezli öğretim uygulamalarını bazı sınırlılıklar ile uyguladığı için PAB-B kategorisinin özelliklerini göstermektedir.

Değerlendirme Bilgisi

Ders imecesi döngülerine başlamadan önce Deniz hazırladığı içerik gösteriminde fen kazanımlarını değerlendirmek için çoktan seçmeli soruları tercih etmiştir **(bireysel içerik gösterimi),** dolayısıyla fene özgü PAB'a sahiptir. Ders imecesi 1 sırasında mühendislik tasarım sürecini değerlendirmek için rubrik kullanılmasını önermiş fakat fen kazanımları ya da öğrencilerin ürünlerini değerlendirmek için bir önerisi olmamıştır **(araştırmacı gözlem notları ve ön görüşme-1).** Deniz'in değerlendirme konusunda odak noktası bir STEM disiplininde olduğu için ders imecesi 1'i PAB-B kategorisinde tamamlamıştır. Bunun yanı sıra Deniz, ders imecesi 2, ders imecesi 3 ve ders imecesi 4'ü PAB-B kategorisinde tamamlamıştır. Diğer ders imecesi döngülerinde Deniz'in odak noktası fen kazanımlarının değerlendirilmesi üzerindedir ve öğrenci ürünlerinin değerlendirilmesi, matematik kazanımlarının değerlendirilmesi gibi STEM dersinin farklı alanlarına yoğunlaşmamıştır **(ön görüşme-3, ön görüşme-4).**

Araştırma Sorusu 2: Ders İmecesi Döngüsündeki Bileşenlerin STEM'e yönelik PAB'a Katkısı

Tüm katılımcılar ders imecesinin işbirlikli planlama aşamasının öğretim programı, öğrencileri anlama bilgisi, öğretim yöntemleri ve değerlendirme üzerindeki olumlu etkisinden bahsetmiştir. Örnek olarak, Ada kazanımları belirlerken herkesin kendi bakış açısını savunduğunu dolayısıyla farklı fikirlerden yeni şeyler öğrendiğini belirtmiştir **(son görüşme-2).** Katılımcılar planlama toplantısında içerik gösterimi kullanmanın özellikle öğrencileri anlama bilgisi konusundaki bilgilerine yardımcı olduğunu da söylemişlerdir. Ece, içerik gösterimindeki kavram yanılgısı ve zorluklar ile ilgili maddenin derse girmeden önce bu durumlara hazırlık yapmaları ve planlamayı ona göre ayarlamaları konusundaki faydalarından bahsetmiştir **(ön görüşme-4).** Katılımcıların çoğu, dersin öğretimi aşamasının öğretim programı, öğrencileri anlama bilgisi ve öğretim yöntemleri konusundaki etkisinin altını çizmişlerdir. Deniz, öğretim sırasında öğrencilerle etkileşim içine girdikçe kavram yanılgılarını daha rahat belirlemeye başladığını söylemiştir **(ön görüşme-4).** Öğretim programında ile ilgili bilgilerinin artmasında ise Ada öğretim aşamasına dikkat çekerek, farklı fen konuları arasındaki bağlantıyı dersin öğretiminden sonra daha rahat bir şekilde kurabildiğini belirtmiştir **(son görüşme-1).** Ayrıca katılımcılar ders imecesinin öğretim üzerine yansıtma aşamasının STEM'e ilişkin PAB gelişimlerinin tüm boyutları üzerinde etkili olduğundan bahsetmişlerdir. Örnek olarak Defne, daha önce probleme dayalı öğrenme yöntemini kullanmamasına rağmen, yansıtma aşamasından sonra dersin yeniden öğretim aşamasında kendini çok daha güvenli hissettiğini çünkü planın ilk hali üzerinde tartışarak olumsuzlukları gidermek için düzeltmeler yaptıklarına vurgu yapmıştır **(son görüşme-4).** Deniz ise dersin öğretimi sırasında öğrencinin enerji transferi ile ilgili kavramı anlamakta zorlandığını fark ettiğini, yansıtma toplantısında bu konuyu konuşurken bir arkadaşının bu zorluğun üstesinden gelmek için önerdiği yolu çok beğendiğini ve bundan sonra kullanacağını belirtmiştir **(ön görüşme-4).**

Tartışma

Bu çalışma, fen bilgisi öğretmen adaylarının STEM'e yönelik PAB'larının ders imecesi bağlamında nasıl geliştiğini araştırmıştır. Bu amaca paralel olarak, dört fen bilgisi öğretmen adayı ile dört ders imecesi döngüsü gerçekleştirilmiştir. Çalışmanın temel sonuçları, katılımcıların STEM eğitiminin ana unsurlarını çalışmanın başında içerik gösterimlerine entegre edemediklerini ve PAB'larının konuya özel olduğunu (PAB-A) göstermektedir. Bununla birlikte, çalışmanın sonunda tüm katılımcılar PAB-B (geçiş PAB'ı) ya da PAB-C (STEM'e ilişkin PAB) düzeylerinde gelişim göstermişlerdir. Bu sonuçlar alanyazındaki çalışmalarla uyumlu olarak fen bilgisi öğretmen adaylarını uzun süreli ve sürekli olarak desteklendiklerinde PAB'larının geliştiğini desteklemektedir (Adadan & Oner, 2014; Aydin-Gunbatar vd., 2020; Ekiz-Kiran vd., 2021).

STEM'e yönelik PAB boyutları göz önüne alındığında, bulgular, katılımcıların gelişim örüntülerinin farklılıklar gösterdiğini ortaya koymaktadır. Örneğin, dört ders imecesi döngülerini tamamladıktan sonra Ada ve Ece, STEM'e yönelik PAB'ın tüm bileşenlerinde en yüksek PAB düzeyine ulaşmıştır. Öte yandan, Deniz'in öğrencileri anlama hakkındaki bilgisi PAB-C kategorisinin özelliklerini karşılarken, diğer üç boyut PAB-B kategorisinin özelliklerini göstermektedir. Ek olarak, katılımcılar çalışmayı aynı PAB kategorisinde bitirmiş olsalar bile PAB boyutlarına göre gelişim örüntüleri de değişiklik göstermiştir. Örneğin Ada, ders imecesi 2'yi tamamladıktan sonra değerlendirme bilgisi açısından PAB-C seviyesine yükselirken, Ece ders imecesi 3'ün sonunda PAB-B'den PAB-C'ye geçmiştir. Dolayısıyla, her katılımcının PAB gelişimi kendisine özgüdür. Alanyazında da benzer bir durum gözlemlenmiştir; örneğin, Belge-Can ve Boz (2022), öğretmen eğitimi programında aynı derslere katılmalarına rağmen iki kimya öğretmeni adayının PAB gelişim örüntülerinin, iki yıllık çalışmada farklılıklar gösterdiğine dikkat çekmiştir. Bu bulgu PAB'nin kendine özgün doğası ile açıklanabilir (Gess-Newsome, 2015; Park & Oliver, 2008).

Ders imecesi döngüleri ilerledikçe katılımcılar STEM ders planı hazırlamak için STEM eğitiminin doğası ile uyumlu olarak farklı disiplinlerden kazanımlar yazmaya başlamışlardır. Katılımcılar mühendislik tasarım süreci ile ilgili hazır bir öğretim programı olmadığı için kazanım yazmakta zorlandıklarını belirtmişlerdir. Fakat mühendislik tasarım sürecini doğru bir şekilde kullanmaya başladıkça, mühendislik ile ilgili yazdıkları kazanımlarda iyileşme olduğu görülmüştür. Benzer şekilde, Faikhamta ve arkadaşları (2020) öğretmenlerin STEM eğitiminde PAB tabanlı mesleki gelişim programının başlangıcında sadece fen ilgili kazanımlar yazmaya odaklandıklarını ancak program sonunda mühendislik tasarım süreci, matematik ve 21. yüzyıl becerileri ile kazanımlar yazdıklarını belirtmişledir. Öğrencileri anlama bilgisi, alanyazın ile paralel olarak diğer PAB boyutları arasında en kolay gelişim gösteren boyut olmuştur (Park & Oliver, 2008). Katılımcılar çalışmanın sonunda, öğrencilerin en az iki STEM disiplininde sahip olduğu kavram yanılgıları ve yaşadıkları öğrenme zorluklarına eşit şekilde önem vermişler. Ders imecesi yoluyla daha fazla öğretim tecrübesi kazanma ve öğretimin gözlenmesinin katılımcıların öğrencileri anlama bilgisine katkıda bulunduğu düşünülmektedir. Çünkü Boz ve Belge-Can'ın (2020) öğretmen adaylarının öğrencilerin çözünürlük kavramları konusundaki kavram yanılgısı ve zorluklara ilişkin bilgilerinin ders imecesine katıldıktan sonra değişmeden kaldığını belirtmişlerdir. Ancak araştırmacılar mikro öğretim ders imecesi uygulamışlar ve öğretmen adayları ders planını gerçek sınıf ortamında uygulayamamışlardır. Bu nedenle, sonuçlar arasındaki farklar, bu çalışmada fen bilgisi öğretmen adaylarına öğrencilerle etkileşime girme fırsatı verilen gerçek bir sınıf ortamındaki öğretim deneyimleriyle ilişkilendirilebilir. Öğretim yöntemleri konusunda çalışmanın sonunda katılımcıların çoğu STEM ile uyumlu öğretim yöntemlerinden bahsetmiş ve neden bu yöntemi seçtiklerini detaylı bir şekilde açıklamışladır. Ayrıca, bu katılımcılar tasarım merkezli öğretim uygulamalarını düzgün bir şekilde kullanmaktadırlar. Bu durum, alanyazındaki çalışmaların sonuçları ile benzerlik göstererek, ders imecesi döngülerine katılmanın öğretim yöntemleri üzerindeki katkısının altını çizmektedir (Belge-Can, 2019; Juhler, 2016). Değerlendirme bilgisi konusunda ise katılımcıların yarısı PAB-C kategorisine ulaşırken, diğer iki katılımcı PAB-B kategorisinde kalmıştır. Bu durumun öğretmen adaylarının fen dışındaki kazanımları değerlendirme konusundaki tecrübesizliğinden kaynaklandığı düşünülmektedir çünkü "mevcut değerlendirmeler tek bir disiplindeki bilgiye odaklanma eğilimindedir " (NRC, 2014, s. 6). Bu çalışmada, öğretmen adaylarının öğretmen eğitimi programında aldıkları dersler göz önüne alındığında, mühendislik veya matematik kazanımlarını değerlendirmeye alışık olmadıkları görülmüştür. Buna bağlı olarak, STEM derslerinde çok boyutlu değerlendirmeyi eş zamanlı olarak uygulamakta (fen, matematik, mühendislik tasarım süreci ve öğrenci ürünlerinin değerlendirilmesi) zorlanmış olabilirler.

Ders imecesinin en temel özelliklerinden biri, öğretmenlerin bilgiyi birlikte yapılandırmasıdır (Holden, 2022). Ders imecesi grubu içindeki etkileşimler, öğretmenlerin bir dersi planlamanın çoklu yolları hakkında ufkunu genişletir (Anfara vd., 2009). Bu çalışmanın başında fen bilgisi öğretmen adaylarının STEM eğitimi ile ilgili bilgileri oldukça sınırlıydı; ancak, STEM derslerini iş birliği içinde planlarken yapılan tartışmaların öğretmen adaylarının STEM'e ilişkin PAB'larını şekillendirdiği sonucuna varılmıştır. Önceki araştırmalarla uyumlu olarak, öğretmen adayları bu işbirlikçi çalışma ortamında akranlarının alternatif fikirlerinden çok şey öğrendiklerini belirtmişlerdir (Anfara vd., 2009). Ayrıca, katılımcılar ders imecesindeki öğretim deneyimlerinin özellikle öğretim programı bilgilerini, öğrencileri anlama bilgilerini ve öğretim yöntemleri bilgilerini geliştirmede etkili olduğunu belirtmişlerdir. Bu çalışmanın bulguları, öğretim deneyiminin öğrencilerin PAB gelişimi üzerindeki etkisini ortaya koyan çalışmalarla uyumludur (Aydin vd., 2013; Brown vd., 2013; Lange vd., 2022). Benzer şekilde önceki PAB çalışmaları, öğretim üzerine yansıtmanın PAB gelişiminin ana kaynaklarından biri olduğunu vurgulamaktadır (Carlson vd., 2019; Henze & Barendsen, 2019). Bu çalışmanın katılımcılarının çoğu, öğretim sonrası yapılan yansıtma toplantılarının STEM'e ilişkin PAB boyutlarının hepsi açısından etkili olduğunu belirtmişlerdir.

Bu çalışmada ders imecesi Öğretmenlik Uygulaması-1 dersine entegre edilmiştir. Ders imecesinin temel bileşenlerinden biri öğretim olduğundan, fen bilgisi öğretmen adaylarının gerçek bir sınıf ortamında öğretim yapmaları için fırsatlar sunulan Alan Deneyimi ve Öğretmenlik Uygulaması derslerinde uygulanmasının uygun olacağı düşünülmektedir. PAB kademeli olarak geliştiği için, katılımcıların birden fazla ders imece döngüsüne ihtiyacı olduğu bulunmuştur. Bu nedenle, fen bilgisi öğretmen adaylarıyla ders imecesi çalışması yapılırken çoklu döngüler tercih edilmelidir. Bu şekilde fen bilgisi öğretmen adaylarının STEM eğitimine yönelik PAB'ları adım adım gözlemlenebilir. Öte yandan, ders imecesinde amaç öğrencilerin öğrenmesine odaklanmaktır; ancak, fen bilgisi öğretmen adaylarının sınıfta çok az öğretmenlik deneyimi olduğundan, bu nokta onlar için zorlayıcı olabilir ve öğretmen eğitimi programlarında ders imecesi kullanmanın bir sınırlılığı olabilir. Bu nedenle, çalışmanın bulgularına göre gelecekteki çalışmalarda fen bilgisi öğretmen adaylarının STEM' ilişkin PAB'larını geliştirmek ve öğrencilerin öğrenmesine odaklanmalarına yardımcı olmak için içerik gösterimi ve ders imecesini bir araya getirmek önerilmektedir. Ayrıca, PAB gelişimi için alan bilgisi gerekli olduğundan (Shulman, 1987), fen bilgisi öğretmen adaylarına giriş seviyesinde mühendislik ve mühendislik tasarım süreci ile ilgili bir ders açılması önerilmektedir. Bunun yanı sıra öğretmen eğitim programlarında yer alan Fen Öğretiminde Değerlendirme, Fen Öğretiminde Kavram Yanılgıları, Fen Öğretim Programları gibi derslerde disiplinlerarası bağlantılara vurgu yapılması önerilmektedir.

Gelecek araştırmalar, fen bilgisi öğretmen adaylarının STEM anlayışlarının ve konu alan bilgilerindeki değişimin STEM ile ilgili PAB değişimine olan etkisini inceleyebilir. Ders imecesi gruplarına farklı bölümlerden (matematik öğretmenliği, bilgisayar öğretmenliği gibi) öğretmen adayları dahil edilerek STEM ders planları hazırlanabilir. Son olarak, bu çalışmada öğrencilerden toplanan mühendislik defteri, bütçe kağıdı gibi materyaller STEM ders planlarını revize etmek için kullanılmıştır. Gelecek araştırmalarda ders imecesinin doğasıyla uyumlu olarak öğrencilerden veriler toplanarak öğretmen adaylarının STEM'e ilişkin PAB'ları ile öğrencilerden toplanan veriler karşılaştırma yapmak için kullanabilir.

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