EXAMINATION OF CHEMISTRY TEACHERS' TOPIC-SPECIFIC NATURE OF PEDAGOGICAL CONTENT KNOWLEDGE IN ELECTROCHEMISTRY AND RADIOACTIVITY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

SEVGİ AYDIN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
SECONDARY SCIENCE AND MATHEMATICS EDUCATION

MAY 2012

Approval of the thesis:

EXAMINATION OF CHEMISTRY TEACHERS' TOPIC-SPECIFIC NATURE OF PEDAGOGICAL CONTENT KNOWLEDGE IN ELECTROCHEMISTRY AND RADIOACTIVITY

submitted by **SEVGİ AYDIN in** partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Secondary Science and Mathematics Education Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ____________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ömer Geban ____________
Head of Department, **Secondary Science and Math. Edu.**

Assoc. Prof. Dr. Yezdan Boz ____________
Supervisor, **Secondary Science and Math. Edu. Dept., METU**

Assoc. Prof. Dr. Esen Uzuntiryaki ____________
Co-Supervisor, **Secondary Science and Math. Edu., Dept., METU**

Examining Committee Members:

Prof. Dr. Ömer Geban ____________
Secondary Science and Math. Edu. METU

Assoc. Prof. Dr. Yezdan Boz ____________
Secondary Science and Math. Edu., METU

Assoc. Prof. Dr. Deborah L. Hanuscin ____________
Learning, Teaching, and Curriculum
University of Missouri, MO, USA.

Assoc. Prof. Dr. Mine Işıksal ____________
Elementary Education Dept., METU

Assist. Prof. Dr. Ömer Faruk Özdemir ____________
Secondary Science and Math. Edu., METU

Date: 10.05.2012

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name :

Signature :

ABSTRACT

EXAMINATION OF CHEMISTRY TEACHERS' TOPIC-SPECIFIC NATURE OF PEDAGOGICAL CONTENT KNOWLEDGE IN ELECTROCHEMISTRY AND RADIOACTIVITY

Aydın, Sevgi

Ph.D., Department of Secondary Science and Mathematics Education

Supervisor: Assoc. Prof. Dr. Yezdan Boz

Co-Supervisor: Assoc. Prof. Dr. Esen Uzuntiryaki

May 2012, 268 pages

The purpose of this study was to examine topic-specific nature of pedagogical content knowledge (PCK). Two experienced chemistry teachers' PCK was examined in electrochemistry and radioactivity. To capture participants' PCK, all PCK components were studied. To get deep and rich answers to research questions asked, qualitative methodology was used. Participants were selected through purposeful sampling. Data were gathered through card-sorting activity, Content Representation (CoRe), semi-structured interviews, classroom observations, and field notes. Results revealed that participants had two types of PCK, namely, PCK A for teaching electrochemistry and PCK B for teaching radioactivity. PCK A included content-based and teacher-centered instruction, many links to other topics in chemistry and in physics. The assessment was coherent which included different types of assessment strategies used at the beginning, during, and at the end of teaching. In PCK B, it was less teacher-centered. The link to other topics was limited. Additionally, teachers used fragmented assessment and were less knowledgeable about learners' difficulties and misconceptions in radioactivity than they were in electrochemistry. Differences between PCK A and B may be related to nature of the topics. Learners need to have much pre-requisite knowledge both from chemistry and physics to learn electrochemistry. Also, there are more concepts in electrochemistry than there are in

radioactivity. It seems that when teachers have to focus on more concepts to teach, they may have a tendency to teach more-teacher centered to save time. Teacher education programs should focus on topic-specific nature of PCK and provide topic-specific training to teachers.

Keywords: Pedagogical Content Knowledge, Science Teacher Education, Topic-specific Nature of Pedagogical Content Knowledge,

ÖZ

KİMYA ÖĞRETMENLERİNİN PEDAGOJİK ALAN BİLGİLERİNİN KONUYA ÖZGÜ DOĞASININ ELEKTROKİMYA VE RADYOAKTİVİTE KONULARINDA İNCELENMESİ

Aydın, Sevgi
Doktora, Orta Öğretim Fen ve Matematik Alanları Eğitimi Bölümü
Tez Yöneticisi: Doç. Dr. Yezdan Boz
Ortak Tez Yöneticisi: Doç. Dr. Esen Uzuntiryaki

Mayıs 2012, 268 sayfa

Bu çalışmanın amacı pedagojik alan bilgisinin (PAB) konuya özgü doğasını incelemektir. Deneyimli iki kimya öğretmeninin PAB'ları elektrokimya ve radyoaktivite konularında incelenmiştir. Katılımcıların PAB' larını tam olarak anlayabilmek için tüm PAB bileşenleri çalışılmıştır. Belirlenen araştırma sorularına derinlemesine ve zengin cevaplar bulabilmek için, nitel araştırma yöntemi kullanılmıştır. Katılımcılar amaçlı örneklem yöntemi ile seçilmiştir. Veriler kart gruplama aktivitesi, içerik gösterimi, yarı-yapılandırılmış görüşmeler, sınıf gözlemleri ve gözlem notları ile toplanmıştır. Sonuçlar katılımcıların elektrokimya ve radyoaktivite öğretimi için PAB A ve PAB B olmak üzere iki tür PAB' a sahip olduğunu ortaya koymaktadır. PAB A içerik temelli, öğretmen merkezli ve kimya ve fizikteki diğer konulara bağlantılar içeren bir öğretimi temsil etmektedir. Burada yapılan ölçmede, farklı ölçme yöntemleri konu boyunca devamlı olarak kullanılmıştır. PAB B ise göreceli olarak daha az öğretmen merkezlidir. Diğer konulara yapılan bağlantılar da göreceli olarak daha azdır. Ayrıca, öğretmenler parçalı bir ölçme yapmışlardır. Öğretmenler, öğrencilerin zorlandıkları noktalar ve sahip oldukları yanlış kavramalar ile ilgili olarak radyoaktivite konusunda elektrokimyaya göre daha zayıftırlar. PAB A ve B arasındaki farklar konuların doğaları ile açıklanabilir. Elektrokimyayı öğrenebilmek için hem kimya hem de fizik

alanından çok fazla ön bilgiye ihtiyaç vardır. Ayrıca elektrokimya konusu radyoaktivite konusundan daha fazla kavram içermektedir. Öğretilecek daha çok kavram olduğunda öğretmenler zaman kazanmak adına daha çok öğretmen merkezli bir öğretimi tercih edebilmektedir. Öğretmen eğitimi programları PAB'ın konuya özgü doğasına odaklanmalı ve öğretmenlere konuya özgü eğitim sunmalıdır.

Anahtar Kelimeler: Pedagojik Alan Bilgisi, Fen Öğretmen Eğitimi, Pedagojik Alan Bilgisinin Konuya Özgü Doğası, To myself, to the weekends and nights that I had to study, and to my family

ACKNOWLEDGMENTS

I would like to thank to my advisor Assoc. Prof. Dr. Yezdan BOZ for her valuable support for conducting this research. You are always kind and helpful to me. Whenever I came to your office, I felt relax after our conversation. I remember our first year. You made me sit and taught how to write and submit an abstract to a conference. You always supported and encouraged me to study. Thank you very much. I also want to thank to my co-advisor Assoc. Prof. Dr. Esen UZUNTİRYAKİ for her support and encouragement.

The committee members also deserved special thanks. Assoc. Prof. Dr. Mine IŞIKSAL and Assist. Prof. Dr. Ömer Faruk ÖZDEMİR. Thank you very much for your valuable feedback and encouragement. When I need feedback, you always agreed to come together and provided the support that I needed. I am grateful for your support, ideas, and suggestions. You made my research much better and richer.

I am grateful to faculties in University of Missouri (MU), Columbia. You are always a great role model for me as an academician. I cannot thank enough to Prof. Dr. Sandra K. ABELL (RIP), Assoc. Prof. Dr. Deborah L. HANUSCIN, Assoc. Prof. Dr. Patricia J. FRIDRICHSEN, and Assoc. Prof. Dr. Mark J. VOLKMANN for their great patience, support, feedback, and encouragement. I am also grateful to Prof. Dr. Lloyd BARROW for letting me take his class. I had a great year in MU. You never let me feel that I was a visiting scholar. Rather, I always feel as a member of MU family. Without your contribution, I could not make it. Thank you very much…

Prof. Dr. Ömer GEBAN, the head of SSME department, also deserves special thanks for his support and his way of behaving us. I feel as a member of a large family in SSME department. Our breakfasts, lunches, and chats in the afternoon were unforgettable.

I also want to thank to my special friends who are Ayşegül, dBetül, Fatma Nur, Selcan, eBetül, Ayla, Demet, Cansel, and all friends in the SSME department. Thank you for your support and feedback during instrument development, data collection, and data analysis. I feel so lucky to meet you. It was great to have a PhD journey with all you people. I learnt, enjoyed, and developed myself with your help. It was my pleasure to study together. Hopefully, we will have a chance to study together for a long time to make Turkey a better country. In addition to that, I have great friends in MU. I would like to extend my gratitude to Aaron, Somnath, and Dane for your valuable help for conducting pilot study.

I also have to thank to my close friend Arzu ZABUN, and my family for their patience and support. I think I am intolerable especially when I am busy. I am grateful for being part of my life, being a great friend and sister. And my family… I am sorry that I could not spend enough time with you. My mother, Gülay AYDIN tried her best to raise us, me and my sister Yıldız, as an intellectual, honest, and useful people to society. Thank you very much for everything that you give to me. I also would like to thank to my father, Ali AYDIN for his financial supports for participating to conferences.

Last but not the least, thank you to TUBİTAK (The Scientific and Technological Research Council of Turkey) for financial support during the PhD. I had a chance to take BIDEP- 2211 scholarship provided to PhD students in Turkey. Also, special thanks to the program (ÖYP) that I enrolled to.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURES

LIST OF TABLES

TABLES

LIST OF ABBREVIATIONS

PCK:	Pedagogical Content Knowledge
PK:	Pedagogical Knowledge
SMK:	Subject Matter Knowledge
KofC:	Knowledge of Context
NRC:	National Research Council
PISA:	Program for International Student Assessment
OECD:	Organization for Economic Co-operation and Development
NME:	National Ministry of Education
PCKg:	Pedagogical Content Knowing
GTA:	Graduate Teaching Assistant
RTOP:	The Reformed Teaching Observation Protocol
CoRe:	Content Representation
PaPeRs:	Professional and Pedagogical experience Repertoire
ACP:	Alternative Certification Program
PD:	Professional Development
PNM:	Particulate Nature of Matter
SSME:	Secondary Science and Mathematics Education
UEE:	University Entrance Exam
STS:	Science, Technology, and Society
RE-SMAR^{2}T:	Researching Science and Mathematics Teacher Learning in Alternative Certification Models
US:	United States
IRB:	Institutional Review Board
NOS:	Nature of Science
STSE:	Science, Technology, Society, and Environment
SHE:	Standard Hydrogen Electrode
R:	Researcher

CERN:	European Organization for Nuclear Research
WW-II:	World War-II

CHAPTER 1

INTRODUCTION

In the 21st century, science and technology have been progressing rapidly, which makes it challenging to follow developments. Rapid alteration leads to changes in the knowledge and skills needed to be a successful employee, responsible citizen, and intellectual person (Boltz & Swartz, 1997). To be able to keep up with the all changes mentioned, people in this era have to be knowledgeable about science and technology (Organization for Economic Co-operation and Development [OEDC], 2009). Due to the essential role of having scientific knowledge and science process skills (e.g. formulating hypothesis, interpreting data, and controlling variables) both in daily life and workplace, scientific literacy is major goal of many reforms in science education (Bybee, 1997; Roberts, 1988). "Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (National Research Council [NRC], 1996, p.22).

Programme for International Student Assessment (PISA) tests focus on students' ability to explain scientific phenomena, to use scientific evidence to predict phenomena, and to apply scientific knowledge to health, environmental and technological issues. To assess 15-year old students' reading, mathematics and scientific literacy, PISA assessments were carried out in 2003, 2006, and 2009 all around the world. PISA assessment system describes proficiency levels from one to six in science. In 2006, only 1.3% of students from OECD countries could reach level 6 which is the highest level.

> The number of students at very low proficiency is also an important indicator – not necessarily in relation to the development of future scientific personnel but in terms of citizens' ability to participate fully in society and in the labor market. At Level 2, students start to demonstrate the science competencies

> that will enable them to participate actively in life situations related to science and technology. Across the OECD, on average 19.2% were classified as below Level 2, including 5.2% below Level 1 (OECD, 2007, p.3).

PISA results showed that Turkish students' results were lower than the mean of OECD countries (OECD, 2007). In addition to PISA scores, university entrance examination scores have provided further evidence of students' low level of achievement especially in science. For instance, in 2009, 704,712 students out of 1,294,074 scored 0.25 or lower raw score than 0.25 from the Science-1 test (Selection and Placement of Students in Higher Education Institutions, 2010). So, these disappointing results, changes in other countries science programs, and ever changing needs of society made reforms inevitable. In response to all of them, Elementary Science and Technology curriculum was started to be revised in 2004 （National Ministry of Education [NME], 2006). Moreover, in 2007, reforms for high school physics, chemistry, and biology curricula have been started (NME, 2007). However, changes in the curricula do not guarantee a solution to educational problems and to raise scientifically literate citizens. Even if the new curricula suggest new strategies and methods for teaching and assessment, teachers have difficulties in reflecting the new curriculum to their teaching (Aydın & Çakıroğlu, 2010).

Teachers are one of the most important factors in students' understanding and achievement (Lumpe, 2007; Miller, 2001; Sanders, 2000; van Driel, Beijaard, & Verloop, 2001), which increases the importance of professional development activities enriching teachers' knowledge and skills (King & Newmann, 2000). Committee on Science and Mathematics Teacher Preparation (2001) stated that teachers' responsibility and job demands are very similar to those of airline pilots. Due to the teachers' role in students' learning and on the society in the long term, similar to pilot training, teacher training requires demanding and long running preparation. Teacher training should lead to increased teacher effectiveness, which is assumed to result in positive student learning gains. Therefore, research on teacher knowledge and practice is needed due to their role in providing rich and valuable data for reforms in professional development and teacher education programs

(Avraamidou & Zembal-Saul, 2005; Friedrichsen, 2008; van Dijk & Kattmann, 2007; van Driel, Verloop, & de Vos, 1998).

In the teacher education field research, researchers have been studying on teachers' knowledge (Abell, 2007; Grossman 1990; Magnusson, Borko, & Krajcik, 1999; Shulman, 1986, 1987), teachers' learning (Loughran, 2007; Putnam & Borko, 2000), and teachers' beliefs (Nespor, 1987; Pajares, 1992; Southerland, Sinatra, & Matthews, 2001). In this research, teachers' knowledge was focused on. In 1986, Pedagogical content knowledge (PCK) was introduced by Shulman (1986) as a knowledge base for teaching. In this qualitative study, I used PCK as a theoretical framework to study teachers' knowledge due to the fact that it is a useful and an acknowledged framework to study teachers' knowledge (Carlsen, 1999; Gess-Newsome, 1999). In PCK framework, in addition to SMK, teachers should know learners' prior knowledge about the topic, the difficulties that may have, how to teach the topic, how to organize lesson, which representations, figures, activities, and assessment strategies are better than others, and how to use instructional strategies (Abell, 2007; Magnusson et al., 1999; Tobin & McRobbie, 1999).

Shulman (1987) described PCK as a unique mixture of content and pedagogical knowledge for teaching a topic in an understandable way to students. As a construct, PCK is important. First, PCK is formed through the *transformation* of many different knowledge bases for teaching; however, it is not the ordinary mixture of them. Rather, the components inform and interact with each other (Magnusson et al., 1999). Second, PCK has a significant role in defining effective and competent teachers, and their practice. The practical value of PCK is related to its nature because it informs aspects of science teacher education programs, in terms of both pre-service and in-service teacher education. Additionally, PCK is also related to learners' understanding of science topics due to the fact that knowledge of learner component of PCK focuses on learners' difficulties, misconceptions, and pre-requisite knowledge (van Driel et al., 1998). Furthermore, PCK and its components are useful for researchers studying on teacher knowledge and practice because they provide a road map to find your way (Friedrichsen, 2008; Marks, 1990). Therefore, in order to gain a better understanding of teachers' knowledge and to realize its importance, the thing that should be done is to uncover teachers' knowledge, which is the major purpose of research in teachers' PCK field (Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000; Marks, 1990).

1.1. Significance of the Study

Since 1986, the introduction of PCK, scholars have studied how PCK develops, sources of it, and how components of PCK interplay with each other. From the acknowledged research, it has been asserted that PCK is a topic-specific construct (Cochran, King, & DeRuiter, 1991; Loughran, Mulhall, & Berry, 2004; van Driel, et al., 1998; Veal & MaKinster, 1999). However, research has not been shown how PCK is topic-specific and how teachers transform SMK of different topics into PCK for teaching them (Abell, 2008; van Driel et al., 1998). Therefore, the literature has clearly identified the need for more topic-specific PCK research within the complexity of the classroom to determine how teachers' use their PCK in transforming their SMK into pedagogically powerful representations to support student learning (Abell, 2008; Avraamidou & Zembal-Saul, 2005; Bucat, 2004; de Jong, et al., 2005; Geddis, Onslow, Beynon, & Oesch, 1993; Loughran, et al., 2004; Magnusson, Borko, & Krajcik, 1994; Morine-Dershimer & Kent, 1999; Shannon, 2006; van Driel et al., 1998). Related to this point, Loughran et al., (2004) highlighted the scarcity of *concrete examples* of teachers' PCK. Therefore, the current research is supposed to provide valuable information about experienced teachers' PCK and how they use their PCK in teaching for particular topics because PCK is specific to topic (van Driel, et al., 1998).

In addition to that, PCK literature calls for more research which compares and contrasts teachers' PCK in different topics within the same discipline (Abell, 2008)."If we take PCK to be a paradigm for teacher knowledge research, many normal science puzzles within that paradigm present themselves" (p.1410). To be able to solve other pieces, the comparison studies are valuable. Although examining teachers' PCK in a particular topic provides valuable information to the literature, focusing on teachers' PCK in different topics in the same discipline is supposed to push further the PCK literature how topic-specific PCK is and where the overlaps and differences for diverse are, which may be a step beyond just describing nature of PCK for a particular topic.

The significance of the study also roots in the data collected from real classroom context. As mentioned above, to enrich PCK literature about the nature of the construct, the practical knowledge that teachers actually use in their teaching was focused in this study. To deepen the topic-specific nature of the concept, real practitioners' experience would help the literature understand how topic shapes teachers' teaching and assessment practices. Unlike to the some other studies (e.g. Magnusson et al., 1999), this research was based on the experienced teachers' teaching practice in real classroom contexts.

In addition to the theoretical part, the results of the study are hoped to provide practical knowledge for other chemistry teachers who teach the same topics in their classes. Experienced teachers' rich repertoire of teaching practices may enrich other teachers' teaching as well. Through the sharing experience, PCK is useful regarding to developing teachers' practice in addition to a theoretical construct (Loughran et al., 2004).

Related to the practical use, Bucat (2004) criticized the convention of teaching profession which has been likened to *'re-invention of the wheel'*. Unlike the other professions, valuable experience of qualified teachers is not shared to form a professional agenda. The researchers diagnosed the problem as '*professional amnesia'*. To remedy the problem, Bucat (2004) provided two suggestions. First, teachers, chemists, and experts in chemical education should come together and study to form an archive including knowledge about learning, learners' ideas, strategies for teaching particular topics, and tips for enacting them. Second, experienced teachers' vignettes should be formed as in other professions (e.g. architecture). The vignettes formed should be used in order to show other teachers how they should plan and how they should use instructional strategies. Formed agenda by the use of veteran teachers' insights and practices will be a precious source both for pre-service teacher education and professional development programs for in-service teachers (Bucat, 2004). Similar to Bucat (2004), van Driel et al., (1998) stated that giving end to *reinvention of the wheel* by every teacher is one of the basic purposes of the PCK research. Unless experienced teachers' knowledge and practice are depicted, we, as teacher educators, cannot take advantage of their wisdom for inexperienced ones (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008), which makes the teaching a game played *without audience* (Shulman, 1987). Therefore, this study also focused on Bucat's (2004) second suggestion which is examining experienced teachers' PCK. Similarly, Geddis et al., (1993) and van Driel et al., (2001) highlighted the importance of studying experienced teachers' PCK because although they had rich PCK, they did not share it with pre-service and novice teachers. Therefore, their knowledge can be made explicit through elaborating and sharing teachers' *wisdom of practice* for the development of cases, which will be a valuable resource for both pre-service teacher education programs and in-service teacher trainings.

Finally, the study is hoped to contribute to PCK literature by studying with experienced teachers. In the related literature, research studies generally have focused on PCK development of pre-service teachers (e.g. Loughran et al., 2004; Nilsson, 2008; Shannon, 2006; van Driel, de Jong, & Verloop, 2002; Zembal-Saul, Krajcik, & Bluemenfeld, 2002). However, pre-service and novice teachers generally do not have a robust PCK (Magnusson et al., 1999; Shulman, 1987). Therefore, to focus on experienced teachers' practice would provide a valuable example of how teachers use PCK in teaching.

To sum up, in light of the literature, the main purpose of the study was to examine experienced chemistry teachers' PCK in two different topics in chemistry field. This study has three powerful aspects; first, examining teachers' PCK in different topics and presenting valuable information about how topic-specific PCK is, second, providing concrete example of experienced teachers' PCK in specific topics, and finally, dealing with interaction between PCK components. Concrete examples are expected to be an important source for pre-service and beginning teachers, which helps them relate theoretical and practical parts of teaching (van Driel et al., 2001). Moreover, they are hoped to be used in professional development programs.

In addition to contribution of this study to the PCK literature, it is hoped to provide beneficial insights regarding the how PCK components interplay. Although PCK is a theoretical construct, it has also practical aspect (Abell, 2008). PCK models identified components of PCK; however, they do not indicate how the components interact (Friedrichsen, van Driel, & Abell, 2011). Are these relations one-sided and/or mutual? How does orientation component influence other components? These questions have not been answered yet. They should be focused on by the use of empirical evidences taken from real classroom context. Therefore, research should elaborate on how teachers use PCK components simultaneously in order to make the topic more understandable to learners (Abell, 2008; Friedrichsen, et al., 2011; Henze, van Driel, & Verloop, 2008). A better understanding of the components' interplay informs the literature about nature of PCK, which provides useful information for the design and revision of teacher education programs (NRC, 1996). In response to the call for research into examining the interplay of PCK components, we sought to examine how experienced teachers' PCK components interact to make the topic more comprehensible for learners.

In this research to get deeper knowledge about teachers' topic-specific PCK and to examine the interplay among the components of PCK, all components of PCK were studied. Due to the nature of PCK, focusing on only one component is really hard in terms of data collection, analysis, and discussion (Friedrichsen & Dana, 2005; Abell, personal communication, February, 2010). Due to the interaction between components, studying only one component of PCK makes it hard to draw borders among which component starts and finishes (Friedrichsen & Dana, 2005). Correspondingly, Loughran et al., (2000) pointed out that PCK is not one of the components rather "the nature of PCK is a result of the different ways the elements can overlap and be portrayed, and this portrayal varies through the variations in the overlap of the elements" (p. 4).

Regarding the topics selection, electrochemistry and radioactivity were studied because (a) the nature of the topics are very different (e.g. focus, type of reactions, level of abstractness, etc.), (b) they have not been studied in terms of topic-specific PCK yet; (c) research on students' misconceptions in electrochemistry has provided misconceptions and difficulties that students have (Garnett & Treagust, 1992a; 1992b; Sanger & Greenbowe, 1997a). The nature of the topics should be different to elaborate how PCK is specific-to topic. It is also important to choose the topics that have not been studied yet.

This study in which experienced chemistry teachers' topic-specific PCK was examined is a qualitative case study which provides a detailed picture of the people, event, or group focused on (Merriam, 1988, as cited in Merriam, 1998). Case studies provide deep information to the researcher. Therefore, to get rich and deep information from the teachers, case study design was preferred to be used.

1.2. Research Questions Addressed

How is experienced high school chemistry teachers' PCK different and/or similar for teaching different topics within the same discipline?

1.2.1. Sub-research Questions:

1. What is the nature of experienced chemistry teachers' PCK for teaching electrochemistry and radioactivity topics?

a. What is the nature of experienced chemistry teachers' knowledge of learner for teaching electrochemistry and radioactivity topics?
b. What is the nature of experienced chemistry teachers' knowledge of instructional strategy for teaching electrochemistry and radioactivity topics?
c. What is the nature of experienced chemistry teachers' knowledge of curriculum for teaching electrochemistry and radioactivity topics?
d. What is the nature of experienced chemistry teachers' knowledge of assessment for teaching electrochemistry and radioactivity topics?

2. How do PCK components interplay for teaching electrochemistry topic?

The second research question was based on data collected from one of the participants in electrochemistry topic. I decided not to include both participants' data due to the complex nature of the interplays. The data of Mr. Demir who had richer PCK than Mrs. Ertan was analyzed for the second sub-research question. Details were provided in methodology part.

1.3. The intended Audience of the Research

The intended audiences of the research are teacher educators (specifically chemistry and science teacher educators), researchers who are interested in teacher education, pre- and in-service chemistry teachers, and policy makers in higher education. It is hoped that the results of the study will present useful and valuable information about nature of PCK construct to the PCK literature, and to teacher educators who design professional development (PD) and pre-service teacher training programs. Moreover, concrete examples of participant teachers' PCK can be used as cases in both pre-service and in-service teacher training programs as well.

1.4. Definitions of Important Terms

Pedagogical content knowledge (PCK) "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). PCK is measured by use of observations of teachers' teaching, interviews with teachers, examining teachers' lesson plans, and with instruments such as content representations (CoRe) and pedagogical and professional-experience repertoire (Pap-eRs). In this study, PCK was studied by the use of card-sorting activity, CoRe, semi-structured interviews, and observations.

Subject matter knowledge (SMK) is knowledge of content belonging to a specific field. In this study, SMK is participant teachers' chemistry knowledge that includes substantive and syntactic components. The substantive compasses the knowledge of facts, rules, principles, concepts, and theories in a specific field of science whereas the syntactic component covers knowledge of the process through which knowledge is generated in the field (Schwab, 1963, as cited in Tamir, 1988). In this study, SMK was not measured because it was not in the scope of the study. It was assumed that participants have strong SMK in chemistry. The researcher was careful about the participants' SMK during observations made. Whenever I realized a weakness and/or strength in SMK, notes were taken.

Pedagogical Knowledge (PK) is related to teaching but it is not specific to any field such as science teaching or history teaching. It includes general knowledge (e.g., classroom management and communication with learners, etc.) for all teachers.

Knowledge of context (KofC) is a necessary knowledge for teachers regarding to be aware of the nature, properties, and facilities of the district in which the school exists.

Orientation to science teaching, overarching component of PCK, "represents a way of viewing or conceptualizing science teaching" (Magnusson, et al., 1999, p. 97). The participants' orientation to science teaching was described by the use of card-sorting task, semi-structured interviews, and observations of teachers' teaching.

Knowledge of learner is PCK component that is related to learners' difficulties and misconceptions in learning specific topic and prerequisite knowledge necessary to learn the topic (de Jong, et al., 2005). Knowledge of learners was measured with CoRe, semi-structured interviews, and observations.

Knowledge of instructional strategies, another PCK component, “includes knowledge of representations and activities for teaching a specific topic“(de Jong et al., 2005, p.949). Knowledge of instructional strategies was measured by use of CoRe, semi-structured interviews, and observations.

Knowledge of curriculum, yet another component of PCK, consisted of knowledge of curriculum goals, and of curricular materials provided by the curriculum developers (Magnusson et al., 1999). Knowledge of learners was measured with CoRe, semi-structured interviews, and observations.

Knowledge of assessment, still another component, comprises knowledge of what to assess, purposes of assessment, and how to assess students’ learning. Knowledge of assessment was measured with CoRe, semi-structured interviews, collection of homework and quizzes given by the teachers, and observations.

Experienced teachers are the practitioners who have at least five or more years experience in teaching. Although there is no fixed time to develop proficiency in the profession, five or more years in teaching is acceptable time span to be an expert (Berliner, 2001). Moreover, I was also careful about the other related points. For instance, they have been participating to professional development activities for a long time. To be sure about their experience, before the study, opinion of the principals and of researchers who had studied with chemistry teachers was taken. Moreover, in a priori meeting, I asked them how they teach. Also, pre-service teachers who studied with teachers in their practice teaching course were requested to share their idea about teachers’ teaching. With help of the information collected from different sources, participants were selected.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a detailed review of the PCK literature was presented. To make the review more useful and comprehensible, some sub-titles were formed. This chapter included 6 sub-titles; (a) Historical Development of PCK and PCK Models in the Literature, (b) Research on science teachers' PCK, (c) Research elaborating SMK's influence on PCK and teaching, (d) Research on in-service science teachers' topic-specific PCK, (e) Conclusions for PCK-SMK relation and interplay among PCK components, and, finally, (f) PCK studies in Turkey. At the end of each sub-title, the summary of it was provided. At the end, difficulties of studying PCK were also provided to make researchers aware of them and to make them think how to cope with them.

Although valuable and essential studies have been conducted in math area (e.g. Ball, Hill, & Bass, 2005; Işıksal, 2006; Seviş, 2008), due to the differences in PCK models used in math and science fields, and my unfamiliarity with math teaching, studies only from science fields were summarized here.

2.1. Historical Development of PCK and PCK Models in the Literature

Since mid-1980s, the attention of teacher education research has changed from teachers' behaviors to their knowledge and beliefs. Kagan (1992) called teacher education research as *learning-to-teach* focus of which development of teachers' beliefs, cognition, and knowledge. The new trend becoming popular in 1980s in teacher education research was different from the previous one in terms of the methodology. *Learning-to-teach* literature has, generally, utilized naturalistic inquiry. Therefore, the sample of these studies was smaller than those of other research which utilized quantitative inquiry.

In recent years, attention of the research on teacher education has been practical knowledge of teachers (Carter 1990, as cited in van Driel, et al., 1998). In 1986, Shulman criticized the reforms carried out in that year in the US. He argued that these reforms viewed teaching simpler than as it really was and its difficulties were not taken into consideration. In addition, Shulman identified a *missing paradigm* in the educational research area, namely, teachers' understanding of subject matter content and its effects on teachers' instruction. Shulman also wondered how teachers transform their knowledge of subject matter into a form which helps students to understand. PCK was first offered by Shulman in 1987 as "the special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p.8). With the introduction of PCK construct, Shulman caused a *paradigm shift* in teacher education research area (Carlsen, 1999).

In 1986, Shulman stated that teachers' knowledge could be examined under three basic categories, namely, subject matter content knowledge, pedagogical content knowledge, and curricular knowledge. In his view, PCK includes knowledge of analogies, examples, illustrations, demonstrations in order to represent the subject matter knowledge to learners in understandable ways. In addition to that, PCK compasses the knowledge related with learners' difficulties and misconceptions about the subject. Finally, knowledge of curriculum includes knowledge about curriculum materials, lateral curriculum knowledge, and vertical curriculum knowledge. In his following study in 1987, he extended categories of teachers' knowledge base and added general pedagogical knowledge, knowledge of learners and their characteristics, knowledge of educational context, knowledge of educational ends, purposes and values and their philosophical and historical grounds.

In the following years, many researchers conducted research on PCK. In many of these studies, Shulman's idea of PCK was used as a framework. Magnusson et al., (1999) attributed the importance of it to its emphasis on the subject specific knowledge which has significant roles in teaching and learning science. In addition to Shulman’s model, other scholars used different models of PCK, which means that there is no consensus on the conceptualizing of PCK (Abell, 2007; Smith, 1999; van Driel et al., 1998). Although PCK literature has different models that have different components, there are two parts which are common for all scholars, namely, knowledge of representations of subject matter and knowledge of students’ difficulties and conceptions (van Driel et al., 1998).

Following the Shulman’s idea, Tamir (1988) focused on subject matter, general pedagogical, and subject matter specific pedagogical knowledge in his idea of PCK. The researcher’s view of teacher knowledge was influenced by Shulman’s view. In Tamir’s view, teacher knowledge has two basic components that were subject matter knowledge and pedagogical knowledge. However, pedagogical knowledge consisted of two subcategories that were general pedagogical and subject matter specific pedagogical knowledge which was indeed PCK. Subject matter specific pedagogical knowledge consisted of knowledge of students’ understanding, curriculum, instructional strategy, and assessment. Knowledge and skills for assessment is Tamir’s (1988) contribution to the PCK models.

Later, Grossman (1990) formed a teacher knowledge model with four main components, namely, SMK, general pedagogical knowledge, knowledge of context, and pedagogical content knowledge. Contrary to Shulman and Tamir, Grossman schematized the components and domains forming PCK rather than listing them (Figure, 1). Among the sub-components, ‘conceptions of purposes for teaching subject matter’ were teachers’ both knowledge and beliefs regarding to why they teach a particular topic in a particular grade level, which was an *overarching* component. The second sub-component of PCK was described as knowledge about learners’ prior knowledge and difficulties in a specific topic. Third, curricular knowledge included both vertical and horizontal curriculum knowledge for a topic, and materials provided in the curriculum for the topic. The last sub-component comprised knowledge of representations and instructional strategies that are appropriate to use in a particular topic. Although Grossman formed a model includes separate components, she stated that the division between them is not clear in practice.

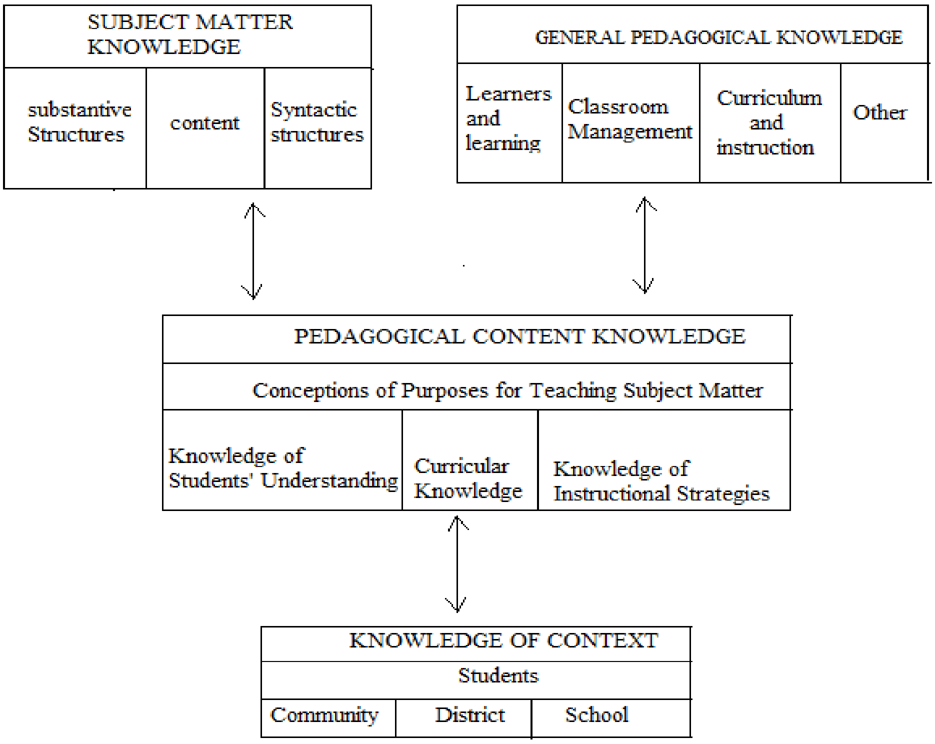


Figure 1. Grossman's model for teacher knowledge (1990, p. 5)

Another PCK model was suggested by Marks (1990) in light of the data collected from eight elementary mathematics teachers through task-based interviews. In these interviews, participants were requested to plan a lesson, criticize a video-taped lesson, and determine the students' misconceptions and provide strategies to eliminating them in equivalence of fractions topic. Analysis of the data showed that teachers' knowledge was based on four different categories, namely, subject-matter, students' understanding, media for instruction, and instructional processes (Figure 2)

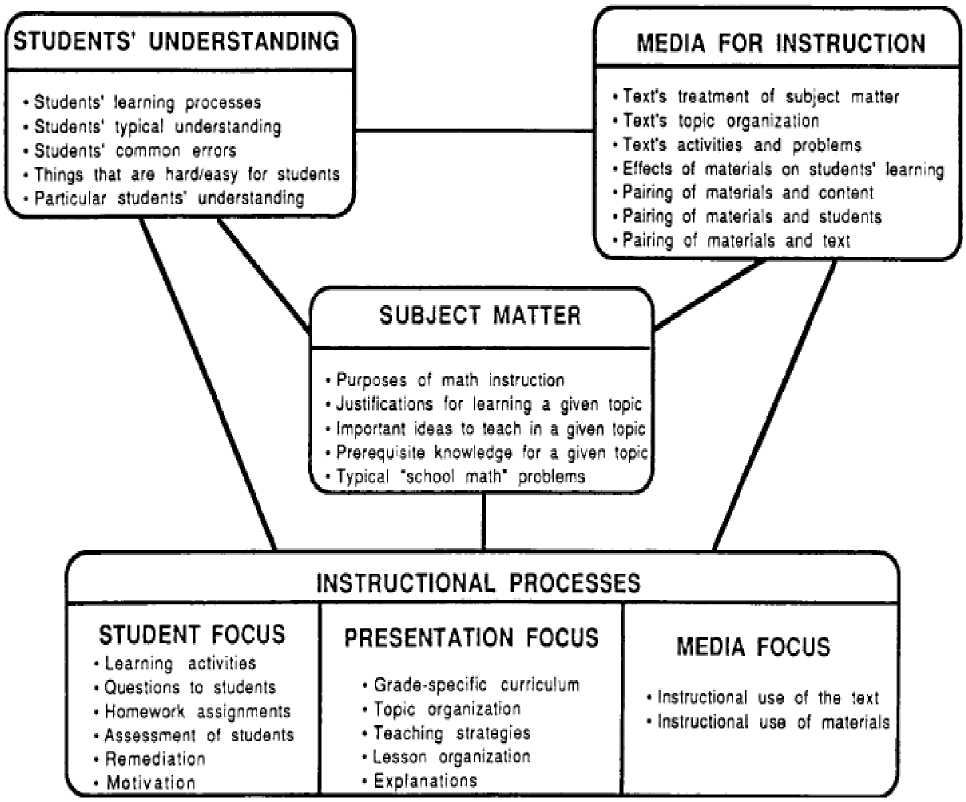


Figure 2. PCK structure suggested by Marks (1990, p.5)

In the model, teachers' curriculum and assessment knowledge was put under instructional processes. Different than the other PCK models, Marks integrated knowledge of media for instruction to the model. Another difference is that PCK is not shown as a separate structure as in other models (e.g., Grossman, 1990), on the contrary, PCK is sum of these structures existing in the model (Figure 2). Yet another difference was that he did not use 'beliefs' in his study, rather he focused on only 'knowledge'. Marks (1990) also stressed the integration of components with each other, which makes it hard to structure PCK. Similar to Grossman (1990), Marks also explained the blurry line between components with some examples. For instance, if a teacher realized that the textbook s/he used lacked necessary representation for teaching a topic, this includes his/her knowledge of media, SMK, and knowledge how students learn. Although the relation between the components was represented with solid lines in the model, he stated the indistinct boundary between them in the paper.

Cochran et al., (1991) and Cochran, DeRuiter, and King (1993) extended Shulman's (1986) PCK idea in light of the Constructivist view of learning (Figure, 3). They preferred to use Pedagogical Content Knowing (PCKg) because knowledge reflected a static nature, which contradicted to PCK's ever developing structure. The arrows in the model show the development of knowledge in time with experience. In PCKg model evolution of PK and SMK occurred in the light of the knowledge of learner and knowledge of context.

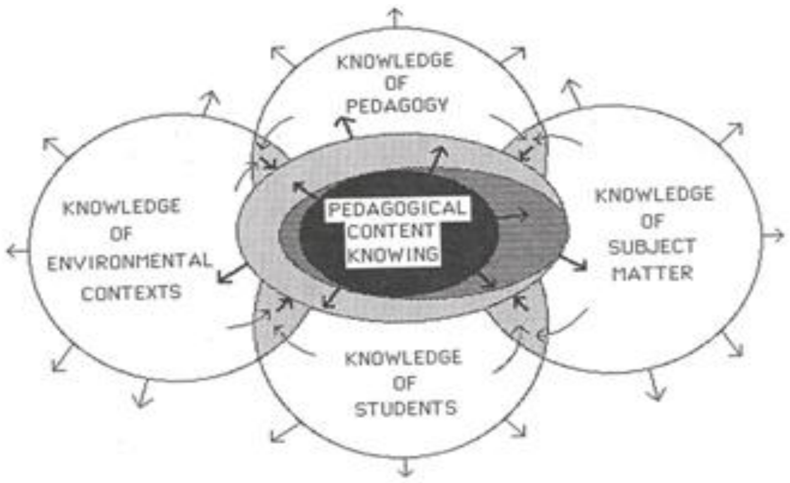


Figure 3. Cochran et al.'s (1993) PCK model

Different from Shulman's (1986) PCK conceptualization, knowledge of curriculum, knowledge of educational goals and purposes, and knowledge of the content components were not thought as separate parts, rather, Cochran et al., examined knowledge of curriculum and educational goals and purposes components under PK in PCKg model. Moreover, the researchers criticized Shulman (1986) in terms of the PCK definition which was transformation of SMK into another form. In their model, they viewed PCKg as combination of four basic components, namely, knowledge of environmental context, knowledge of pedagogy, knowledge of students and knowledge of subject matter. "…theoretically, the four components become so integrated and interrelated that they no longer can be considered separate knowledges" (Cochran et al., 1991, p.12).

Different than the other scholars (e.g. Shulman, 1986; Tamir, 1988), Fernandez-Balboa and Stiehl (1995) based their PCK study on the teaching practice. In other words, data were gathered from classroom context, which makes their PCK view stronger than others due to the dependence of PCK on teaching practice. They focused on the nature of PCK by studying college professors' teaching. Another divergence that their study offers to the PCK literature was the focus on which they built their study. Rather than subject-specific PCK, they analyzed generic PCK for teaching different subjects. Data were collected through the interviews with 10 professors teaching at different areas (e.g. music, nursing, etc). By the use of data collected, Fernandez-Balboa and Stiehl listed categories that form participants' PCK. Similar to Shulman (1986; 1987) and Tamir (1988), Fernandez-Balboa and Stiehl (1995) did not suggest a PCK model showing the components, sub-components, and how they are related. Results indicated that knowledge of subject matter, learners, instructional strategies, teaching context, and own teaching purposes are basic constituents which structured PCK. If the "knowledge about one's teaching purposes "component is related to recent literature, it is seen that it is examined under orientation towards science teaching component (Friedrichsen et al., 2011). Furthermore, in their PCK analysis, knowledge of assessment was not included. However, they stated that participant professors highlighted the implementation of assessment of both learners' understanding and enthusiasm. They placed knowledge of assessment under knowledge of learner category.

In addition to components forming PCK, they also paid attention how those components are related to each other. To be a successful teacher, the interplay among the components of PCK is essential. In other words, separate entities of components does not result in good teaching, therefore, PCK components should be employed simultaneously when it is necessary. In addition to that, the interplay existing between the components is not *linear* rather different integrations are possible for a specific situation.

Another model of PCK was developed by Veal and MaKinster (1999). Researchers built up two taxonomies that were *General Taxonomy of PCK* and *Taxonomy of PCK*

Attributes for secondary teachers' knowledge base for teaching. They described PCK as making the content understandable to learners by the enactment of varying suitable instructional strategies. Veal and MaKinster likened teaching to translation of words from one language to other. Teacher is the translator and should know how to translate well (PCK) for people talking another language (learners) to understand the phrase (content). Veal and MaKinster criticized the existing teacher preparation programs which did not relate content and pedagogy. The other point they underlined was the inadequate guide for existing PCK models for teacher education programs. Therefore, Veal and MaKinster developed two taxonomies for secondary teacher education. The researchers stated that although different models were developed by teacher education researchers, taxonomies including PCK components have not been developed. Moreover, they criticized the lack of PCK models representing the hierarchy between PCK components.

The *General Taxonomy of PCK* (Figure-4) shows the *specificity* of the PCK levels. It demonstrates that teachers teaching science at secondary level develop PCK hierarchically. At the very outside of the General Taxonomy of PCK development Pedagogy exits, which means pedagogy covers all others because all teachers have pedagogy independent from the content area such as wait time, feedback and evaluation. In the taxonomy, General PCK is between pedagogy and domain-specific PCK in terms of specificity. At this level, the focus is enactment of pedagogical knowledge for specific disciplines such as science, history or math. Teachers from different disciplines may use the same orientations in their class; however, the answers of why and how they use them may be different. Domain-specific PCK is related to different domains under a specific discipline such as physics or chemistry for science. Finally, topic-specific PCK is for different topics under a specific domain, for example, chemical equilibrium, acids and bases, etc. for chemistry. To have a solid topic-specific PCK, teachers' domain and subject-specific PCK and PK are supposed to be solid as well.

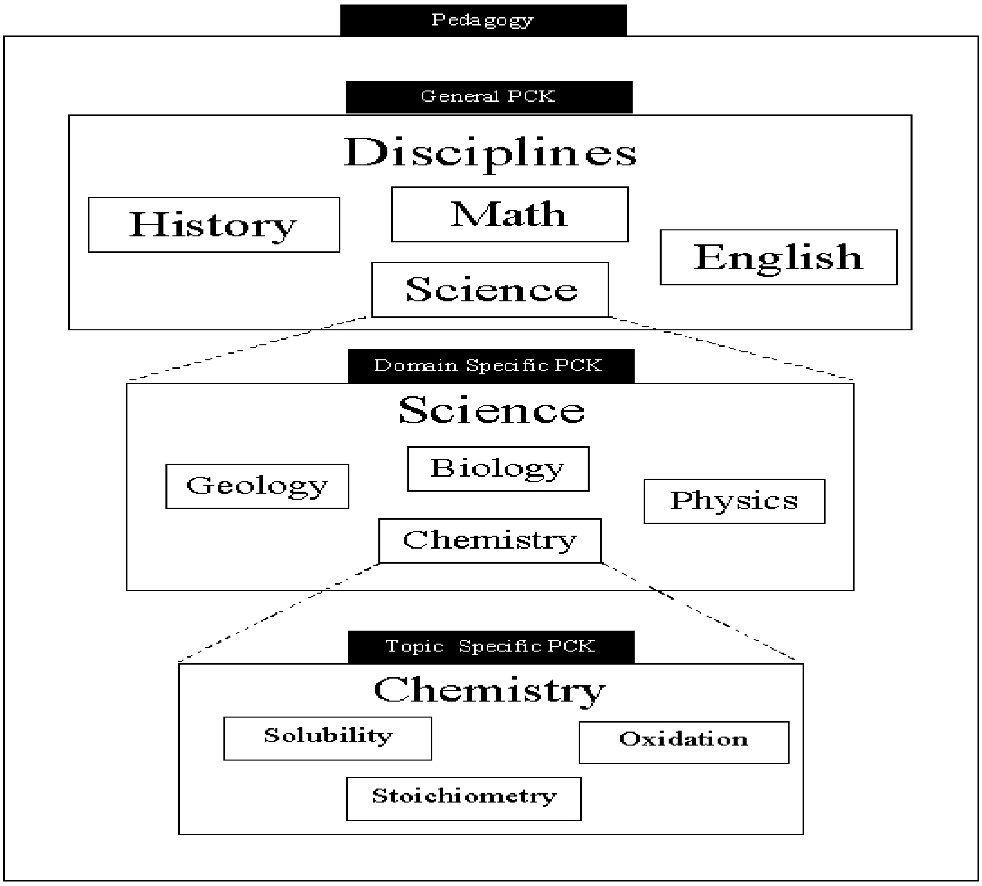


Figure 4. General taxonomy of PCK proposed by Veal and MaKinster (1999, p.7)

For the taxonomy of PCK attributes (Figure 5 and 6), they used four levels that are content knowledge, knowledge of students, PCK attributes, and PCK. Similar to PCK's nature, content knowledge may be general, domain-specific, or topic-specific. Knowledge of learner is another essential knowledge for developing a solid PCK. According to hierarchical structure of the taxonomy, content knowledge, knowledge of learner, and PCK attributes are prerequisite for development of PCK. However, the researchers stated that this does not indicate a linear development; on the contrary, they acknowledge the reciprocal relationship between them. It is interesting that although other parts of the taxonomy include hierarchy between knowledge types, this is not the case for PCK attributes. Moreover, they are interrelated and the development in one of them also influences development of others. PCK is at the center of the taxonomy, which shows its significance.

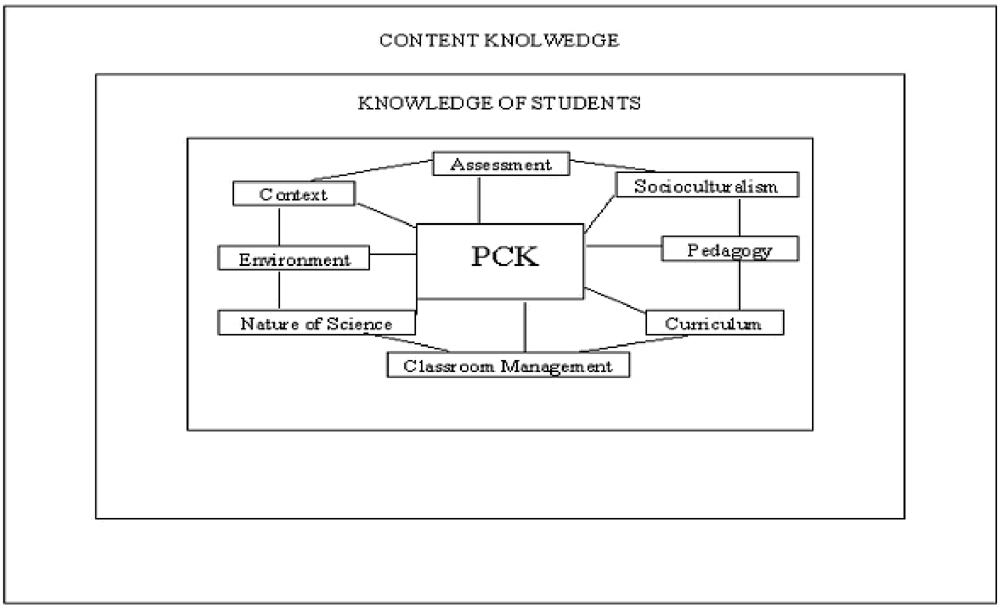


Figure 5. Bird's eye view of taxonomy of PCK attributes (Veal & MaKinster, 1999, p.11)

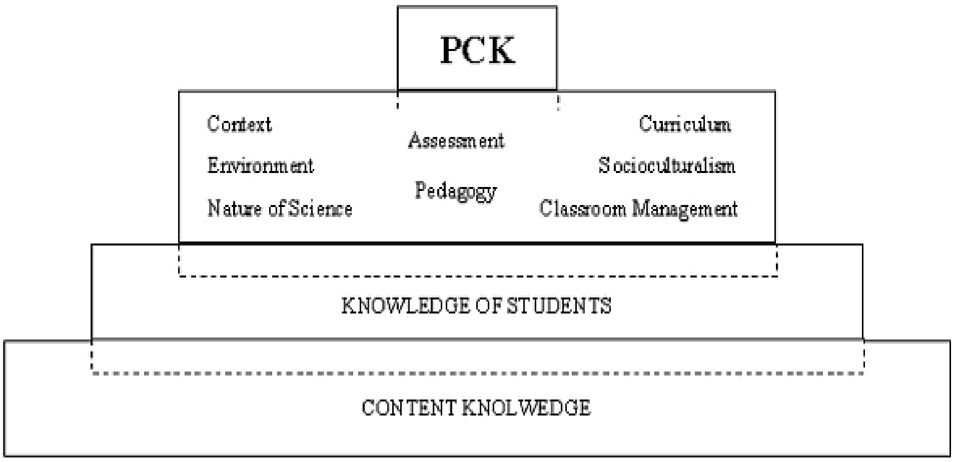


Figure 6. Side view of taxonomy of PCK attributes (Veal & MaKinster, 1999, p. 11)

Yet another model for PCK was formed by Magnusson et al., (1999) who view PCK as a new type of knowledge formed by the conversion of other domains of knowledge. If we explain this with an analogy from chemistry, similar to a chemical process, reactants (e.g. SMK, PK, and KofC) react and product, PCK, with a different nature is formed. Similar to Grossman, Magnusson et al.'s model includes four fundamental knowledge domains that are SMK, PK, knowledge of context and PCK (Figure 7). Moreover, double arrows show the mutual influence of domains on each other. However, in their model, Magnusson and her friends added beliefs to knowledge because they thought that beliefs are also influential on teachers' teaching.

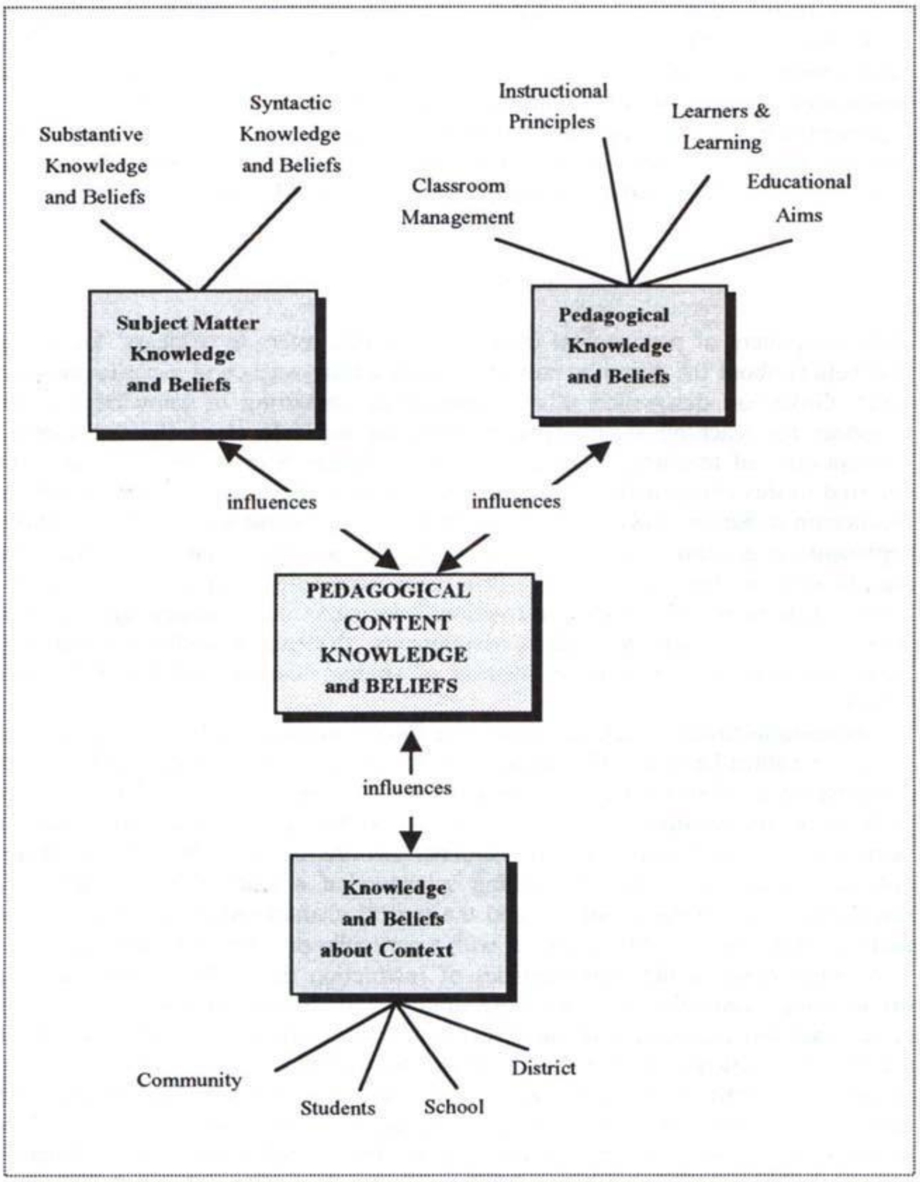


Figure 7. Knowledge domains formed teacher knowledge and their relations (Magnusson et al., 1999, p. 98).

Magnusson et al., (1999) described five separate but related components of PCK (Figure, 8).

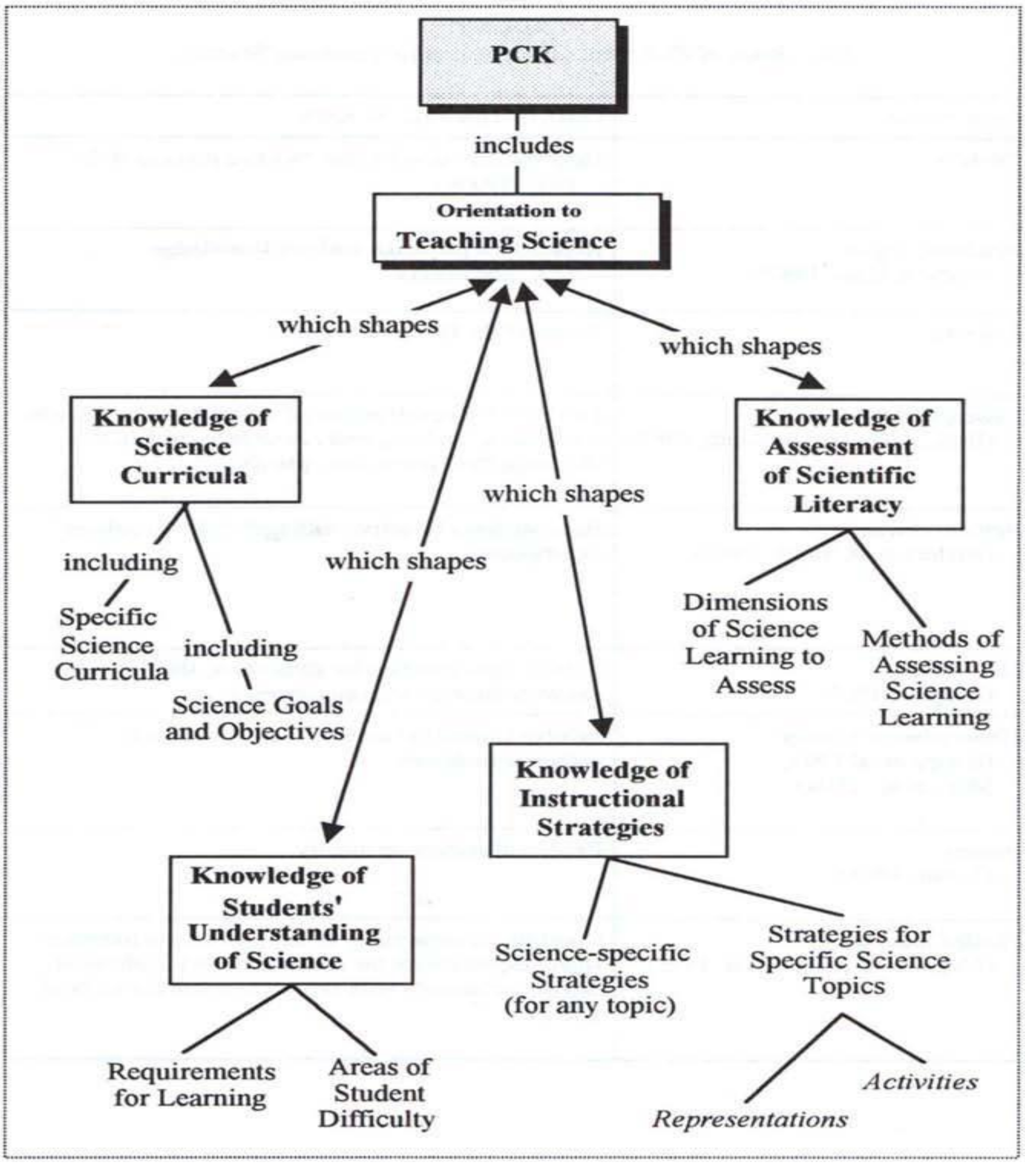


Figure 8. Model of PCK showing the components of PCK for science teaching (Magnusson et al., 1999, p.99)

In the model, PCK consists of five components which are orientations to science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specifics science topics, knowledge and beliefs about assessment in science and knowledge and beliefs about instructional strategies for teaching science. Inspired by Tamir (1988), Magnusson et al., (1999) added knowledge of assessment of scientific literacy to the model. Moreover, they renamed Grossman's "conceptions of purposes for teaching subject matter" and called it "orientation to science teaching".

Orientations to science teaching component of PCK is related to teachers' both knowledge and beliefs about goals of science teaching at a specific grade level. Orientation is a window through which teachers look at science teaching. According to Magnusson and her colleagues, orientations can be process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry. Although some of the orientations share similar characteristics, the rationale behind the instruction differentiates them. Borko and Putnam (as cited in Magnusson et al., 1999, p.97) likened orientation to science teaching to "*conceptual map*" which reflects teachers' decisions related to their teaching and students' learning such as use of instructional strategy, types of homework assigned or types of evaluation of learning. In other words, teachers' orientation to science teaching directs their planning, instruction, and evaluation.

Knowledge and beliefs about science curriculum component of PCK includes mandated goals and objectives, and specific curricular programs and materials. Although Wilson, Shulman, and Richard (1987) view knowledge about science curriculum as a fundamental knowledge domain, Magnusson et al., (1999) consider it as a component of PCK. Similar to Grossman's (1990) description, knowledge of goals and objectives includes horizontal curriculum knowledge that is the relation of topics in the same grade and vertical curriculum knowledge that is relation of topics taught in different grades. The second component is related to teachers' knowledge about the curriculum that they use and the materials needed to teach science or a particular topic.

Knowledge of students' understanding of science related to possessing information about the learners to assist them in learning science. There are two subcomponents of this knowledge, namely, knowledge of requirements of learning and knowledge of areas that students have difficulties. The former includes knowledge about prerequisite skills which are necessary for learning a new topic. Moreover, teachers' knowledge of students' differences in terms of developmental and ability is under the former category. A successful teacher is one who knows learners' individual differences and provides varying opportunities to learners with different needs. The latter is related to being aware of students' difficulties and their causes. Abstract nature of the topic, students' lack of effective planning skills for problem solving, and misconceptions are the basic sources of the difficulties students encounter. In light of the research conducted on teachers' knowledge of students' difficulties, Magnusson et al., (1999) concluded teachers have good understanding of students' difficulties in learning specific topics, however, their knowledge for helping students to solve the learning difficulties is not rich, which indicates "the independence of the components of pedagogical content knowledge in that changes in teachers' knowledge of one component may not be accompanied by changes in other components that are also required for effective teaching" (p. 108).

Knowledge of assessment in science was examined knowledge of assessment under two categories; namely, knowledge of dimensions of science learning to assess and knowledge of methods of assessment. Knowledge of dimensions of science learning to assess is knowledge about important aspects of students' learning which is worth to assess (e.g. knowledge, application, science process skills, etc.). The knowledge of methods of assessment is related to being aware of suitable assessment methods for assessing the particular aspect of learning (e.g. portfolio, paper-pencil test, poster presentation, etc.). Additionally, teachers should know strengths and weaknesses of particular assessment techniques.

Knowledge of instructional strategies is last component of Magnusson et al.'s PCK model includes two sub-categories, namely, knowledge of subject specific strategies and knowledge of topic specific strategies (Figure 8). Although they are not distinct strategies, the difference is the extent of them. Subject-specific strategies are broader than the topic-specific ones. The former is used for science teaching whereas the latter is for teaching a particular topic in science.

Knowledge of subject specific strategies consists of general approaches (e.g. learning cycle, conceptual change, etc.) used in enactment of science instruction. Teachers should be aware of the description of the strategies and implement the strategies in an effective way. This category is much related with the other component of PCK which is orientations towards science teaching.

Knowledge of topic-specific strategies consists of teachers' knowledge about appropriate strategies for particular science topics. Magnusson et al., (1999) examined this type of knowledge under two subcategories which are topic-specific representations and activities (Figure 8). Teachers should know when and how to use the representations which are analogies, models, illustration and examples, and how to create representations to help learners understand. Moreover, they should be aware of the advantages and disadvantages of using a particular representation. The latter subcategory includes knowledge of simulations, demonstration and experiments to help learners to construct science knowledge and understand relations between them. Magnusson et al., (1999) stressed the importance of viewing the PCK as a whole. In addition, they thought that relations between the components of PCK are very important. They said that for being an effective teacher, having a solid knowledge of one component is not adequate. Moreover, there is a multifaceted relation between the components of PCK, which makes focusing on the relation and its influence on teaching valuable to the PCK field.

Finally, Park and Oliver (2008) developed a hexagon model which indicates that PCK is at the center due to its nature (Figure 9). Improvement observed in one of the components may trigger the development of other components and PCK as well. However, this does not mean that advancement in one component causes PCK development. On the contrary, the more concordance between the components is, the more progress in PCK is achieved. The five components of PCK that they mentioned are the same with those that was pointed out in Magnusson et al.'s model. Similar to

Magnusson et al., (1999), they put orientations to teaching science to the top because they acknowledge the orientation's influence on teachers' practice. For the knowledge of students' understanding in science, they added students' motivation and interest to knowledge that teachers should have. For the other components of PCK, they agree with Magnusson et al.'s (1999) definition. Although they adopted the pentagonal model in light of the literature at the beginning of the study, the data indicated the existence of self-efficacy as a component of PCK.

In light of Shulman (1986) and Baxter and Lederman (1999) work, Park and Oliver (2008) elaborated PCK at two levels; *understanding* and *enactment.* Understanding is teachers' awareness of difficulties of teaching a topic, learners' misconceptions in a topic, and/or effectiveness of an instructional strategy used to teach a particular topic. Enactment is the performance of teachers' understanding of difficulties, misconceptions, and/or the strategies that are suitable to implement to teach a topic in real classroom context. Results indicated that self-efficacy activates teachers in realization of what they understand in class.

In the model, reflection-in and reflection-on-action are put at the center because reflection is vital for development of PCK and assists teachers incorporate PCK components (Figure 9).

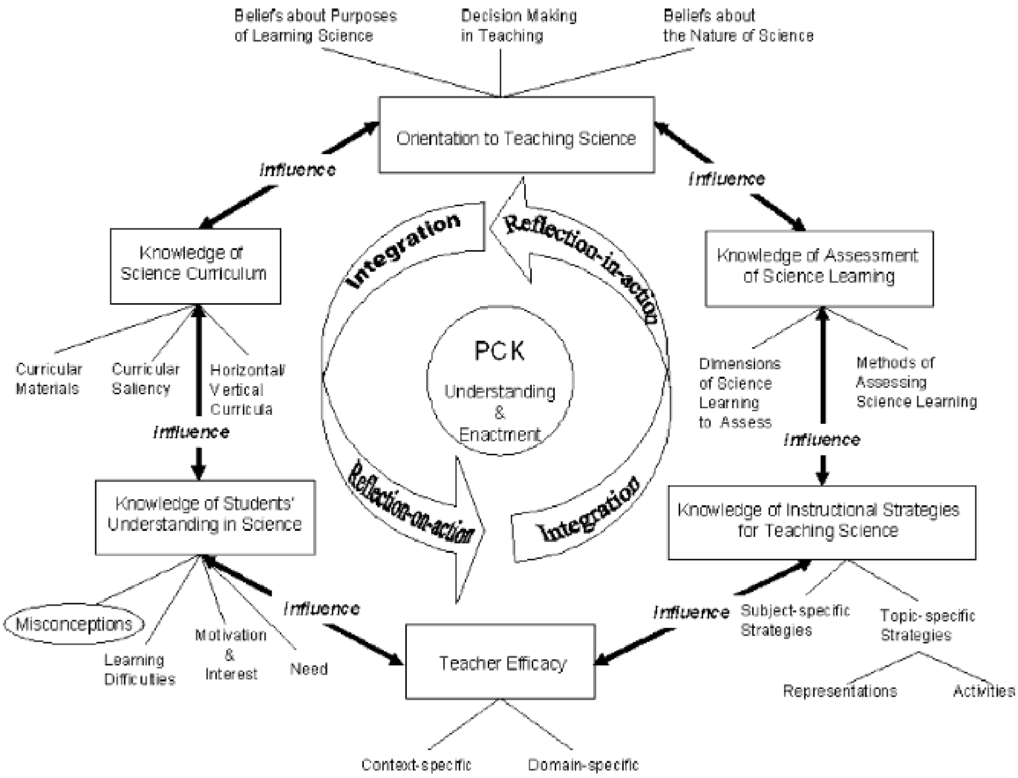


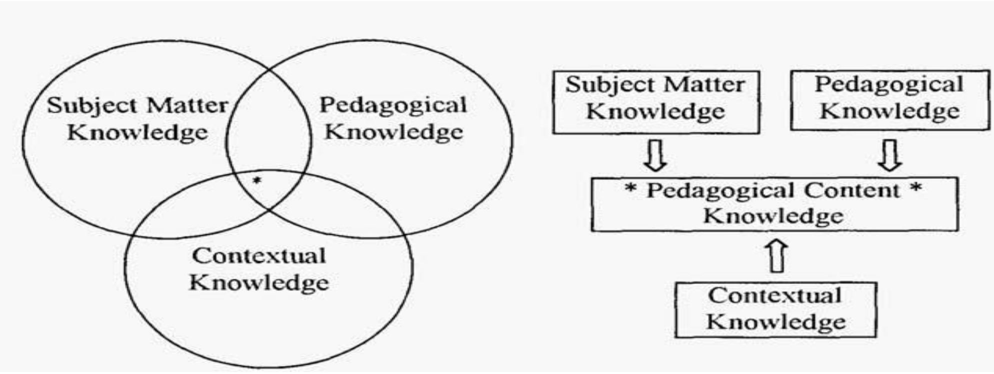
Figure 9. Hexagonal model of PCK developed by Park and Oliver (2008, p. 279)

Park and Oliver (2008) developed this model with help of the study that they conducted with three experienced chemistry teachers working at the same high school. They observed teachers through three units, took field notes, conducted interviews, and took their lesson plans and students' products for data analysis. Results revealed that the development of PCK occurs through the teachers' reflection-in and reflection-on their knowledge. For example, two teachers had an unexpected event that was the shattering of zinc when students hit it. One of them used her PCK including her SMK, knowledge of curriculum, and knowledge of learner at that moment and reacted to the situation by asking students the reason of it. Then they talked about elements, compounds, the differences between them and oxidation of zinc, which is an example of knowledge-in-action which is generated in the case of unexpected events or results during teaching and by doing reflection-in-action (Schön, 1983, 1987, as cited in Park & Oliver, 2008). However, although the other teacher had the same experience in the lab, she did not do anything when zinc was shattered. Rather, she decided to reorganize by providing metals in different shape for the next year, which is an example of knowledge-on-action produced by thinking on the practice after teaching. Another point that they got from the data was teachers' self-efficacy that is affective part of PCK. Although it was an unexpected result, data showed that the higher self-efficacy teachers have about their PCK, the more they use PCK in the class.

They also interpreted that teachers' PCK is developed with learners' influences; e.g. that can be a difficult question which is beyond the scope of teachers' SMK learners' reactions to the instructional strategies used in the class, and their ideas that help teachers to find new and useful strategies for future classes. When a teacher is asked a difficult question, s/he researches for that, understands it and then explains it in a way that is understandable for learners, which helps teachers develop PCK. Moreover, teachers' observations about learners' pleasure related to strategies, or activities used facilitate their PCK development because they change them if students do not like them. Additionally, students' suggestions or ideas about a phenomena or event in the class may provide a new idea to teacher for implementing in next year. Yet another point was that misconceptions that students have manipulate teachers plan, performing the plan and assessment. The more knowledge teachers have about students' misconceptions, the more *sophisticated* PCK they have.

Finally, Park and Oliver (2008) realized idiosyncratic nature of PCK that can be explained with differences in teachers' orientations to science teaching, learners' features, teachers' experience and teachers' characteristics.

In PCK literature there are many models that have different view of PCK. Gess-Newsome (1999) categorized PCK models and formed two main groups that are *integrative* and *transformative* PCK models (Figure 10). Integrative model indicates that PCK is knowledge formed by combination of SMK, PK, and knowledge of context. On the contrary, for the transformative model, PCK is special kind of knowledge formed by conversion of SMK, PK, and knowledge of context into a new type of knowledge. The former is like formation of solution which is physical. In other words, the components of mixture still have their own properties. However, for the latter form of PCK, the formation is like formation of compounds, which is chemical reaction and results in a new type of substance. According to Gess-Newsome, whatever the nature of teacher knowledge, it is a valuable construct for research, practice, and teacher education programs.



* = knowledge needed for classroom teaching (Gess-Newsome, 1999, p. 12)

Figure 10. Integrative and transformative models of PCK

The figure on the left represents integrative PCK which is a mixture of SMK, PK and contextual knowledge. In this type of PCK construction, PCK is not viewed as a separate knowledge domain. On the contrary, the figure on the right represents transformative PCK which means PCK is a new type of knowledge formed. “While knowledge bases containing subject matter, pedagogy, and contest exist, they are latent resources in and of themselves and are only useful when transformed into PCK.” (Gess-Newsome, 1999, p. 12)

Although many scholars have focused on nature of PCK construct, the definition of PCK is still not clear. Hashweh (2005), in a recent review of PCK literature, indicated the same point. Moreover, he mentioned the ignorance of teachers’ beliefs from PCK models. Hashweh suggested to use *“teacher pedagogical construction“*(TPC) instead of PCK. With help of the recent research about PCK and by reconsidering his own and Shulman’s conceptualization of PCK, Hashweh provided seven characteristics of PCK, that are;

1. PCK is specific to teacher,
2. PCK is formed through the formation of pedagogical constructions,
3. With help of preparation for teaching, teaching experience, and post-teaching periods, teachers develop pedagogical constructions,
4. With the interaction of teacher's knowledge types and beliefs, teachers form pedagogical constructions,
5. Pedagogical constructions are recollections accumulated through both occasions in class and narratives,
6. Pedagogical constructions are formed for special topics,
7. There should be links between these constructions and different knowledge types that teachers have.

Hashweh (2005) does not view conceptualization of PCK as a new type of knowledge and explained the idea with an analogy from chemistry; pedagogical constructions are molecules and PCK is a mixture consisting of different molecules, pedagogical constructions. However, he does not view PCK as a compound.

2.1.1. Conclusions Drawn from PCK Models

To sum up, first, different models include different components, sub-components, and relations between them, however; the common domains of teacher knowledge are SMK, PK, PCK, and knowledge of context for most of the PCK models. Additionally, there are two parts which all scholars reached a consensus regarding to their existence as PCK components, namely, knowledge of representations of subject matter and knowledge of students' difficulties and conceptions (van Driel et al., 1998). Some of the models view PCK as a new type of knowledge (e.g. Magnusson et al., 1999), and a mixture of knowledge (Cochran et al., 1991; 1993). Second, due to the missing pieces in PCK paradigm, although some scholars mentioned the interplay between PCK components, the field needs more research for clear understanding of how teachers use different components simultaneously in a harmony to make the topic easily understandable to learners. Third, PCK is a construct with components, which helps researchers to study PCK. However, the boundary between them is not straightforward as it was drawn in PCK models (; Fernandez-Balboa & Stiehl, 1995; Grossmann, 1990; Marks, 1990). Fourth, PCK is not one or some components; rather, it has an integral nature. The integration of components in a synchronization results in PCK development (Fernandez-Balboa & Stiehl, 1995; Magnusson et al., 1999; Marks, 1990; Veal & MaKinster, 1999). Finally, in addition to cognitive components, PCK may include affective components for instance, beliefs (Hashweh, 2005; Magnusson et al., 1999) and self-efficacy (Park & Oliver, 2008).

In the PCK literature, in addition to the theoretical papers digging into nature of PCK, lots of research studies have focused on teachers' PCK use in classroom. In the subsequent part, they will be reviewed.

2.2. Research on Science Teachers' PCK

Some studies in the literature were focused on teachers' topic-specific PCK, general science PCK, and some components of PCK rather than studying PCK as a whole. In this part, studies elaborating general science PCK and elaborating some components of PCK were reviewed.

Orientation to science teaching is one of the PCK components that has been studied rarely (Abell, 2007). In order to catalog tertiary teachers' teaching conceptions, Samuelowicz and Bain (1992) collected data from six participants through semi-structured interviews. Questions related to teaching, learning, and learning outcomes were asked to participant teachers. Results showed that teaching conceptions could be analyzed under five categories, namely; teaching as supporting student learning, teaching as an activity aimed at changing students' conceptions or understanding of the world, teaching as facilitating understanding, teaching as transmission of knowledge and attitudes to knowledge within the framework of an academic discipline, and teaching as imparting knowledge.

In the same study, to be able to identify teachers' conceptions of teaching, Samuelowicz and Bain (1992) defined five dimensions that were "*the expected outcome of learning, the knowledge gained or constructed by a student, students' existing conceptions, directionality of teaching, and control of content"* (p. 102-103). Researchers concluded that teaching conceptions do not have a hierarchy rather those five conceptions are in order from student-centered to teacher-centered. Moreover, the conceptions of teaching that teachers held may be influenced by the context in which they teach (e.g. the audience of the course). Finally, researcher stated that teacher may have dual teaching conceptions which are ideal and working teaching conceptions. Although they may think that they have ideal conception of teaching, their actual practice may contradict with it. Different factors (e.g. loaded program of the course, or testing) may cause this situation.

In another study related to orientation to science teaching, Friedrichsen and Dana (2003) pointed out a distinction between experienced and prospective teachers' orientations. Teachers' orientation to science teaching was provided by a card sorting process. The researchers preferred to ask additional questions such as in which condition they would or would not use the strategy mentioned in the card rather than giving details about the scenarios written in the cards. Experienced teachers needed more information about the context and focused on contextual information, however; information given in the cards was adequate for prospective teachers.

Due to its pivotal position, orientation to science teaching deserves deep study on it (Friedrichsen & Dana, 2005). The researchers studied four highly-regarded biology teachers' orientations to science teaching and their sources. In the case study, they collected data in terms of card-sorting task, interviews with teachers and observations of participants' teaching. Results showed the complexity of the teachers' orientations. Furthermore, they found that teachers' science teaching orientations are specific to courses that they taught. In the study, Friedrichsen and Dana used *central and peripheral goals* to show participants' orientations, which also points to the sophisticated nature of orientations to science teaching. Central goals were described as goals that direct teachers' teaching and decisions about teaching practice whereas peripheral components are goals that have little control on teachers practice. In the study, participants have multiple central and peripheral goals. Another point discussed in the study was the relation between orientations and course levels. Teachers had different orientation for different course that they taught, additionally, the goals had different positions for different courses in terms of central and peripheral status. For the nature of the orientations, the composite structure of orientations includes *affective*, *schooling*, and *subject-matter* goals. For affective goals participants mentioned developing positive attitude toward science, self-confidence, and having curiosity, which were important for participants. To prepare students for college and for life were schooling goals. Finally, teachers also had goals related to the content, however; they were neither fundamental nor the only goals for them. Related to orientations nature, the researchers also stated that they are not static so researchers can get teachers' orientations that are for the time data collected. Friedrichsen and Dana (2005) criticized the labeling teachers' orientations with just one orientation determined in the literature because it contradicts the multifaceted nature of the orientations. The same point was also indicated in Käpylä, Heikkinen, and Asunta (2009) and Volkmann, Abell, and Zgagacz (2005).

Different from Friedrichsen and Dana (2005), Volkmann et al., (2005) studied instructors', graduate teaching assistant's (GTA) and pre-service teachers' experiences in an inquiry-based physics course in undergraduate program. They focused on the three orientations that were didactic, discovery, and guided inquiry because they were used by the instructor, and GTA in the research. Field notes from the course, and meetings of instructor and GTA, interviews with instructor, GTA and students, and reflection of instructor and GTA were the data sources. To sum up, the instructor's teaching was influenced by three orientations that were didactic orientation because of early experience in teaching, inquiry orientation as a university instructor, and discovery orientation due to changes made in inquiry in light of his ideas. The instructor indicated that orientation is resistant to change so it is hard to leave it. GTA of the course had a didactic orientation due to the influence of the education system that she had experienced as student, and the undergraduate program she graduated. She viewed science as a body of knowledge that should be taught in a traditional way to students. According to students, they were taught with discovery orientation because the instructor wanted them to discover everything. Finally, the dissonance between instructors' and GTAs' goals, and goals of guided inquiry may explain why they do not prefer to use inquiry in class. Therefore, if teachers are supposed to use inquiry, the first thing that they need is support for modification in their teaching. Then, they should learn how people learn, which helps them recognize the importance of basic points in inquiry such as relations between students and teacher.

Recently, Nargund-Joshi, Park-Rogers, and Akerson (2011) examined two Indian secondary teachers' orientation to science teaching. Researchers stressed that although orientation to science teaching component of PCK has been studied with teachers in western culture, there has been a gap regarding to teachers' orientation in Eastern cultures in PCK literature. In order to fill the gap, they focused on two Indian teachers' orientation to science teaching, its relation with their teaching practice, and how it is aligned with recent reform in Indian education system. In the case study, they collected data through interviews, observations, and documents of reform in India. Similar to Samuelowicz and Bain (1992), results showed that teachers' orientations that they explained and their practice in class had differences in terms of (a) what science is, (b) how science is taught, and (c) how science learning is assessed. Although they thought that science is creative and imaginative, they did not focus on them in their class. Laboratory activities did not include the role of creativity and/or imagination. Instead, they were used for the verification. Regarding to science teaching, they underlined the importance of learners' actual experiences in science learning during the interview; however, their instructions were traditional, and based on content and textbook. Similarly, discrepancies were observed with their ideas about assessment and their assessment practices. Teachers stated that learners' wrong answers do not make them uncomfortable because learners would need time to relate to what they learnt. However, in the class they looked for correct answers most probably because of high-stakes exams in India. The authors discussed that exam-based science teaching had a large impact on teachers' practices, which creates a large gap between their beliefs and actual practices. They thought that if reforms do not take teachers' orientations toward science teaching into consideration, the achievement on rate of the reforms is most probably be low than expected rate. In addition to it, time necessary for grading, lack of materials in classes, classroom management, and teachers' concerns regarding to adequacy of their SMK were factors influencing their orientation. Finally, different from other studies summarized above, due to contextual factors such as college entrance exam, researchers suggested that cultural and contextual factors be part of studies on orientation to science teaching.

Rather than focusing on specific PCK components, some researchers studied PCK as a whole. In order to fill a gap that is lack of teachers' PCK from teachers' view, Lee and Luft (2008) focused on five experienced science teachers' general PCK. The purpose of the study was to elicit experienced teachers' view about necessary knowledge for science teaching. The data were collected through interviews, classroom observations, lesson plans and monthly reflective summaries for more than two years. In the first interview, biographical data were gathered whereas in the second interview, which was conducted after teaching, teachers were asked about clarification of the teaching that was observed. Finally, at the last interview teachers constructed a diagram representing the components of PCK. To get teachers' view about what types of knowledge are necessary for teaching, card sort task was used. Teachers were provided types of knowledge and asked for relating them. SMK, knowledge of goals, students, of teaching, of curriculum organization, of assessment and resources were mentioned as knowledge that is important in teaching. All the teachers thought that SMK was the most important knowledge in teaching science whereas there were differences for other knowledge in rating. Participants stated that their PCK developed with help of the experience in teaching and participating to workshops. Although they had consensus on the knowledge necessary for teaching science, their representations for general PCK were different in terms of grouping knowledge and their interactions. In addition to other types of knowledge, knowledge of resources were mentioned very much by participants, which necessitates further research whether it may be another component of PCK.

Different than the other studies, Lee, Brown, Luft, and Roehrig (2007) examined 24 beginning teachers' PCK through induction year. They did not study all of the PCK components rather they focused on knowledge of learner and knowledge of instructional strategy of the participants who were enrolled to the different induction programs (e.g. e-mentoring and science-specific, etc.). Data were gathered through pre and post interviews, observations of participants' teaching, and collecting documents related to teaching. Analysis of interview and observation data was carried out by using a rubric including three levels of participants 'use of knowledge of learner and instructional strategy. The levels were limited, basic, and proficient. Kruskal-Wallis test results showed that there was no significant difference between the teachers from the different induction programs in terms of PCK levels ($H(4, 24) = 2.89$, $p=.44$). Descriptive statistics revealed that all of the participants' PCK was either limited (76%) or basic level (%24) at the beginning of the school year whereas at the end of the school year, 65 % of the teachers' PCK was at limited level, 34 % of them was at basic and only 1% of them was at the proficient level. Based on these, researchers concluded that beginning teachers' PCK is not adequate, which reflects weakness of pre-service teacher education programs in PCK development. Although participants had strong SMK, they could not use their SMK during teaching activities that were suitable for learners' level and interests.

In a recent study, Park, Jang, Chen, and Jung (2011) focused on seven biology teachers' PCK and their implementation of reforms in photosynthesis and heredity topics. In the correlation study, to assess participants' PCK, PCK rubric developed by Park, Chen, and Jang (2008, as cited in Park et al., 2011) was used. In this rubric, only two components of PCK, namely, knowledge of instructional strategy and knowledge of learner are included. For implementation of reforms, The Reformed Teaching Observation Protocol (RTOP) developed by Sawada, Piburn, Turley, Falconer, Bloom, et al., (2000, as cited in Park et al., 2011) was utilized. In addition to data collected through PCK rubric and RTOP, observations of participants' teaching, and pre and post interviews conducted with teachers were data sources as well. Results showed that there is a significant correlation between teachers' PCK and RTOP scores ($r= .831$, $p< 0.01$). In other words, the more robust PCK that teachers have, the higher probability is for integrating reform-based teaching into teachers' practice. Additionally, all subscales of RTOP had positive and significant correlation with PCK. The highest correlation was observed between procedural knowledge subscale of RTOP and PCK scores ($r=.805$, $p<0.01$), which means teachers with rich knowledge of science content have a tendency to pay more attention to reform-based teaching in their classes. Due to correlational nature of the study, no causal effect was concluded; however, the study was interesting regarding to be able to show the relation of teachers' PCK and their implementation of reformed-based teaching practice. Although PCK was not assessed totally rather two components were focused on, still the study provided beneficial result to PCK literature.

To sum up, as the studies summarized above showed that teachers may have more than one goal to teach science, namely, central and peripheral for a specific grade. In addition to subject matter goals, teachers' goals can be also related to affective domain and schooling (Friedrichsen & Dana, 2005). Due to the fact that orientation is the chief component manipulating the others, to make a change in the orientation is challenging (Volkmann, et al., 2005). Additionally, teachers' perception of own orientation and their teaching practice may not be the equivalent possibly because of the loaded curriculum or the nation-wide exams (Nargund-Joshi, et al., 2011; Samuelowicz & Bain, 1992).

In addition to pre-service and in-service teachers' PCK, some research studies also analyzed instructors and GTAs (Volkmann, et al., 2005), and beginning teachers' PCK through the induction year (Lee et al., 2007). Although extensive training was provided to beginning teachers, PCK development was not enormous. In other words, to yield progress in PCK, support offered to teachers should be long-running. Finally, teachers' PCK and their view about what constitutes PCK may be specific to teacher (Lee & Luft, 2008).

In the next part, research focusing on SMK's influence on teachers' PCK and teaching was reviewed. As Shulman (1986) and other scholars pointed, SMK is essential for development of robust PCK.

2.3. Research Elaborating SMK's Influence on PCK and Teaching

Some of the researchers studied the effect of SMK of teachers on their planning, and teaching. To investigate how SMK manipulates PCK and teaching, researchers compared and contrasted teachers' teaching in the area which they have certification and no certification. In some of the research, discourse in the class and quality of questions were also examined.

Sanders, Borko, and Lockard (1993) studied three experienced secondary science teachers' planning, teaching and reflecting in two fields of science one of which was their major and the other was not. Their experience in their certified area was between three to eight years whereas experience in the uncertified area was one or two times. For teaching of certified area, teachers stated that teaching experience was the basic source of their knowledge for teaching. With help of the experience, they all made revisions each year. Moreover, they had strong knowledge of learner and the classroom. Results indicated a discrepancy between teachers' planning and reflection, and their teaching in those areas. First, they stated that they were capable of changing the flow of the lesson in light of students' needs in the familiar one. Another point was the attention that teachers paid to the decision of use of instructional strategies in class. Although teachers had rich archive of activities and handouts, and a rich understanding of how to plan a lesson in their area of specialization, they were weak in planning for the topic that was out of their area of specialization. So, they lost lots of time on planning those classes and needed activities and help. Limitation in SMK caused difficulties in determining the key concepts, activities to use, how to teach, and what learning goals should be attained. For teaching the area of outside of certification, their PK was also weak. For example, they could not predict how long an activity would take. Therefore, they planned more activities than they needed for the case of failure or time left after teaching planned activities. In terms of PCK, they felt inadequate especially about knowledge of learners. Similarly, they were unconfident in determining the teaching methods used for teaching the topic that they did not know very well. Although they decided everything about the teaching topic from their area as an expert, they were self-doubting when doing those in the area that was out of their specialization.

Second, differences also occurred in their teaching. For instance, in the area that was out of specialization, they had difficulties in focusing on students' questions. They did not let students to talk much and used teacher-centered activities. Moreover, they tried to use the exact definitions of terms from the unfamiliar area. Interestingly, classroom management problems were also observed while teaching the topic out of specialization. In terms of PCK, although they were confident in flow of activities and the changes made during teaching in the certified area, they could not do these automatically in the other area. In reflection part, differences were also found. Although they focused on learners' comprehension and discussed their understanding for different ability groups in the familiar area, teachers concentrated on their teaching procedures while reflecting the unfamiliar area.

Finally, participant teachers had unique features when they taught out of area of specialized area. When they were compared to novice teachers, it can be said that their PK helped them a lot. Furthermore, experience in subject specific PCK made another difference between them and novice teachers. According to the researchers, when content knowledge is weak, PK took a major role in planning and enacting teaching till content knowledge is conceptualized by teachers.

Similar to Sanders et al., (1993), Ingber (2009) compared and contrasted six science teachers' PCK in planning in and outside of their area of expertise. Particularly, participants' planning, use of resources, and use of instructional strategies were studied. Data were gathered through survey and think aloud sessions while participants were planning. Results showed that teachers were better in terminology use in their area than outside of it during planning. They could relate more concepts in their area than they did outside of their expertise. Similarly, they were more knowledgeable about the resources necessary for enriching SMK and teaching when they planned for a unit in the area of expertise than they did it for a unit outside of the expertise. However, there was no significant difference in their choice of instructional strategy in planning for all units. Ingber stated that instructional strategy use was teacher-specific rather than being topic-specific.

In a yearlong study, Carlsen (1993) examined influence of SMK on teachers' discourse in class. The participants were four novice biology teachers. By employing card sorting task, they determined in which topics participants feel adequate. Both high and low- ranked subjects that participants indicated were observed. Additionally, interviews including questions to understand which interests, hobbies, and other experiences in professional development program might support their SMK were carried out. The researchers observed each teacher for four hours two of which were for low-ranked subject and two for high-ranked one. Results showed that teachers had a tendency to ask low level questions when they were unfamiliar to the topic taught. Furthermore, they let learners more talk in class if they were knowledgeable about the topic. Another interesting result was the less knowledge teachers had about the topic, the more questions they asked to the learners. Despite these results, Carlsen concluded that the results did not tell that SMK effects classroom discourse due to differences in teachers' teaching activities in different topics and with different learners.

Similar to Carlsen (1993), Newton and Newton (2001) studied how SMK influences elementary teachers' classroom discourse. Researchers observed 50 teachers working in 17 different schools by the use of observation schedule including recording instruction, teachers asking, teachers telling, and non-oral provision parts. In the study, they focused on how much time teachers devoted on questioning and telling. Results showed that participant teachers spent much time on descriptive/factual questions that could be put under low-level questions category. Additionally, some of the participants had science background and some of them did not. So, they run t-test to compare and contrast those two groups' amount of oral discourse and amount of asking causal questions. Results showed that teachers with science background had much more oral discourse than those without science background ($t(48)=2.50$, $p= 0.02$, effect size= 0.73) and asked more casual questions during teaching ($t(48)=2.24$, $p= 0.03$, effect size= 0.65). In light of the results, researchers stated that content knowledge is not the only knowledge that a teacher should have, however, it is vital for fluent and effective teaching. Newton and Newton (2001) suggested that teachers should be informed about how to get necessary knowledge from reliable and valid sources, and how to use that piece of knowledge in their planning and teaching rather than loading all pieces of information to them.

To examine the influence of SMK in teaching, Rollnick et al., (2008) studied with three experienced teachers two of whom were working in high school and the other was working in an access program that provides help students to be ready for university science courses. In the high school context, they studied mole concept whereas researchers focused on the other teacher's teaching in chemical equilibrium topic. The data were gathered by using CoRe, PaP-eRs, interviews before and after teaching, observation, and field notes. In the study, participants did not fill the COREs, however, researchers filled them with the information gathered from other data sources. In the first case study, both teachers started with the conceptual part of mole concept and they continued with the calculation part of the topic. However, teachers did not stress the conceptual understanding of the mole concept. Rather, they focused on calculations because of the external exam system which includes algorithmic questions. Furthermore, neither of the teachers provided the relation between the conceptual and calculation part. Researchers stated that teachers' shallow understanding of the topic might make the relation difficult for teachers. In addition to that, interviews during which questions related to SMK were asked to participants, they realized that teachers had limited SMK in the mole concept. One of the participants acknowledged that her SMK in the topic was inadequate; however, the more she learned about the mole concept through her career, the more she focused on how to teach the topic effectively. The case study in the access program context, the participant had strong SMK in chemical equilibrium topic, deep understanding of curricular saliency which is related to sequence and relation of the topic in the curriculum, and rich knowledge of learners due to his experience in teaching. The teacher could achieve the transformation of SMK to knowledge for teaching by amalgamation of knowledge of learner and context. In other words, results revealed the vital role of SMK for developing rich and deep PCK because teachers with limited PCK taught algorithms whereas teacher with strong PCK stressed the conceptual part of the topic and used different strategies in a flexible way such as “extreme case reasoning” for K_c, equilibrium constant. Finally, although the SMK of participants influenced their teaching, researchers took notice on the context in which teachers teach. So, they thought that only focusing on development of SMK is not a realistic idea, therefore, they also suggested to make the school and classroom context better. In my opinion, in addition to SMK, topic-specific and context-specific nature of PCK may also explain the differences between studied cases.

From the research studies mentioned in this section, we could reach several conclusions. For example, when teachers’ SMK is weak, planning, using terminology, making changes in the flow, enacting learner-centered activities, and letting learners talk in the class are very demanding for teachers (Carlsen, 1993; Ingber, 2009; Sanders et al., 1993). Similarly, they had a tendency to ask low-level questions (Carlsen, 1993; Newton & Newton, 2001), and not to relate algorithmic and conceptual parts of the topics (Rollnick et al., 2008). However, robust SMK does not entail the solid PCK. Ingber (2009) observed teachers in different topics in which they had good and weak SMK. However, teachers’ use of instructional strategies was the same for both topics, which contradicts to topic-specific nature of PCK.

2.4. Research on In-service Science Teachers’ Topic-specific PCK

In this part, studies that specifically focused on in-service teachers’ topic-specific PCK in science area were summarized. Many studies investigated pre-service science teachers’ PCK and PCK development in the literature. Due to the fact that pre-service teachers have little experience in real classroom context, their PCK is not robust (van Driel et al., 1998) Although teaching experience does not guarantee for rich PCK (Friedrichsen, Lankford, Brown, Pareja, Volkmann, & Abell, 2007) research has showed that teaching experience is one of the important sources of PCK development (Grossman, 1990; Shulman, 1987). Therefore, studies only conducted with in-service teachers were summarized in this part.

Berg and Brouwer (1991) examined 20 high school physics teachers' knowledge of students' misconceptions and knowledge of instructional strategies to eliminate them in rotational motion and gravity topic. The data were collected through the interviews. Results revealed that teachers were not aware of learners' common misconceptions in rotational motion and gravity topic; moreover, they thought that most of the learners could answer the questions asked correctly. For example, only one of the 20 teachers was aware that students think that due to lack of air on the moon, there is no gravity there. Although it was a very widespread misconception, they did not mention it during interviews. When teachers were asked about the teaching strategies they used during teaching the topic, they stated that they employed expository, demonstration, analogies and questioning-discussion. Most of the teachers preferred to utilize expository teaching and analogies that are very brief. Additionally, discussion and questioning were used by less than 10 % of participant teachers. Three of teachers stated that they would focus on misconception held by learners. Generally, teachers were oblivious of the conceptual change strategies to address them. Similarly, their suggestions for addressing misconceptions also indicated that the instructional strategies implemented were not helpful for students to have conceptual change because they did not provide any dissatisfaction with the existing conceptions. Rather, teachers insisted on the scientifically accepted knowledge. The final point was that the unawareness of participant teachers about the research on learners' conceptions.

Although their focus was two student teachers' PCK on isotopes**,** Geddis et al., (1993) also provided an experienced chemistry teacher's PCK on the topic. Both student teachers had faced with an unexpected difficulty when teaching isotopes. They only focused on the content delivered. They did not take into account that learners had prior knowledge about average concept; however, they did not know weighted average necessary for learning calculation of average atomic mass.

Therefore, students could not understand the topic meaningfully. On the contrary, the cooperating teacher with 20-year experience in teaching chemistry employed a strategy which aimed to introduce weighted average concept to the students. The researchers attributed the difference to teachers' level of *curriculum saliency* that is being knowledgeable about when the topics should be taught and how topics are related to each other (Rollnick et al., 2008) and to their choices in use of alternative representation of SMK. The student teachers preferred to use representations close to scientific one whereas experienced teacher preferred to use representations which could be understood easily by learners. They concluded that the point beginning teachers need is thinking pedagogically which necessitates considering about learners and context rather than simply focusing on how to deliver it.

In some of the topic-specific PCK studies, researchers examined the changes in participants' PCK throughout workshops. For instance, Clermont, Krajcik, and Borko (1993) focused on the influence of a two-week workshop about demonstrations on eight in-service teachers' PCK in density and air-pressure. Data were gathered by using clinical interviews before and after the workshop. The workshop included two basic parts that were theoretical and application part. After providing information about demonstrations, three different application parts which were demonstrations conducted by instructors, by participants to the group and by participants to middle school children were carried out. Result showed that although teachers could suggest only one demonstration, if any, before the workshop, they increased the number of effective demonstrations to three or four at the end of the workshop. Furthermore, they started to make modifications on provided demonstrations to make them more meaningful. Additionally, participants' awareness about the relatedness of complexity of demonstration with students' learning increased. Another increase was observed in teachers' awareness about the benefit of inquiry use during demonstrations. However, there was no change in recognizing what teachers should do during demonstration. They concluded that teachers' PCK could be broadened by participating workshops. However, in some points no difference was observed, which was attributed to the complex nature of PCK construct.

Another study including in-service teachers was conducted by Magnusson, et al., (1994). It focused on teachers' SMK, knowledge of learner, and how teacher stress the difference between heat and temperature concepts in teaching. Data were gathered by using semi-structured interviews during which participants were asked to answer open-ended tasks used to measure teachers' knowledge of learner and problem solving tasks to measure their SMK. Results showed that some of the teachers had some misconceptions in heat energy and temperature topic. Additionally, although participants were generally aware of learners' misconception in heat energy and temperature topic, they were weak in questioning why students think so. Finally, though the difference between heat energy and temperature is important point, teachers generally preferred not to stress the difference in their activities rather they focused on either heat energy or temperature separately. Similarly, Van Driel et al., (1998) examined the influence of a workshop on 12 in-service chemistry teachers with more than five-year chemistry teaching experience. Specifically, the study focused on learners' misconceptions and difficulties in chemical equilibrium topic and employing different strategies and techniques to help learners understand the topic. After the first part of the workshop during which they discussed possible misconceptions, difficulties of learners' in chemical equilibrium, and how to remedy them, teachers taught the topic in their classes with help of the course plan provided by researchers. Then they came together and reflected on the participants' experiences. Before teaching the topic in their classes, teachers' argumentations did not include learners' view whereas after teaching, they focused on students' reasoning in learning dynamic nature of equilibrium. Moreover, they produced more analogies for the dynamic nature of equilibrium after the workshop to help learners understand the point. Additionally, teachers used molecular level to help learners understand the dynamic nature of equilibrium. Researchers concluded that the workshop was useful for teachers in enriching their knowledge of learner and knowledge of instructional strategies in chemical equilibrium.

Similar to Clermont et al., (1993) and Van Driel et al (1998), to examine how teachers reflect the training about acid and base chemistry to their classes, Drechsler and van Driel (2008) studied with nine experienced teachers. Two years before the study, they provided training about learners' difficulties and use of models in acid-base, and electrochemistry. Then, they focused on teachers' knowledge of students' difficulties in acid-base chemistry, whether they use models during teaching acid-base topic, and how their satisfaction with teaching the topic has changed during their career. However, they did not observe the participants' classes so whether the teachers really use them or not is unknown. Teachers stated three basic categories that were difficulties in calculations, in writing and meaning of reaction equations, and in understanding bases topic. Related to the use of models, six teachers used them whereas three of them did not use because they explained that using different models in this topic makes it more difficult for students to learn the topic. However, five teachers believed that students could understand the models used in acid-base or other topics of chemistry. For the changes in their teaching the topic, teachers modified the way of explaining the topic, algorithmic calculations used, and laboratory activities. The reason of these revisions were observing students' difficulties, sharing ideas with colleagues, research, and thinking critically about their teaching. For their satisfaction level, four categories that were completely increasing, completely decreasing, starting with a decrease then increasing, and starting with an increase then decreasing were determined. The reserachers stated that the differences in the level of satisfaction might be related to the support that teachers received from an expert of teaching and/or a reseracher in science teaching area. The more assistance teachers are given, the higher level of satisfaction teachers have. Finally, although participants were provided training on use of models, they stated that they need training how to use them in class.

Different than the other studies reviewed in this part, Veal and Kubasko (2003) compared geology and biology teachers' teaching the common topic that is evolution in both areas. They tried to answer why and how geology and biology pre-service and in-service teachers differ in teaching evolution that was included by the both subjects. Data were gathered through classroom observations, field notes, interviews and informal conversation with participants. Results showed that while geology teachers tend to tell evolution by relating it to rocks and earth, biology teachers used animate and life. Moreover, when they compared pre-service and in-service teachers,

they stated that pre-service teachers had a tendency to teach evolution more traditionally than in-service teachers, which could be attributed to inadequate knowledge of learner and of activities for teaching the topic.
In addition to high school chemistry and physics teachers' topic-specific PCK, undergraduate professors' topic-specific PCK was also examined. Padilla, Ponce-de-León, Rembado, and Garritz (2008) studied with four experienced undergraduate professors' PCK in the amount of substance topic. In the research they argued that the reason behind the difficulty in learning and teaching the topic may be related to paradigm that professors had. Therefore, the researchers tried to categorized professors' view by using data collected with CoRe. To analyze the CoRe data, Conceptual profile Model developed by Mortimer (1995, as cited in Padilla et al., 2008) was used. Five zones of conceptual profile, namely, perceptive/intuitive, empiricists, formalist, rationalist, and formal rationalist were described by the researchers. CoRe data were read and tried to be categorized. Then, they drew graphs showing how many times participants' answers to CoRe were labelled with in five zones. They calculated percentage of times that professors thought was coherent with a particular zone. Results revealed that two of the participants were at the two extremes of the zones. One of them used equivalentist paradigm which stresses mass and volume while teaching amount of substance, which shows she was in the empiricist zone. The other one had atomistic paradigm that focuses on sub-microscopic level and counting them, which indicates that she was in the formal rationalist zone. Other two professors were between these two extremes, however, their teaching was not categorized as one of the zones because they did not have a particular paradigm rather they almost applied all of the strategies described under all of the zones. Finally, they suggested the use of CoRe and Conceptual profile model as a new way of analyzing teachers' PCK and ideas and ways of thinking related to the topics that they taught.

Henze et al., (2008) studied nine experienced science teachers' PCK in 'Models of the Solar System and the Universe'. Although teachers were experienced, they did not have much experience in implementation of the new science curriculum. They studied PCK development; however, they focused on knowledge about instructional strategies, knowledge about students' understanding, knowledge about assessment of students; and knowledge about goals, and objectives of the topic in the curriculum. Semi-structured interviews were used to collect data. Interviews were conducted following three years. Data analysis showed that there were two types of PCK that participant teachers had. Type A focused on content of models whereas type B focused on the models and model development in science as well as model content. In type A PCK, knowledge of instructional strategy is at the center and is surrounded by other three components, namely, knowledge of students' understanding, assessment, and goals and objectives of the topic in the curriculum. There was a harmony between knowledge of goals and knowledge of instructional strategy. Additionally, learners' difficulties and understanding of the topic informed knowledge of instructional strategy. Another relation was between knowledge of assessment and knowledge of learners. Data gathered from exam papers help teachers update their knowledge of students. Finally, knowledge of instructional strategy and knowledge of assessment were also corresponding to each other. Teachers taught content of the model during instruction and assessed the content of it in the exam. Similar to type A PCK, there was a consistency between knowledge of goals and of instructional strategy in type B PCK. Specific to these types of PCK, the relation between knowledge of learner, of assessment and of instructional strategy was reciprocal. Both knowledge of instructional strategy and of assessment supported knowledge of learner. Similarly, development in knowledge of assessment was informed by both knowledge of instructional strategy and knowledge of learner. In both types of PCK, knowledge of goals did not change. Each type of PCK has its own development and interaction among the subcomponents. Authors argued that PCK development is influenced by PK and beliefs. The development of type A PCK may be explained by inadequate SMK and teachers' positivist view about the models. Correspondingly, adequate SMK, relativist and instrumentalist view of models can be attributed for development in type B PCK. Another remarkable result was that the amount of development in PCK components was not similar. For instance, although a substantial progress was noticed in instructional strategy, the progress of assessment strategies was little.

In her dissertation, Lankford (2010) elaborated six experienced biology teachers' PCK in diffusion and osmosis topic. Five of the participants had a constructivist orientation that underlines students' active role in learning and engagement with investigations to construct knowledge. However, one of them held a "*knowledge transmission orientation*", which made her use lectures and validation experiments in her teaching. When Lankford (2010) focused on the sources that influenced teachers' orientations, she realized that teachers' experience in teaching, interaction with colleague, participation in professional development activities were related to how to use *student-driven research*. Five teachers with constructivist orientation implemented implicit 5E instructional model in teaching diffusion and osmosis. Additionally, all participants preferred to teach diffusion before teaching osmosis. In terms of representations used, all participants were careful about use of them from simple to complex. So, they started with cellular level and then went on more complex representations of organs of plants. Teachers diagnosed the difficulties that students may have in use of terminology used to explain diffusion and osmosis, visualization of the events at molecular level, and determining direction of water movement in osmosis. Teachers attributed the second and the third one to students' inadequate chemistry knowledge. Four of the participants' knowledge of learners' difficulties informed their instructional decisions so they used animations showing diffusion and osmosis at molecular level. In terms of assessment, teachers had students tell their predictions before demonstrations and investigations, which formed a base for detecting students' prior knowledge. Moreover, taking learners' idea provided fruitful information to teachers for designing teaching and determining what they have learned until a particular point. With help of the data gathered through these strategies, teachers decided to implement analogies and animations to help students understand diffusion and osmosis. Finally, regarding to curriculum knowledge, their goals were determined by state standards, however, at some points (e.g., random molecular motion) teachers provided more knowledge than necessary. Teachers also made horizontal connections to prior topics taught to teach the topic in a better way.

Different than the other studies summarized above, Friedrichsen et al., (2007) studied PCK in Alternative Certification Program (ACP). To gain insights regarding participants' PCK for teaching genetic variations, data were collected through lesson preparation method and interview following the lesson preparation. Participants were two interns with no teaching experience and two science teachers with some experience in real classroom context. All PCK components were compared and contrasted between the two groups. Results showed that all participants' orientation to science teaching was didactic that focuses on the transmission of knowledge from teacher to students. In terms of knowledge of learners, although participants stated that students may bring some prior knowledge regarding genetic variations to the class, they could not specify them. When asked the sources of their knowledge of learner, interns mentioned own experience whereas the teachers referenced teaching experience in class. Another difference was observed in their knowledge of students' difficulties in learning the topic. Interns thought that learners would not have any difficulty; however, teachers stated that abstract nature of the topic makes it difficult to learn. When they focused on the instructional strategy component, researchers realized that both groups had the same instructional sequence including teacher-led discussions, lecture, and practice what was learned. Teachers used small groups during practice time whereas interns did not. One of the disappointing results was related to knowledge of assessment component which was a missing part in both groups' lesson plans. So, researchers asked directly how they assessed students' understanding. Interns stated that they would use summative assessment at the end while teachers preferred to do informal assessment during teaching. Regarding to how to use assessment results, both of them mentioned that they used it to see whether learners need re-explanation of the concepts. The major difference was observed in knowledge of curriculum. Interns almost lacked this type of knowledge and used textbooks as curriculum guide. On the contrary, teachers were knowledgeable about state and district standards. Finally, interplay between PCK components was focused. Interns' PCK lacked relation between components while teachers' PCK included interaction among the components to some extent.

To sum up the research studies in this section, topics have been studied are amount of substance (Padilla et al., 2008), rotational motion and gravity topic (Berg & Brouwer, 1991), isotopes (Geddis et al., 1993), heat and temperature (Magnusson et al., 1994), chemical equilibrium (Van Driel et al., 1998), density and air-pressure (Clermont et, al., 1993), acid-base chemistry (Drechsler & van Driel, 2008), and osmosis and diffusion (Lankford, 2010). These studies were conducted with undergraduate professors (Padilla et al., 2008), physics teachers, (Berg & Brouwer, 1991), chemistry teachers (Geddis et al., 1993; Van Driel et al., 1998; Drechsler & van Driel, 2008), and middle school teachers (Magnusson, et al., 1994).

Results showed that teachers may not be aware of learners' misconceptions and difficulties (Berg & Brouwer, 1991). Furthermore, they may have some of them (Magnusson et al., 1994). Even if they know which misconceptions that learners have, they may not be able to use appropriate instructional strategies to eliminate them (Berg & Brouwer, 1991). Teachers' knowledge accusation about what makes the topic hard for learners and which pre-requisite knowledge necessary for learning a new topic seem to develop through experience, which is labeled as *curricular saliency* (Geddis et al., 1993). In light of these, to accelerate the PCK growth, workshops and PDs are useful for teachers to enrich repertoire of activities (Clermont et al., 1993), analogies (Van Driel et al., 1998). Finally, the development level of PCK components (e.g. knowledge of assessment) may be different for a specific topic (Henze et al., 2008).

Research on teachers' PCK and topic-specific PCK also premises rich and valuable information regarding to how SMK influence teachers' PCK and how PCK components interplay. Although the results for interplays among the components and SMK-PCK relations were mentioned above when the studies focused on them, in order to make the conclusions about the interplay more obvious, in the next part, conclusions for interplays were presented.

2.4.1. Conclusions for Interplay among SMK, PCK, PK, and PCK Components

In the literature many studies mentioned how SMK and PK influence PCK, and how PCK components influence each other. Grossman (1990) stated that PCK has five components but the division of them is not clear in practice. Marks (1990) also stressed the incorporation of components with each other, which makes it hard to structure PCK. Similar to Grossman (1990), Marks highlighted the blurry line between components. In their model, Cochran et al., (1991) viewed PCKg as combination of knowledge of environmental context, knowledge of pedagogy, knowledge of students and knowledge of subject matter. "…theoretically, the four components become so integrated and interrelated that they no longer can be considered separate knowledges" (Cochran et al., 1991, p.12). Likewise, Magnusson et al., (1999) stressed the importance of viewing the PCK as a whole.
In addition to components forming PCK, Fernandez-Balboa and Stiehl (1995) also paid attention how those components are related to each other. To be a successful teacher, the interplay among the components of PCK is essential. In other words, separate entities of components does not result in good teaching, therefore, PCK components should be employed simultaneously when it is necessary. In addition to that, the interplay existing between the components is not *linear* rather different integrations are possible for a specific situation. Similarly, Magnusson et al., (1999) thought that relations between the components of PCK are very important. They said that for being an effective teacher, having a solid knowledge of one component is not adequate. Moreover, there is a multifaceted relation between the components of PCK, which makes focusing on the relation and its influence on teaching valuable to the PCK field.

In some of the studies scholars focused on how SMK influence teachers' practice. Sanders et al., (1993) examined three experienced secondary science teachers' planning, teaching and reflecting in two fields of science one of which was their major and the other was not. The richer SMK teachers have, the less time that teachers spent on planning. Moreover, it was more difficult for teachers to find out the key concepts, activities, how to teach, and what learning goals should be attained in the area which they have less SMK. Similar to SMK, their PK was also deficient in the area of outside of certification. Teachers also felt inadequate especially about learners' difficulties and misconceptions. Correspondingly, Carlsen (1993) studied teachers' teaching in familiar and unfamiliar topics. The more teachers are knowledgeable about the topics, the higher level questions they asked and the more teachers let learners more talk in class. In a similar type of research, Ingber (2009) examined six science teachers' PCK in planning in and outside of their area of expertise. Results showed the stronger SMK teachers have, the better they use the terminology. They could relate more concepts in their area than they did outside of their expertise. Similarly, they were more knowledgeable about the resources necessary for enriching SMK and teaching when they planned for a unit in the area of expertise than they did it for a unit outside of the expertise. In another comparison study Newton and Newton (2001) focused on how SMK influences elementary teachers' classroom discourse. Similar to Carlsen (1993), they also noticed that teachers spent much time on descriptive/factual questions that could be put under low-level questions category when they had inadequate SMK. Moreover, teachers with science background had much more oral discourse than those without science background ($t(48)=2.50$, $p= 0.02$, effect size= 0.73) and asked more casual questions during teaching ($t(48)=2.24$, $p= 0.03$, effect size= 0.65). In addition to that, Rollnick et al., (2008) studied with experienced teachers' teaching in mole concept. They stated that teachers' inadequate understanding of the topic might make the relation between calculations and conceptual parts of the topic difficult for teachers. On the contrary, when they have robust PCK for teaching a particular topic, teachers could achieve the transformation of SMK to knowledge for teaching by amalgamation of knowledge of learner and context. In other words, teachers with limited PCK taught algorithms whereas teacher with strong PCK stressed the conceptual part of the topic and used different strategies in a flexible way.

In some of the research, the relation among PCK components was also studied. Padilla et al., (2008) indicated how instructors with different orientations to science teaching teach the same topic in different ways. For instance, one of the participants had atomistic paradigm that focuses on sub-microscopic level. His/her teaching was based on the particulate level. Different than Padilla et al., (2008), Henze et al., (2008) dig into different types of PCK including different types of interactions of components. In type A PCK, there was synchronization between knowledge of goals and knowledge of instructional strategy. Namely, teachers focused on content so they used videos to help learners learn the content of the Solar system and universe. Another relation was between knowledge of assessment and knowledge of learners. Data gathered from exam papers help teachers update their knowledge of students. Finally, knowledge of instructional strategy and knowledge of assessment were also corresponding to each other. Teachers taught content of the model during instruction and assessed the content of it in the exam. Similar interplays were observed between knowledge of goals and of instructional strategy in type B PCK. The interplay between knowledge of learner, of assessment and of instructional strategy was reciprocal. Both knowledge of instructional strategy and of assessment informed teachers about the possible difficulties that learners may have. Furthermore, the more developed knowledge of instructional strategy and learner that teacher possess, the better assessment was done by teachers. Henze et al., (2008) stated that each type of PCK has its own development and interaction among the subcomponents. Finally, Friedrichsen et al., (2007) revealed that intern teachers' PCK lacked relation between components while teachers' PCK included interaction among the components to some extent.

To sum up, SMK is essential for rich PCK, high-quality planning, asking higher-level questions, allowing learners to contribute class, and focusing on learners' difficulties. Moreover, robust SMK is necessary for making available the content to learners. In addition to knowledge domains (e.g. SMK), PCK components inform each other. The interplay among the components makes it possible to learn at which points learners may have problems and/or which strategies should be used to solve the difficulties. For instance, the knowledge gathered from exam papers enriches teachers' knowledge of learners' possible misconceptions. Furthermore, the development of PCK may be different for different teachers with diverse orientations to science teaching. Additionally, different types of PCK may contain varying interplays among the components.

In the sections above, research studies in the international area were discussed. Now, PCK research conducted in Turkey context will be reviewed. Due to context-depended nature of PCK, examination of Turkish PCK studies is important because they are supposed provide information about teachers' PCK in Turkey and how context influences teachers' PCK.

2.5. PCK Studies in Turkey

PCK has been an extensively studied construct in Turkey especially in the last years (Aydın & Boz, 2012). In this part of the literature review, studies conducted in Turkey were gone over. Contrary to international studies, Turkish researchers carried out the research mostly with pre-service teachers. Therefore, different than the previous sections focusing on in-service teachers, literature about pre-service teachers' PCK had to be presented here. When studies done in Turkey were reviewed, I realized that these studies can be categorized into four groups, namely, studies focusing on some of PCK components, studies conducted in different contexts (e.g. professional development program or science teaching method course, etc.), studies elaborating PCK-SMK relation, and studies focusing on PK.

In a pivotal study, Nakiboğlu and Karakoç (2005) introduced PCK construct and provided important implications for teacher education programs. They criticized a point that in Turkey PK and SMK were seen as basic domains for teaching. However, PCK was not viewed as a knowledge domain that a teacher should have. With the influence of international literature, recently PCK has been an important aspect of teacher education in Turkey. Nakiboğlu and Karakoç (2005) stressed the importance of teacher education programs in teachers' construction of PCK. Therefore, they highlighted that teacher education programs should be designed in a way that support teachers to develop rich PCK. Although those programs include science teaching method courses, the courses may not provide rich experiences to pre-service teachers to develop PCK. Therefore, content of the method courses should be enriched with different activities that provide a chance to mix content and pedagogy. Another important point that they mentioned was that at which points of teacher education programs courses to build up PCK should be offered. In addition to pre-service teacher education, they drew attention to permanent in-service training. When they graduate, pre-service teachers do not have rich PCK, therefore, to support PCK development, in-service training was suggested.

When I examined Turkish PCK studies, I realized that some of them focused on one or two components of PCK rather than examining PCK as a whole, focusing on SMK-PCK relations, and focusing on PCK development in PD or pre-service education. Therefore, it would be better to organize the review under sub-parts. In the next part, they will be provided.

2.5.1. Studies Focusing on some of PCK Components.

Boz and Boz (2008) studied pre-service teachers' knowledge of instructional strategy and sources of it. 22 pre-service chemistry teachers were provided a vignette with a teacher who would teach 'particulate nature of matter (PNM)' after teaching 'matter' topic. Participants were asked how they would teach PNM, if they had been that teacher. In light of the participants' answer to that question, researchers selected four of them who had different ideas for the case study. Those four pre-service teachers were requested to prepare a detailed lesson plan. Finally, they were interviewed with help of the lesson plan they prepared. Pre-service teachers favored the use of traditional teaching method, animations, and hands-on activities in the introduction of PNM. Two of them stated that they would implement animations and hands-on activities because they knew that learners had difficulty in understanding empty space between particles. In other words, knowledge of learner informed their choice for instructional strategy. In addition to that, PK notified them in terms of making the topic more concrete to learners and learners may have different learning styles, therefore, they preferred to implement a particular instructional strategy. Another source was participants' beliefs about the instructional strategies. One of the participants stated that if s/he used animations, learners would not take him serious. Researchers concluded that similar to Shulman's (1986) amalgamation analogy, participants mix different types of knowledge to make decisions for use of instructional strategy.

Similarly, Uşak (2009) studied six pre-service science and technology teachers' PCK in cell topic. Although it was not specified, the study is a qualitative case study for which data were collected by lesson plans, lab reports, interviews after teaching, and concept maps. Results showed that pre-service teachers' plans were not parallel with suggestions of Ministry of Education in terms of time spent on the cell topic. Additionally, all participants except one stated that they would use teacher-centered methods, cookbook-type laboratory activities, and traditional assessment strategies to gauge learners' understanding. Only one of the participants planned to implement open-ended laboratory activity and alternative assessment strategies (e.g. performance evaluation).

In another study, Aydın, Boz, and Boz (2010) focused on factors influencing pre-service chemistry teachers' choice of instructional strategy in 'separation of mixtures' topic. Data were gathered through lesson plans, observation of participants' teaching in cooperative high school, and semi-structured interview after teaching. All of the six participants stressed the influence of mentor teacher in the high school in their choice. Even they had to abandon use of instructional strategy that they want to implement because of mentor's restrain. Second, pre-service teachers mentioned the effect of the topic taught, which is parallel to PCK literature that stresses the topic-specific nature of PCK construct. Pedagogical knowledge was another factor that influenced their choice. Due to the fact that they want to make the topic more concrete and to attract learners' attention, they implemented hands-on activities. Yet another aspect had an influence on them was class time which limited their use of student-centered methods. Participants also indicated SMK manipulated their choice. Participants with solid SMK were keen to use discussion and conceptual change strategy whereas those with deficient SMK were reluctant to use them due to possibility of extra questions that learners may ask. Finally, classroom management had an impact on them. Pre-service teachers implemented traditional method, teacher demonstration, discussion, and questioning strategies. However, participants, except one, did not prefer to use learning cycle, inquiry, or conceptual change strategies which were taught in teaching methods course. Additionally, with the exception of two pre-service teachers, they were not aware of learners' possible misconceptions and/or difficulties in the topic. To conclude, researchers stated that pre-service teachers had a difficulty in implementation of student-centered teaching strategies. Although they were in the last semester of the teacher education program, they were unwilling to use different teaching strategies to help learners construct the knowledge. Due to inadequate SMK, they had a preference for teacher-centered methods. Therefore, Aydın et al. (2010) suggested that mentor selection be made more carefully for internship. They should be a good role model for preservice teachers in terms of implementation of alternative teaching methods. Moreover, similar to van Driel et al. (1998), workshops should be organized for pre-service teachers to enrich their PCK.

Finally, Uşak, Özden, and Eilks (2011) analyzed 30 pre-service elementary science teachers' PCK and SMK in chemical reactions unit. In this case study, knowledge of learner, instructional strategy, and assessment subcategories were studied. SMK was assessed by the use of multiple-choice test including the written part for the reason of participants' answer. To assess PCK, by the use of interviews eight participants' PCK was assessed. Similar to other studies conducted with pre-service teachers (Aydın et al., 2009; Özdemir, 2006; Çekbaş, 2008), results indicated the pre-service teachers' inadequate SMK in chemical reactions unit. Pre-service teachers had big problems especially in understanding limiting agent and stoichiometry topics. Pre-service teachers' explanations for the reasons of their answers showed that they did not have conceptual understanding of chemical reactions. In terms of PCK, first, they were not aware of learners' difficulties in chemical reactions. Only one participant could provide learners' possible difficulties and explain reason of them. Pre-service teachers stated that they generally would teach the unit through didactic teaching whereas one of them planned to use concept map to teach it. Similarly, only one participant planned to implement alternative assessment methods suggested in the curriculum whereas others would prefer traditional paper-pencil test including multiple-choice questions.

Research on pre- and in-service teachers' were studied in varying context (e.g. during PD activities, teaching experience course, etc.) In the following sub-part, they would be provided.

2.5.2. Studies Conducted in Different Contexts

Tekin (2006) studied with 56 senior pre-service teachers' PCK in the context of science teaching method course. Through the semester, participants prepared lesson plans and taught them in the course. The researcher observed their teaching with the use of observation form including points related to instructional materials, instructional strategy, questions asked by pre-service teacher, and handling with students' needs. Moreover, participants were asked to write about the critical evaluation of their own teaching, the contribution of previous courses and science teaching method course on their teaching. Results showed that pre-service teachers were adequate in terms of SMK, however, they had difficulty in providing SMK that is suitable to students' level. Only 30 % of them could teach by relating the topic to other topics. In terms of making students active, 14 % of pre-service teachers could achieve it. Regarding to questions asked during teaching, 36% of them were questions that help learners to inquire. Finally, pre-service teachers stated the positive influence of science teaching method course on their teaching development. Teaching and preparation for teaching, and observing peers' teaching helped them to develop high self-efficacy in teaching. So, Tekin (2006) suggested the integration of teaching part into science teaching method courses to develop PCK and high self-efficacy in teaching.

In another study, Aydın, Demirdöğen, Tarkın, and Uzuntiryaki (2009) studied development of pre-service teachers' SMK and knowledge of learner, and knowledge of instructional strategy in the context of an elective course named "High School Chemistry Curriculum Review". In the case study, data were collected through pre- and post administration of SMK test and reflection papers written at the beginning, during and at the end of the course. In the course, after introducing the concepts, researchers discussed the related concepts and daily-life events each week.

Regarding to PCK, high school students' possible misconceptions and difficulties related to the topic of the week, and how pre-service teachers can handle them were discussed. Moreover, researchers checked whether pre-service teachers have the similar misconceptions indicated in the literature each week. Finally, researchers started to topic of the week with a conceptual question, a daily-life event, or demonstration. Wilcoxon t- test results showed that post-test results were significantly higher than pre-test results ($Z=-2.38$, $p < .018$). Similar to high school students, pre-service teachers had some misconceptions and difficulties indicated in the related literature. For instance, they thought that particles of matter have the same properties that matter in the macroscopic level has. Lots of misconceptions detected in the literature were faced with in the pre-test. Although many of them were eliminated in the post-test, some of them were resistant to change. It was also interesting that pre-service teachers stated that they were aware of their own misconceptions in the reflection papers. Regarding to PCK, participants indicated the enrichment and awareness of their knowledge of students' misconceptions and difficulties. To eliminate misconceptions, pre-service teachers stated that they would use demonstrations and analogies whereas they did not think to use conceptual change and/or learning cycle. Finally, regarding to course, they indicated that it was so useful for them to experience how chemistry teaching can be done learner-centered, conceptual, and activity-based. Therefore, the researchers suggested the integration of this type of courses to the teacher education programs.

Similarly, Nakiboğlu, Karakoç, and de Jong (2010) analyzed nine pre-service chemistry teachers' PCK development in teaching experience course context. Participants prepared two lesson plans for two hours teaching of electrochemistry topic at the beginning and at the end of the course. Nakiboğlu et al., (2010) focused on two PCK components that were knowledge of learners and instructional strategy. In the first lesson plan, five of the participants planned to use student-centered instructional strategies (e.g. inquiry, learning-cycle, etc.). Other four participants preferred to use traditional, teacher-centered teaching. When prompted, the former group related to their choice to pedagogy courses whereas the latter related to observations of traditional teachers during internship. It was interesting that four of the five pre-service teachers who planned learner-centered teaching at the beginning of the course, changed their plan at the end of the course and prepared a teacher-centered one. When asked, they stated with help of the observations in cooperative high school, they realized that traditional teaching method was more effective than others so they preferred it. In terms of implementation of activities, four of five participants, learner-centered group, gave up to use them in the second lesson plan whereas in the second group, two of them planned to use teacher-centered activity in the second lesson plan. Activities planned to use were taken from textbooks. Similarly, participants' use of representation decreased through the end of the course. Second, pre-service teachers were unaware of learners' misconceptions related to the topic and sometimes they ignored them. Only one of the participants mentioned possible misconceptions in the second lesson plan due to a course that s/he was taking in that semester. It was unfortunate that pre-service teachers' experience in real classroom context could not inform them regarding to learners' misconceptions through the semester. Researchers stated that teaching experience courses had a negative influence on pre-service teachers' implementation of instructional strategies, activities, and representations. Moreover, they stressed the disparity regarding to preference of instructional strategy by teacher preparation programs and high schools. Due to negative impact of mentors in cooperating high schools on pre-service teachers, mentors should be trained about how to implement learner-centered strategies.

Similar to Nakiboğlu et al., (2010), Mıhladız and Timur (2011) studied in the context of teaching practice course. The focus of the study was intern pre-service teachers' view of mentor teachers' SMK, PK, and PCK. The data were collected from ten pre-service elementary science teachers by the use of focus group interview. Most of the participants thought that mentors were inadequate in terms of SMK. They also found themselves inadequate in terms of SMK. They stated that SMK is the pre-requisite for being an effective teacher. Regarding to PCK components, three participants indicated that the mentors with whom they observed implemented different instructional strategies. However, others stated that mentors taught in a didactic way and did not use technological devices and laboratory facilities. In terms of curriculum knowledge, pre-service teachers provided that some of the mentors precisely followed a textbook and did not use any other activity. In addition to that, mentors did not follow the new curriculum; however, they focused on the topics asked in exams for entrance to high school, which had influence to their teaching as well. Due to exam style, multiple-choice test, teachers had a tendency to perform exercises as much as possible. Mentors generally used traditional assessment strategies (e.g. tests) and just focused on grading. However, some of them had a chance to observe mentors implementing alternative assessment strategies and providing feedback about learners' development. Finally, in terms of PK, participants stated that mentors were strict more than necessary, did not attract learners' attention to the topic, and did not have eye-contact with learners.

Different from the previous research, Çoruhlu and Çepni (2010) focused on six in-service teachers' assessment knowledge in the context of in-service training. In this case study, data were collected through PCK achievement test, attitude scale, and semi-structured interviews with participants. The PCK achievement test including five open-ended and 13 multiple-choice questions was administered as pre and post-test. Similar to PCK test, attitude toward in-service training scale was administered at the beginning and at the end of the training. Finally, during the semi-structured interviews conducted at the end of the training participants were asked about contribution of training and the effect of it on their attitude. Results showed that post-test results of PCK test were statistically higher than those of pre-test results ($z=2.20$, $p<.05$). However, though participants' attitude toward training increased during the course of training, the difference was not statistically significant ($r=0.722$, $p>.05$). In the interviews, participant teachers stated that they learned about alternative assessment strategies, especially they were trained both theoretically and practically about how to prepare rubric, about philosophy of the new curriculum, and about structure of the new curriculum. Finally, researchers stated that teachers had difficulties in implementation of alternative assessment techniques suggested by the new curriculum. Therefore, they have a tendency not to use them in their classrooms. Trainings providing implementation of those techniques both theoretically and practically to teachers are hoped to increase teachers' use of alternative assessment techniques.

In additions to studies focusing on some of PCK components, and conducted in different contexts, in Turkish PCK literature, some studies focused on PCK-SMK and PCK-PK relations.

2.5.3. Studies Elaborating PCK-SMK Relation

Uşak (2005) studied four senior pre-service elementary science teachers' PCK and SMK in flowering plant topic. In the case study, data sources were audiotaped teaching practices, lesson plans, word association task, interviews, concept maps, and written documents. Pre-service teachers' SMK was assessed with open-ended questions. With help of the concepts maps, participants' conception and curricular knowledge was examined. The conceptual network that participants had in their mind was studied with word association task. Moreover, each pre-service teacher was observed about three or four times. Finally, three semi-structured interviews regarding to nature of teaching, PCK, and SMK were conducted. Results showed that, in terms of SMK, senior pre-service teachers still had misconceptions about flowering plants. Moreover, they could not discriminate concepts from each other. One of the interesting points regarding to SMK was that although they could answer the questions in written format, they had difficulty in drawings and explaining on them. In other words, participants' knowledge of representations sub-component was inadequate. Similarly, their knowledge of learner was deficient. Moreover, even if they had some idea about learners' difficulties and/or misconceptions, it was observed that they could not use them in their teaching. Regarding to curricular knowledge, they put different emphasis on different objectives in the curriculum. Additionally, some of the objectives were ignored. Pre-service teachers preferred to use analogies, models, and simulations in their teaching. They stated that they made learners active during teaching and made abstract points concrete; however, the researcher pointed that their teaching was not student-centered as they had indicated. Finally, pre-service teachers used traditional assessment techniques to assess students' learning. Although it was not explained in the study, it was concluded that SMK-PCK relation was depend to the participants. When I examined the results, it seemed that the richer SMK pre-service teachers have, the better use of analogy in teaching the use in teaching flowering plants and the better focus on the objectives stated in the curriculum.

In another study, Özden (2008) studied the relation between SMK and PCK of 28 pre-service elementary science teachers. Data sources were SMK test, lesson-preparation method, and interviews. Results showed that pre-service teachers' SMK was insufficient in 'phases of matter' topic. They had difficulties in discriminating heat and temperature, factors influencing vapor pressure, and expansion with the effect of temperature. Regarding PCK components, 21 participants were aware of learners' possible misconceptions and difficulties related to the topic. They thought that due to the fact that learners are unable to think at particulate level, they had difficulties in learning the topic. Regarding to instructional strategy, the most popular one was experiment. In addition to that, pre-service teachers planned to use drama, group work, and educational games. Researchers also examined participants' teaching approach. Most of them had a constructivist approach whereas some of them had some aspects of both traditional and constructivist approach. Yet another point that Özden (2008) focused on was the difficulties that pre-service teaches had during lesson plan. He categorized those under four groups: (1) inadequate knowledge of learners' difficulties, (2) Inadequate SMK, (3) unable to motivate students and to attract their attention, (4) classroom management. Finally, Özden (2008) also determined at which points pre-service teachers need support. 15 of the participants stated that they need support related to learners' difficulties and implementation of instructional strategies. Six of them mentioned their need related to introduction of new Science and Technology program. Finally, three participants called for SMK support. Although the researcher did not compare and contrast pre-service teachers' PCK for high SMK and low SMK group, it was stated that in order to develop rich PCK, SMK is essential.

Similar to Özden (2008), the relation between SMK and PCK was examined by Cambazoğlu, Demirelli, and Kavak (2010) in PNM topic. In this case study, pre-service elementary science teachers' SMK was measured by the use of a test including questions related to PNM. Participants with different amount of SMK were selected in light of the SMK test results. Moreover, lesson plan, observation, and semi-structured interviews were used in order to gather data. Results showed that pre-service teachers neglected particles' movement in different states of matter because they did not have enough SMK related to it. Researchers stated that although movement of the particles was included in the curriculum, pre-service teachers ignored the objective. In the chemical and physical change sub-topic, pre-service teachers knowing that matter loses its chemical properties in chemical change and new matter is formed stressed this point in their teaching. Moreover, they provided daily-life examples related to chemical and physical change to facilitate learners' conceptualization. However, participants who thought that chemical change is related to inside of matter could not answer learners' questions. So, they concluded that weak SMK made it difficult to teach for pre-service teachers to teach. Regarding to curriculum knowledge, participants generally did not have adequate knowledge of the objectives. Similarly, their instructional strategy repertoire was inadequate. They implemented traditional method, questioning, daily-life examples, and models to represent particles. Participants stated that they do not have enough knowledge to apply other instructional strategies. Correspondingly, they did not recognize learners' misconceptions. Researchers stated that it might associate with limited SMK because at some points pre-service teachers had similar misconceptions. Another point related to knowledge of learners was that pre-service teachers tried to indicate learners' misconceptions and difficulties with help of their own experience rather than that of related literature. Finally, pre-service teachers preferred to employ traditional assessment strategies. When prompted, they indicated that they did not have adequate amount knowledge to use alternative assessment strategies. Moreover, they said that they did not have any experience how to employ them during teacher education program. Cambazoğlu et al., (2010) recommended that pre-service teacher education programs offer courses related to learners' misconceptions and difficulties to pre-service teachers. The possible reasons of them and how to eliminate them should be discussed in those courses.

Different than the other studies, Kaya (2009) studied PCK and SMK relation and relationships among PCK components in quantitative study conducted with 216 pre-service elementary science teachers. A survey including open-ended questions was used to measure participants' SMK related to Ozone Layer Depletion. Participants were grouped under three groups, namely, appropriate, plausible, and naïve knowledge categories. From these three groups, 25 participants were selected randomly and were interviewed to measure their PCK. The data gathered both from interviews and the survey were graded with help of a rubric developed. In terms of SMK, more than half of the participants (126) had inadequate SMK. Only 20% of them had adequate SMK. In terms of PCK, 29 % of them were in the naïve group, 52 % was in the plausible group, and only 20% of them were in the appropriate group. In terms of PCK components, the most problematic one was knowledge of assessment. Analysis showed that there was a strong positive correlation between SMK and PCK ($r=0.77$, $p<.0001$) Moreover, SMK had a positive and significant correlation with all PCK components. Finally, there were moderate correlations between PCK components. However, knowledge of assessment did not have any significant correlation with other components. Kaya (2009) also provided details about the PCK of three SMK groups. First, participants with adequate SMK generally had adequate knowledge of curriculum, instructional strategy, and learner. In others words, participants with solid SMK had a tendency to have rich PCK. However, pre-service teachers had inadequate knowledge of assessment. Only 16% of the participants had adequate knowledge of assessment. Second, participants with plausible SMK also had plausible knowledge of PCK components. Similar to first group, this group had problems with assessment. They stated that they would use traditional assessment strategies with grading purpose. Finally, in the third group, pre-service teachers had naïve SMK and PCK. MANOVA was carried out and results showed that there was a statistically significant difference between those three groups with different levels of SMK ($F(10, 136) = 11.49$, $p < .001$; Wilks' Lambda = 0.29; $\eta^2 = 0.46$). Kaya (2009) discussed the possible reasons of problems that pre-service teachers faced with. He stated that experience that pre-service teachers had during teacher education program might influence them to think teaching and assessment as two separate aspects. Therefore, they were not able to use assessment to inform their teaching rather use it to grade. In addition to that, Kaya (2009) indicated that another possible reason may be inadequate stress of assessment in teacher education programs. It is tried to be taught through three-credit course. Therefore, he suggested courses in which different components of PCK are related to each other and pre-service teachers have a chance to apply those components altogether. Moreover, courses for SMK, PK, and PCK development are provided in different semesters through the program, which probably impedes PCK development of pre-service teachers. Therefore, it should be changed.

In another study, Özdemir (2006) focused on pre-service teachers' SMK in ecology, ecosystem, and matter cycle. To analyze their SMK, Özdemir used SMK test including 20 questions. Participants'' achievement was between 20 % and 93 %. The average was 62%. Results showed the inadequacy of pre-service teachers' SMK in those topics. The researcher discussed the possible reasons of the situation with the instructors of the related course. Instructors related the failure to pre-service teachers' lack of interest to the course. Another reason was that in the exam for teacher, questions are asked from pedagogical courses rather than from SMK courses. Therefore, pre-service teachers have a tendency to ignore SMK courses due to lack of questions from SMK courses in the exam. They just aim to pass the SMK courses whereas they focused on PK courses.

Similar to Özdemir (2006), Çekbaş (2008) studied pre-service teachers' SMK in basic physics topics (force, kinematic, Newton Laws, momentum, sound, electrostatic, magnetism, etc.). By the use of random sampling, researchers selected 227 pre-service teachers from population of 557 per-service teachers. The participants were at different levels of the teacher education program from freshmen to senior. The SMK test consisting of open-ended and multiple choice-questions was administered. Results showed that participants' achievement in the test decreased from freshmen to senior. In other words, mean of the seniors and juniors' means scores were much lower than those of freshmen and sophomores. In terms of high school graduation, the mean difference among pre-service teachers graduating from different high schools was very high at the freshmen year however; the difference was decreasing through senior year. Additionally, there was no significant difference between male and female pre-service teachers' achievement in the test. The researcher attributed the decrease in the achievement to not remembering them. Due to the fact they did not learn conceptually, the researcher stated that the results were quite expectable. In addition to that, the researcher also indicated the crowded classes and loaded curriculum of the program were also possible reasons of the situation.

2.5.4. Studies Focusing on PK

Another quantitative study was carried out by Kılınç and Salman (2009). They studied the SMK and PK development of 22 pre-service Biology teachers. Data were collected by the use of SMK test administered at the end of 7^{th} and 10^{th} semesters and PK test administered simultaneously with SMK test. Both tests included 30 multiple choice items. Researchers analyzed whether there was a statistically significant correlation between PK and SMK by the use of SMK and PK post test results. Results showed that there was no significant correlation between them ($r=0.165$, $p<0.05$). In terms of PK development, t-test results showed that post-test results were higher (M=15.82, SD= 2.75) than pre-test ones (M=12.23, SD=2,02) and the difference was significant (t(21)= -4,989, p=0.00). Similar to PK, pre-service teachers' SMK post-test mean score was significantly higher (M=15,54, SD=4,74) than pre-test mean score (M= 13, 64, SD=3,64) (t(21)=-3,630, p=0.002). Although both SMK and PK tests' post-test results were higher than pre-test results, when examined in detail, results showed that participants' both SMK and PK were low. They could answer about half of the questions asked in the tests. Kılınç and Salman (2009) aimed to examine pre-service teacher education program in Turkey. They tried to explain the increasing means of PK and SMK tests results with possible reasons such as taking science teaching method courses and participants' experience as a tutor. However, other factors may explain the results gathered, for instance, preparation for the exam to be a teacher in public schools. The researchers did not take pre-service teachers' and/or instructors' idea related to their experience in that program. In other words, external factors may contribute the results. Another point that is very important about the study was that although Kılınç and Salman (2009) studied PK and SMK, they stated that they focused on PCK and SMK. PK is general knowledge that is necessary for all teachers (e.g. classroom management) whereas PCK is specific to a field and /or a topic (e.g. students' difficulty in visualization of atomic models). In the study, although they used questions assessing PK, they viewed them as PCK test and PCK items.

Another construct correlated with PK was pre-service teachers' belief about teaching (Oskay, Erdem, & Yılmaz, 2009). Although they stated that they studied PCK, as in Kılınç and Salman (2009), Oskay et al., (2009) studied PK indeed. Teacher belief about teaching scale developed by Yılmaz-Tüzün (2008) and a PK test formed by the researchers from the previous questions asked in preparation exam to be a teacher in public schools. In the PK test, 30 multiple-choice items were related to teaching methods, assessment techniques, and classroom management. 73 % of the participants believed that they could implement inquiry in their class. The percentage was 59 and 44 for implementation of problem-based learning and conceptual change, respectively. However, only 11 % of the participants believed that they could use learning cycle. In terms of assessment, 62% of them stated that they would use tests to assess students' learning whereas 59% of them would use projects to assess. Regarding to classroom management, 63 % pre-service teachers stated that they could manage the problems occurring during group activities; however, only 36 % of them thought that they could solve the problems of handicapped students. The analysis of PK test, results showed that participants had problems in answering questions related to demonstration, discovery learning, portfolio, formative assessment, classroom testing, and classroom environment control. Finally, results showed that there was no significant correlation between PK and teachers' beliefs about teaching. Additionally there was no significant difference between female's and male's beliefs about teaching.

PCK has been studied since 1986 by many scholars. As a construct, it has some complexities that make studying on PCK tricky for researchers. Following part included which types of difficulties have been faced with by the researchers in the PCK literature.

2.6. Difficulties of Studying PCK

While reviewing the PCK literature, I realized that many researchers also mentioned how difficult to uncover teachers‘ PCK and some of the possible reasons of them. To make aware researchers who want to study PCK, and to give an idea about why and how hard to investigate it, I decided to mention them as well. However, it does not mean that PCK should not be studied. On the contrary, it should be focused on deeply and consciously. If researchers are aware of the intricacies, they can take cautions to handle with them.

Uncovering PCK is not as easy as it seems to be (Avraamidou & Zembal-Saul, 2005; Berry, Loughran, & van Driel, 2008; Park & Oliver, 2008). However, due to its difficulty, it has become more of an issue than ever (Berry et al., 2008). Avraamidou and Zembal-Saul (2005) attributed difficulties related to studying PCK to the nature of construct and measuring it. PCK has different components which have indistinct boundaries (Gess-Newsome, 1999; Loughran et al., 2004; Magnusson et al., 1999). Although separating the components of PCK in the models helps a lot in theory, during data analysis part, it is not that much easy to detect which part belongs to which components (Grossman, 1990; van Driel, Veal, & Janssen, 2001). Another difficulty is related to the time for necessary to capture PCK which necessitated much more than one hour (Loughran et al., 2004). To get teachers' PCK, much time should be spent with teachers. Furthermore, the lack of the sharing language between teachers and researchers makes the situation harder (Loughran et al., 2000). Teachers do not reason about their practice and knowledge because they focus on learners' scores and covering the curriculum (Loughran, Milroy, Berry, Gunstone, &Mulhall, 2001). Moreover, teachers' knowledge is implicit (Baxter & Lederman, 1999) because they lack reasoning tradition about why they implement specific activities or why they teach in a particular way. So, when teachers are asked about their teaching, they tell the reasons in their own language rather than citing PCK (Korthagen & Kessels, 1999). To illustrate, in the longitudinal project, Loughran et al., (2004) realized that participant teachers could not explain why they taught in a particular way by relating their teaching the students' learning.

2.7. Summary of the Literature Review

In light of the studies reviewed in this part, there were different models explaining PCK (Cochran et al., 1993; Grossman, 1990; Magnusson et al., 1999; Veal & MaKinster, 1999). Although there are some differences in terms of components, knowledge of learner and knowledge of representations of subject matter are commonly included by the PCK models.

Literature indicated that PCK is a topic-specific construct which is developed through experience in teaching (Abell, 2007; Grossman, 1990; van Driel, et al., 1998). Moreover, SMK is a must for solid PCK (Abell, 2007; van Driel et al,. 1998). Teaching experience is an essential source of teachers' PCK (Grossman, 1990; Shulman, 1987; van Driel et al,. 1998). However, experience may not always give rise to enhancement in PCK (Friedrichsen et al., 2007). When it is the case, workshops and professional development activities should be provided to teachers (Clermont., et al. 1993; Magnusson et al., 1994; Van Driel et al., 1998). Additionally, PCK should be viewed as whole rather than separate components. The reciprocal interaction of the components is an indication of robust PCK (Fernandez-Balboa & Stiehl, 1995; Magnusson et al., 1999; Marks, 1990; Veal & MaKinster, 1999). Due to the simultaneous use of different components, the line between components is not clear-cut (Grossmann, 1990; Marks, 1990; Fernandez-Balboa & Stiehl, 1995). Among the components, orientation to science teaching is the chief that manipulates the others (Grossman, 1990; Magnusson et al., 1999). Due to the fact that it forms the base for teaching, it is resistant to change (Volkmann et al., 2005). Finally, in addition to knowledge types those teachers have, teachers' self-efficacy, metacognition, attitude towards teaching may supply appealing information about

PCK; moreover, they may be the key to open the locked door of teachers' practical knowledge, PCK (Park & Oliver, 2008).

In terms of Turkey, researchers should conduct more study with in-service teachers, in different context (e.g. PDs, workshops, etc.). Moreover, studies should focus on PCK as a whole rather than examining one or two PCK components. Studies that will be conducted during curriculum reforms, orientation towards science teaching and its influence on other components, development of PCK through years, and finally, studies with induction year, the first year of teaching, seem to promise rich information to Turkish literature.

Due to the fact that there are different PCK models in the literature, the researcher have to select one or to form a hybrid model at the beginning of the study. Therefore, in the next sub-section, PCK conceptualization of the study was summarized.

2.8. PCK Conceptualization in this Research

In the conceptualization of the research, Magnusson et al.,'s transformative PCK model was adopted with help of the literature (Abell, 2007; Grossman, 1990; Magnusson et al., 1999) and the data collected. Although Magnusson et al., (1999) mentioned both knowledge and belief in their PCK model, as stated in the introduction part, only knowledge was focused on in this study. Moreover, I think that PCK is a new type of knowledge used during planning, enacting, and assessing. It is not a mixture of other knowledge. When trying to teach a topic to learners, a teacher reshapes and reorganizes SMK, PK, and other knowledge types, which makes them a new form of knowledge that is PCK. My experience with pre-service chemistry teachers showed me that although pre-service teachers have some SMK, PK, and other types of knowledge, they have difficulties during teaching because they cannot transform those into PCK, which is the reason why I decided to study with experienced teachers.

PCK model used in this study is modified version of Magnusson et al.'s model (Figure 11). As literature has said, although the boundaries between components are not clear, still having components in mind helped me prepare the instruments, collect, and analyze the data. In Magnusson et al.'s model, the PCK components have some sub-components. In this study, some more sub-components were added by following the other studies' suggestions. In figure 11, the sub-components written with larger fonts in red are added to the existent model. For instance, in Magnusson and her colleagues' model, knowledge of curriculum has two sub-components, namely, knowledge of goals and purposes, and knowledge of specific science curricula. In addition to those, knowledge about horizontal and vertical relations between the topics was added to curriculum component. The data collected informed me about the other sub-components, namely, horizontal and vertical relations to the other topics in the same discipline, and altering the sequence of the sub-topics in the curriculum. After realizing the additional sub-components, literature was checked whether any scholar mentioned them. Grossman (1990) mentioned the horizontal and vertical relations under knowledge of curriculum. Moreover, Friedrichsen et al., (2007) called the last sub-component as '*altering the curriculum'*. Furthermore, purpose of assessment was inserted to knowledge of assessment component. How to assess and what to assess sub-components were completed with the purpose of assessment 'why to assess'. In making this change, Friedrichsen et al., (2007) informed this research. Yet another modification was done in orientation component with help of Friedrichsen and Dana (2005), and Friedrichsen et al., (2011). In these studies, they stated that teachers may have more than one orientation; moreover, they focused on the central and peripheral goals of teachers' for teaching science at a specific grade. To sum up, as Lannin, Abell, Arbough, Chval, Friedrichsen, and Volkmann (2008) stated that PCK is more complicated than shown in Magnusson et al.'s (1999) model.

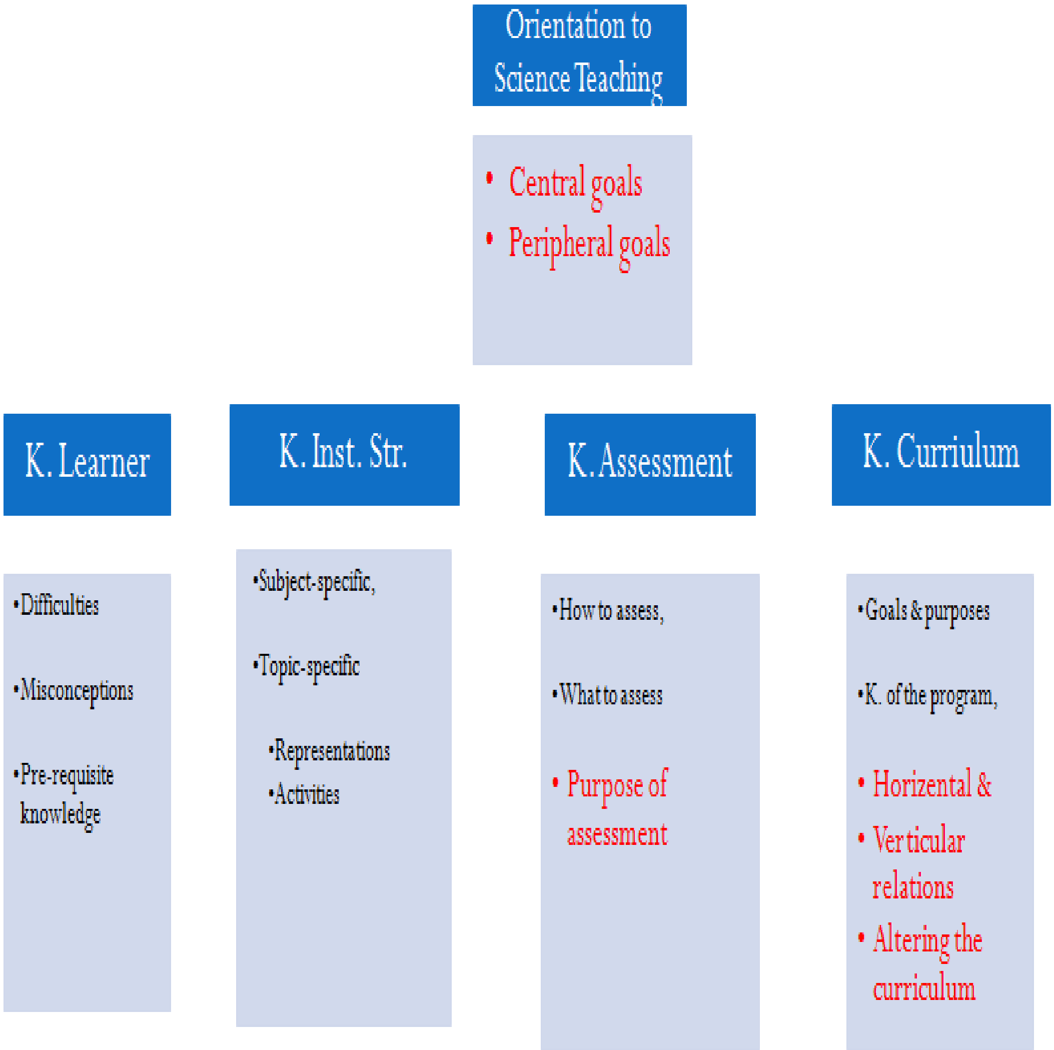


Figure 11. PCK conceptualization of the study: Modification of Magnusson et al.,'s PCK model

CHAPTER 3

METHODOLOGY

Although it has been more than 20 years after Shulman's introducing PCK to the literature, we have known little about PCK's nature and how its components interplay. Therefore, in order to be able to use PCK as a framework for examining teachers' knowledge, it is necessary to focus on PCK's nature and interplay among its components (Abell, 2008; Fernández-Balboa & Stiehl, 1995; Friedrichsen, et al., 2011). To fill the gap in the PCK literature, experienced teachers' PCK was examined qualitatively to get deep insight of topic-specific nature of PCK and interaction of PCK components.

3.1. Overarching Research Question

How is experienced high school chemistry teachers' PCK different and/or similar for teaching different topics within the same discipline?

3.1.1. Sub- Research Questions

1. What is the nature of experienced chemistry teachers' PCK for teaching electrochemistry and radioactivity topics?
   a. What is the nature of experienced chemistry teachers' knowledge of learner for teaching electrochemistry and radioactivity topics?
   b. What is the nature of experienced chemistry teachers' knowledge of instructional strategy for teaching electrochemistry and radioactivity topics?
   c. What is the nature of experienced chemistry teachers' knowledge of curriculum for teaching electrochemistry and radioactivity topics?

d. What is the nature of experienced chemistry teachers' knowledge of assessment for teaching electrochemistry and radioactivity topics?

2. How do PCK components interplay for teaching electrochemistry topic?

Because qualitative research has a power of providing detailed understanding of the phenomenon studied, qualitative inquiry was implemented in the study that seeks a closer look at teachers' PCK in different topics. All research processes that were sampling, data collection, data analysis, and interpretation of the data were guided by the nature of the qualitative inquiry. In this chapter, the method of inquiry was explained in detail. Moreover, information related to the participants, context, data collection process, data analysis, trustworthiness, and ethical issues were provided.

3.2. Research Design

Researchers sometimes desire to answer how questions rather than why questions or "to what extent" questions (Frankel & Wallen, 2006). At this point, qualitative research designs provide opportunity to explore and get insights about the phenomenon focused (Corbin & Strauss, 2008). In order to learn how experienced chemistry teachers' PCK is different for teaching different topics and how PCK components interplay during teaching electrochemistry, this qualitative research was conducted. Qualitative research "is a broad approach to the study of social phenomena. Its various genres are naturalistic, interpretative, and increasingly critical, and they draw on multiple methods of inquiry" (Marshall & Rossman, 2006, p.2).

Qualitative researchers gather data in the natural settings because data collected become more valuable in its ordinary context (Bogdan & Biklen, 1998; Marshall & Patton, 2002; Rossman, 2006). Furthermore, data including transcribes, documents, field notes, videotapes and photographs are descriptive in nature. It necessitates design flexibility which is related to the open-ended temperament of it as well (Patton, 2002). Another characteristic of the qualitative research is the focus of study. Not only the product but also the process is concern of this type of inquiry.

Additionally, vital attribute of the qualitative research is the use of purposeful sampling (Patton, 2002).

Due to the purpose of the study and types of the answers to the research questions asked, qualitative research design was suitable for the study. It is also parallel to the research in the related literature that are generally qualitative in nature (e.g. Avraamidou & Zembal-Saul, 2005; 2010; Clermont, et al., 1993; Clermont, Borko, & Krajcik, 1994; Drechsler & van Driel, 2008; Loughran, et al., 2004; van Driel, et al., 1998).

3.3. Case Study

Qualitative research is an *umbrella term* including many different methodologies such as ethnography, grounded theory, anthropology and case study (Bogdan & Biklen, 1998). Specifically, this study is a case study which provides comprehensive information related to an event, a subject or a setting (Merriam, 1998). Case studies are like a funnel which has a wide starting point whereas its end point is narrow. They start with detailed depiction of the cases and context, and then become specific regarding to data collected and analysis done (Bogdan & Biklen, 1998). Due to the fact that the purpose of the study to get deeper understanding nature of PCK and the interplays among the components, case study was appropriate to conduct.

In this study, the case can be described as two experienced chemistry teachers teaching two different topics, namely, electrochemistry and radioactivity. Due to the fact that the purpose of the study was examining topic-specific nature of PCK rather than comparing teachers' PCK, two teachers were viewed as one case. The minor differences were observed in teachers' PCK so they were provided in the result part.

3.4. Sampling and Participant Selection

It is impossible to conduct the research with everybody who has the characteristics that researcher is looking for. Therefore, the researcher had to make some decisions related to the participants in addition to other choices (e. g., context, time, topic, etc.) (Marshall & Roseman, 2006). I preferred to study with small group of experienced chemistry teachers to get deeper information about their topic-specific nature of PCK. Focusing on a particular group of teachers' PCK was suggested in the previous studies to get detailed insights about PCK (Friedrichsen & Dana, 2005).

Purposive sampling was used to choose the participants. To get better information about experienced teachers' PCK and its nature, teachers who had a potential to provide rich data were selected (Patton, 2002). Teaching experience in real classroom context is one of the vital sources for PCK development (Grossman, 1990). Therefore, pre-service or beginning teachers do not have strong PCK (Abell, 2008; Lee et al., 2007; van Driel et al., 1998). Because of that reason, I decided to study experienced chemistry teachers' PCK. However, the experience does not guarantee of rich PCK (Friedrichsen et al., 2009) Therefore, before the data collection, I started to look for experienced chemistry teachers who could be suitable candidate for the study. To find appropriate teachers, with help of the criteria that were used by other scholars in the literature (e.g., Berliner, 2001; Friedrichsen & Dana, 2005; Lankford, 2010), I determined some criteria such as being experienced in chemistry teaching at secondary level (at least 5 years experience as suggested by Berliner, 2001), teaching in a student-centered way, having a chemistry education degree in teaching chemistry at secondary level, participating to professional development activities, and teaching chemistry in a conceptual way rather than just emphasizing the algorithmic calculations.

In Turkey, teachers teach chemistry very didactically and perform many algorithmic exercises due to university entrance system (Nakiboğlu & Tekin, 2006). Therefore, selecting teachers who use activities, demonstrations, and representations is really hard in Turkey context. To solve the problem of finding teachers, I focused on private school context because they have a tendency to do activities more than public schools. To sum up, by the use of the criteria determined, I decided on two experienced chemistry teachers working in the same private high school in Ankara.

Deciding on the number of the participants is complicated in qualitative research (Marshall & Roseman, 2006). With help of the information gathered from other researchers who conducted research before me in different high schools, from pre-service chemistry teachers who took teaching practice course in high schools, and teaching assistants (TA) of teaching practice course, participants were selected. Especially, information taken from pre-service teachers and TAs was valuable for me because they had a chance to observe experienced teachers' teaching in classroom before I did. Furthermore, I had a chance to talk to them about their teaching before I chose them. After the meeting with the potential participants, I took their schedule. Their weekly schedules let me conduct the research with two experienced chemistry teachers. If I had wanted to study with more teachers, I would have missed some classes of them due to overlap in their schedule. Therefore, I preferred to study with less teachers rather than missing observations of their teaching.

Yet another issue in selecting the participants was the context in which they work. Due to the fact that context influences how teachers teach (Berliner, 2001; Henze et al., 2008; Loughran et al., 2008; Park & Oliver 2008), teachers working in the same or similar context should be selected in order to examine how topics influence teachers' practice. To eliminate the context's manipulation on teachers' practice, two teachers from the same high school were picked as participants.

To sum up, in light of the criteria predetermined, two experienced high school chemistry teachers were selected. In Turkey, after graduation from the undergraduate teacher education programs, chemistry teachers can work both in public and private high schools. To get richer and deeper information and to compare teachers' PCK in different topics, experienced chemistry teachers, having at least 5-year or more chemistry teaching experience in private high school were selected. Participants of the study were working in a private high school in Ankara. Table 1 summarizes the information about the participants. Additional details were also given in results chapter in order to explain the orientation to science teaching component of PCK.

Table 1. Information about the participants of the study

Participant	Teaching Experience	Master/ PhD	Other experiences	School type	PDs and trainings participated
Mr. Demir	15 years	-	Electrical technician in a factory, Elementary science teaching in elementary school for three years,	Private School	Performance-based assessment, Introducing new chemistry curriculum,
Mrs. Ertan	8 years	Master	Tutoring	Private School	Performance-based assessment, Introducing new chemistry curriculum,

3.5. The Subject Matter and Topics Selection

First, chemistry was selected as subject matter due to my background in chemistry education. I graduated from Secondary Science and Mathematics Education (SSME) department that has four basic divisions, namely, chemistry, biology, physics, and mathematics teacher education. I have BA and MA degrees from chemistry education division. Moreover, I have five year-experience as a TA in the same division. I have studied with pre-service chemistry teachers in the context of field experience course since 2007. Therefore, as Friedrichsen and Dana (2005) indicated, studying the same field that I have both solid subject matter knowledge and PCK would be helpful for me, to observe, collect, and analyze the data collected.

Second, in terms of the topics, electrochemistry and radioactivity were studied because these two topics have not been studied in terms of topic-specific PCK yet. Additionally, research has provided misconceptions and difficulties that students have in electrochemistry (De Jong, Acampo, & Verdonk, 1995; Garnett & Treagust, 1992a; 1992b; Sanger & Greenbowe, 1997a; 1997b; Schmidt, Marohn, & Harrison, 2007) and in radioactivity (Nakiboğlu & Tekin, 2006; Millar, Klaassen, & Eijkelhof, 1990; Prather, 2005). Furthermore, research has showed that electrochemistry (De Jong et al., 1995) and radioactivity are difficult topics for students to learn (Alsop, Hanson, & Watts, 1999; De Jong & Treagust, 2002; Nakiboğlu & Tekin, 2006; Yalçın & Kılınç, 2005). The literature calls for research on how teachers teach electrochemistry (De Jong & Treagust, 2002) and radioactivity (Nakiboğlu & Tekin, 2006). Moreover, two topics have to be at the same grade level due to the fact that orientation to science teaching component is grade specific. Additionally, the topics should not be related to each other because the purpose of the study was to compare PCK in different topics. In the chemistry curriculum for 11th grade, there are energy and chemical change, reaction rate, chemical equilibrium, electrochemistry, and radioactivity. The first three are related to each other. Therefore, from the 11th grade curriculum, electrochemistry and radioactivity were chosen to examine PCK in different topics.

Finally, in terms of time issue, I could start data collection in spring 2011 after my visit to University of Missouri, Columbia, USA. Therefore, electrochemistry and radioactivity topics were quite good in terms of both comparison purpose of the study and the timing. Finally, scarcity of research on teachers' PCK in radioactivity and electrochemistry topics motivated me, as the researcher, to focus on them. So, I hope this research will provide rich and original data for understanding how experienced teachers' PCK is specific to topics taught.

3.6. Description of the Setting

People's behaviors vary from context to context (Marshall & Roseman, 2006). Therefore, behaviors should be studied in the real context. In this study, the real context that the researcher can capture teachers' PCK is classroom in which teachers teach. Moreover, the context in which the teaching occurs also has influence on teachers' PCK (Loughran et al., 2000). Therefore, the participants were selected from the same context because the purpose was not to compare and contrast PCK in different context.

The study was carried out in a private high school context in Ankara, Turkey. There were about 400 learners in the high school. The learners are generally between 16 and 18 years old in secondary level. In addition, the classrooms observed have about 20-24 students. All classrooms in the high school have computers. Moreover, the classrooms in which participants' teaching was observed have benches and cupboards for chemicals at the backside. Additionally, they have smart boards in the classes.

3.7. Data Collection

To offer detailed description of the phenomena studied in qualitative research, there exist three basic ways that are interviews, observation, and documents to collect data. Interviews help us to hear participants' voice. They describe and explain their experience, ideas, and emotions. With the observations, we have a chance to see participants' behavior in the real context. Finally, analyzing the documents provide data related to institutional, organizational, and personal vision, plan, and action (Patton, 2002).

In order to get insight about teachers' topic-specific nature of PCK, different types of data were collected through interviews, observations, and document analysis. An important point reported by the previous research was that in order to capture teachers' PCK, researchers need to study on PCK for a long time and with different types of data collection methods. Nature of PCK may not let researchers to characterize participants' PCK neither in an hour nor through one type of data (Abell, 2007; Baxter & Lederman, 1999; Loughran et al., 2000; 2004; Kagan, 1990).

In other words, the more time study on it and the more different types of data collected, the richer and deeper data are gathered about teachers' PCK.

To examine experienced teachers' PCK in two topics, data were collected by the use of card-sorting activity, CoRe, semi-structured interviews, observation, and field notes. Data collection matrix (Figure-12) summarized the details related to each instrument. Moreover, multiple types of data were gathered through more than two months (Figure 13) due to the fact that uncovering PCK requires some time (Loughran, et al., 2004). Additionally, Appendix A shows the schematic diagram of the data collection process of the study.

Primary data source (P) was used mainly to answer the research questions asked. For instance, self-comparison interview was primary data source for sub-research question-1. In the self-comparison interview, teachers compared and contrasted their teaching in both topics, which helped me analyze how their PCK is similar and different for teaching different topics. On the other hand, the data collected through self-comparison interview were secondary source (S) for answering sub-research question-2 which was related to interplay among PCK components. But still self-comparison interview data were useful and used to support primary data collected through observations and weekly interviews.

Sub-questions	**CoRe**	**Card-sorting Task**	**Observations**	**Teacher Interview-1 (Weekly int.)**	**Teacher Interview-2 (self-comparison interview)**
1. Topic-specific nature of PCK	**P**	**S**	**P**	**P**	**P**
2. Interplay among PCK components	**S**	**P**	**P**	**P**	**S**

Figure 12. Data collection matrix

The timeline for data collection (Figure 13) was also provided. It is useful to understand the specific time for data collection through different instruments.

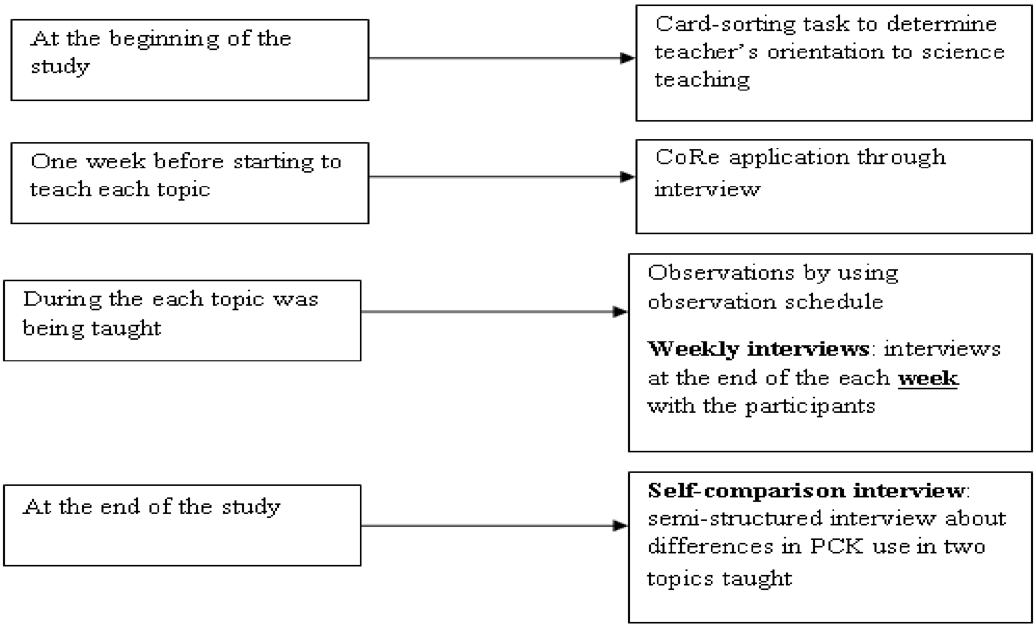


Figure 13. Dissertation data collection timeline

3.8. Details about the Data Collection and Instruments

3.8.1. Card-sorting Task

In this task, cards including scenarios (e.g. activities, strategies and techniques) for teaching electrochemistry and radioactivity at high school level were used to capture teachers' orientations and goals for teaching chemistry (Table 2). In this task, first of all, participants were asked to sort the cards into three groups: representative category including cards that are parallel to their teaching, unsure category including cards that participant is not sure whether s/he teaches in that way, and not representative category including scenarios very different than her/his teaching. After that, the researcher asked about the main similarities and differences between the scenario in the card and the participants' teaching, and the common characteristics of the cards in the same group. Finally, the participants were asked how the scenario is related to their orientations to science teaching, in other words, how it was parallel to their purposes and goals for chemistry teaching (Friedrichsen & Dana, 2003; 2005).

Table 2. The details of the card-sorting task

Data Source	Description of purpose, and method	Time
Card-sorting Task	**Purpose:** To detect participants' orientation to chemistry teaching The task provided data for both sub-research questions.	**Time:** At the beginning of the study
	Method: For the task, scenarios were written. Participants were requested to sort cards and then asked about their reasons for sorting. Conversation during the task was audio-taped.	**Length:** About 40 minutes

In this study, I used card-sorting activity because Friedrichsen (2002, as cited in Friedrichsen & Dana, 2003) criticized defining orientations based on observations. They suggested that teachers should take part in the process of determining the orientations. Moreover, Friedrichsen and Dana (2005) stated that conversation while the sorting the cards provides richer information about teachers' orientations than deciding on a specific scenario. Therefore, to determine teachers' orientations, card-sorting task which includes teachers' voice was used.

3.8.1.1. Development of the Scenarios for Card-sorting Task

To determine participants' orientations to science teaching, card-sorting task was utilized. In the literature, examples of card-sorting tasks have existed. For example, Friedrichsen and Dana (2005) prepared scenarios that were science-specific. However, in Turkey, we do not have secondary science teachers who teach physics, chemistry, and biology. Rather, we have teachers who teach only one subject. Therefore, because of the researcher's major is chemistry, high school chemistry teachers’ PCK was studied. Scenarios related to chemistry topics as electrochemistry and radioactivity were developed.

Although I adopted PCK model developed by Magnusson et al., (1999) in the study, I did not stick to that model in terms of orientations to science teaching because as Friedrichsen and Dana (2005) and Friedrichsen et al., (2011) stated, teachers’ orientations are more multifaceted than Magnusson and her colleagues thought. Furthermore, Friedrichsen and Dana realized that teachers had different orientations in addition to those underlined in Magnusson et al., (1999). They criticized the labeling teachers’ orientations with just one orientation determined in previous studies. They reported that participants have multiple central and peripheral goals which have a composite structure including *affective, schooling* and *subject-matter* goals. The result of the study showed that teachers may have different goals than those indicated in the literature. Therefore, while writing scenarios, new chemistry curriculum goals, literature related to orientation to science teaching (Friedrichsen & Dana, 2005; Greenwood, 2003; Magnusson et al., 1999; Volkmann et al., 2005), and the realities of Turkish education system were considered. Similarly, Friedrichsen and Dana (2003) also took the US conditions into account. University entrance exam (UEE) is very important for Turkish high school students to continue to higher education. Therefore, UEE determines to what extent students, teachers, and high schools are successful (Köse, 1999). In other words, UEE has influence on teachers’ orientation. To sum up, by using these different realities, scenarios were written.

The reason why other sources in addition to curriculum goals were also taken into account was that teachers generally do not follow what curriculum documents state exactly. “In general, the view that shines through in all of the curriculum implementation literature is that educational innovations most frequently falter because teacher actions in the classroom are inconsistent with innovators’ intentions” (Roberts, 1988, p. 43) When a new curriculum is started to be implemented, teachers’ implementation of it is affected by two factors that are *teachers’ interpretation* of the new curriculum policy and *teachers’ loyalty* (Roberts, 1988). Teachers may infer the new curriculum in a different way than the developers do or they may infer it in the same way with developers but they refuse to implement it consciously.

In the scenario writing process, first of all, curriculum goals stated in the Turkish chemistry curriculum (NME, 2007) were labeled in light of Roberts's (1988) curriculum emphases. The labels for the curriculum goals were provided in Appendix B. Roberts stated that there have been seven curriculum emphases which North America has had through the history. These are "everyday coping, structure of science, scientific skill development, the correct explanations, self as explainer, solid foundation, and science, technology and decions." (p.45) Everyday coping stresses the teaching the topic with daily use of scientific process, events and phenomena. Structure of science aims to teach the "how science functions as an intellectual enterprise" (p.35). Nature of science is tried to be emphasized. The highlighting point in science, technology and decisions is the relations between science and technology, and science-technology and society (STS). Scientific skill development emphasizes the skills that are science process skills used during scientific inquiry. For the correct explanations "emphasis concentrates on the *ends* of scientific inquiry, rather than the means" (p.37). The main point is teaching the correct explanations to the students. "*The Self as explainer* emphasis informs the student's understanding of his/her own efforts to explain phenomena by exposing the conceptual underpinnings that influenced scientists when *they* were in the process of developing explanations" (p.37). Finally, Solid foundation "is a reassuring curriculum emphasis, for it indicates to the student that he/she is learning something that fits into a structure that has been thought about and planned" (p.38). Through the time, some of them were more popular in a particular time than the others, however, it does not mean that one is better than others. Political issues, nature of the society, and social events are important factors that inform the preference of curriculum emphasis in a particular era.

In light of the curriculum emphasis suggested by Roberts (1988), scenarios were written for each of them. Second, with help of orientations detected in Friedrichsen and Dana (2005), Greenwood (2003), Magnusson et al., (1999), and Volkmann et al.,

(2005) additional scenarios were written. Finally, some scenarios related to preparation for UEE was added. All scenarios were provided in English in Appendix C and in Turkish in Appendix G. Finally, the questions asked to teachers during the card-sorting task were provided in the Appendix D.

After writing the scenarios, to check whether they were parallel to curriculum emphasis suggested by Roberts (1988), and to check their grammar and wording, expert opinion was taken for both English and Turkish versions. Moreover, the scenarios were piloted in the piloted study. The details of the pilot study were provided later in this chapter.

3.8.2. CoRe.

CoRe is a tool that includes big science ideas/concepts in its horizontal axis and factors that influence teachers' decisions such as teachers' intend, learners' difficulties, and factors in vertical axis (see Appendix H). Big ideas are basic concepts that are necessary to understand a particular topic (Loughran et al., 2004). Loughran and his colleagues thought that determination of big ideas are significant part of the process "because it offers access to the way in which science teachers frame the topic, and may be regarded as the main ideas that teachers see as valuable in helping to conceptualize the topic as a whole" (p.379). They stated that they viewed CoRe as an instrument for both capturing teachers' PCK and for demonstration of their knowledge.

CoRe was employed for getting impression about how teachers constructed the topics that was focused (Loughran, Berry, & Mulhall, 2006). Moreover, CoRe helps us understand the topic-specific nature of PCK (Rollnick et al., 2008). As mentioned in the difficulties of studying PCK through the end of Chapter 2, teachers may not understand the terminology used in PCK literature, Therefore, Loughran et al., (2004) revealed that they did not use them in CoRe. They used a language which can be understandable by teachers.

Similar to Loughran et al., (2004), I used CoRe as an interview tool at individual level. Abell and Volkmann (2010, personal communication) had some experience with CoRe implementation and they suggested me to use it as an interview tool. Therefore, I asked the CoRe's questions to the participants during the interview audiotaped. For instance, in the CoRe application interview conducted one week before teachers start to teach the topic, I asked "What are the difficulties related to teaching electrochemistry topic?" and "Why do you think is it difficult to teach it? What are the factors making teaching it difficult? ". The participants talked about the probable difficulties that students may face with and the reason why students had those difficulties. All questions asked during CoRe interview were provided in Appendix E.

The details of CoRe use was summarized in Table 3.

Table 3. Summary of the purpose, description and time necessary for use of CoRe

Data Source	Description of purpose, and method	Time
CoRe	**Purpose:** To get information about how teacher(s)' PCK is different for teaching different topics and how PCK components interplay CoRe application provided data for both sub-research.	**Time:** One week before the teaching of each topic
	Method: CoRe questions were asked to the participants. The CoRe application was like interview and it was recorded by voice recorder.	**Length:** About 40 minutes.

The permission was taken from Professor John Loughran to use CoRe instrument in the study (Appendix I).

3.8.3. Interviews

Interviews provide valuable information about the participants' point of view which is not observable (Patton, 2002). Two different semi-structured interviews, namely, weekly interviews and self-comparison interview were conducted at the different times of the data collection (Table 4).

Table 4. Details related to interviews conducted

Types of interviews	Description of purpose, and method	Time
Teacher Interview-1 **(Weekly interviews)**	**Purpose:** To gather information about how teachers' PCK is different for teaching different topics, how PCK components interplay. Participants were asked about their teaching practice that are worthy of clarification. The interview provided data for both sub-research questions **Method:** Semi-structured interview protocol was used during the interview. When necessary, additional questions were asked.	**Time:** At the end of each week (During the each topic) **Length:** Each will take between 25-30 minutes.
Teacher Interview-2 **(Self-comparison interview)**	**Purpose:** To get teachers' ideas about the differences and similarities in their PCK for different topics. The interview provided data for research questions 1 and 2. **Method:** Semi-structured interview protocol was used during the interview.	**Time:** At the end of the study **Length:** About half an hour

The reason of the use of semi-structured interview was that an important question may come to the researcher's mind during the interviews. Moreover, participants' answers necessitate asking some additional questions which are different from the prepared questions. Semi-structured interviews were the primary sources of the data due to the fact that they reflect participants' ideas related to their teaching. All interviews were audio-taped by the use of a digital voice recorder with the permission of the participants. All interviews questions asked during different types of interviews were provided in English in Appendix E and in Turkish in Appendix G.

In the semi-structured interviews, questions related to the PCK and its components, teachers' implementation of different activities, and reason why they used them were asked. For instance, participants used a teacher demonstration after teaching electrochemical cells. In the weekly interview that was conducted at the end of that week, the reason why they used the demonstration was asked them. Moreover, how the demonstration would help students to understand the topic and how they decided to use them in the class were all asked.

The semi-structured interview questions were prepared in light of the Observation Cycle Protocol prepared by Sandra K. Abell and her research team for Researching Science and Mathematics Teacher Learning in Alternative Certification Models (RE-SMAR^{2}T) project, literature, and experience of the researcher. The permission was taken from Sandra K. Abell who was the director of the project. After writing the questions, experts' opinion was taken in terms of the quality of the questions, and vocabulary and grammar. Five experts who had experience in PCK and teacher education provided feedback about the questions. After forming the final version of all instruments used in the research, they were used in the pilot study with two chemistry teachers in the US. Finally, I translated the instruments into Turkish. Then, again expert opinion was taken for quality of the translation. Four bilingual experts who have experience both in qualitative study and in chemistry education provided feedback. After all, both Turkish and English versions of the instruments were prepared.

3.8.4. Observations

Although data collected through interviews endow with valuable and rich data, it is not a full description of the participants' PCK. Therefore, for a complete picture of the situation in addition to taking participants'' opinion, participants' teaching was observed (Patton, 2002).

During the observations, I took notes. Observational record is referred as field notes that are the written notes related the researchers' hearing, observations, and experiences during the observation (Bogdan & Biklen, 2006). As Loughran et al., (2000) looked for, the researcher tried to catch “identifiable instances where a concrete pedagogic action was employed for a particular reason in response to, for example, a learning difficulty, or situation, need, or known point of confusion in the content being taught.” (p. 6). Therefore, I tried to take field notes as much as I could.

In the literature there are two different field notes that are descriptive and reflective in nature (Bogdan & Biklen, 1998). Descriptive field notes describe the context people, and behaviors without any judgment. Reflective field notes, on the other hand, include observer’s judgments and ideas, related the observed actions or events. Data gathered through the observation should be rich and exhaustive enough to help the person who reads the research can view the context of the research actions of the participants (Patton, 2002). Therefore, both types of field notes were used to provide a complete picture to the reader in the study.

Table 5 provided the description and purpose of the observation. Moreover, observation protocol was presented in the Appendix F. For Turkish version of the form, please look at Appendix G. In the observation protocol, important points related to PCK components were provided to observer in order to help her/him what to look for. For instance, for knowledge of instructional strategy component of PCK, “The teacher makes an instructional decision that alters the flow of the classroom by asking a question or directing students to perform a particular task” and “The teacher uses an example or analogy or representation to clarify an idea” points were given. However, the observers were not limited to those two points during observations. If something interesting and unexpected happened, it was noted as well. For example, one of the students could not understand how the atom changes in nuclear reactions. It was an unexpected question for Mr. Demir. He stopped teaching and tried to explain. But he did not provide the answer to the student. Rather, he asked some directing questions to the student and helped her to figure it out.

Table 5. Details of observations

Data Source	Description of purpose, and method	Time
Classroom observation	**Purpose:** To gather data to answer for what the nature of PCK is for different topics and how PCK components interplay. Classroom observations provided data for both sub-research questions. **Method:** Field notes were taken. Observation schedule was prepared for helping to determine the important aspects such as instructional strategies used, responding learners' difficulties, and relating the topic with other topics in the curriculum that I focused on.	**Time:** For each participant, one of their 11^{th} grade class was selected and observed that class from beginning to the end of each topic. **Length:** Each class period in Turkey is 45 minutes for high schools. We have 3 class periods for chemistry per week at 11^{th} grade.

3.9. Pilot Study

Piloting the research out helps the researcher to refine the instruments prepared, to increase self-efficacy in conducting the research, and to realize the importance of research study on experienced teachers' PCK (Marshall & Roseman, 2006). Additionally, I had a chance to see whether I can handle the data collected or not. After the pilot study and preliminary analysis of it, I understood that I am able to do the research and do the analysis of the data collected.

The pilot study was conducted during my trip to the US as a visiting scholar. After getting permission to do the research from IRB, I requested one experienced chemistry teacher with seven-year-experience to study with me. She accepted to participate in the pilot study. I compared and contrasted her PCK in two different topics that were "Matter and Measurement" and "Atomic Models" at 11^{th} grade. Due to the fact that high school chemistry curriculum in the US is quite different than it is in Turkey, I could not have a chance to pilot the study in the same topics focused in Turkey. However, it was very useful for me to do pilot study for making some necessary changes in the data collection instruments.

For the pilot study, I observed the participant teacher's teaching for two weeks for each topic. The class that she was teaching was honor's chemistry class with 28 students. The class in which she taught was quite similar to those in the real study. Therefore, when she needed to show something, she had a chance to use chemicals in the classroom with benches. Moreover, it has computer and smart board.

It was the seventh year in teaching for the participant teacher. She graduated from chemistry department; however, she decided to pursue a career in chemistry teaching. Then, she also applied for master program in University of Missouri. At the time of the pilot study, she was taking master courses.

In light of the pilot study experience, some changes were made in the instruments and the time for conducting interviews. Pilot study helped me notice the tacit nature of PCK. To be able to talk to teachers about their teaching, the questions asked should be clear enough for them. For instance, in the self-comparison interview conducted in pilot study I explained what PCK is to teacher and I asked "How was your teaching similar and/or different in terms of PCK for teaching the topics?" She said she did not focus on PCK but just taught them. I realized that even if you explained what PCK was, still they do not share that language with you. After that experience, I checked all the questions and tried to make them more understandable for teachers. Additionally, in the pilot study, I did CoRe interview about ten days before she started to teach. I noticed that she did not start to think how to teach the topic yet. Therefore, in the main study, I conducted CoRe interview about one week before they started to teach the topics.

3.10. Data Analysis

Data analysis is a process through which researchers try to understand what the data tell (Bogdan & Biklen, 2007; Merriam, 2009). In this study, for two sub-research questions, somehow different analyses were conducted. Below, the details of the data analysis were summarized. In qualitative research, the data collection and data analysis are not separate procedures, on the contrary, they occur simultaneously

(Bogdan & Biklen, 2007; Merriam, 2009). During the data collection, I got some insights about how teachers' PCK is specific to topics and how teachers use PCK components concurrently. I took some notes about the points that I noticed, which helped me during the analysis part.

3.10.1. Data Analysis for Topic-specific Nature of PCK

In the first round, after transcription of the all interviews, data coding was started. First, I tried to form a code book. Although I had PCK model proposed by Magnusson and her colleagues in my mind, I was open to other possible codes while reading the data sources (Merriam, 2009). For instance, in the proposed PCK model, there are two sub-categories of knowledge of curriculum, namely, knowledge of curricula, and knowledge of goals and objectives. However, while I was reading the data I noticed another point related to curriculum knowledge. Participants linked the topics by relating the topic to the other topics taught in previous grades (e.g. types of reactions, how to assign oxidation number, etc.), which was coded as "vertical relations". Moreover, they linked it to topics taught earlier in the same grade (e.g. spontaneity of chemical reactions, chemical equilibrium, spectator ions etc.), which was coded as "horizontal relations". Through this process, I formed a code book from the data collected from one participant. Then entire data were coded by the use of the codes formed. Due to the fact that I had two topics to code, I decided to code electrochemistry for both participants first and then to code the data of radioactivity topic.

In the second phase of the analysis, categories were formed (Merriam, 2009). The codes were put under categories which were PCK components suggested by Magnusson et al., (1999) model, namely, orientation to science teaching, knowledge of instructional strategies, curriculum, learner, and assessment. All codes were put under the categories and sub-categories of PCK for both participants and for both topics. For analysis of orientation to science teaching, I analyzed the data collected through the card-sorting activity. The central and peripheral goals of teachers were determined. Additionally, data collected through observation and interviews were helpful in understanding the participants' orientation as well. The main focus was how they teach, how they provide the content to learners, and whether they share the responsibility with learners.

In the third part, in order to have better view of the data, I decided to focus on when, how, and why each teacher enact instructional and assessment strategies, focus on learners' prior knowledge, difficulties and misconceptions, and use curricular knowledge for each topic. At the end of this part, I had four summary tables showing the PCK components, namely, instructional strategy, learner, curriculum, and assessment for Mr. Demir's electrochemistry teaching. Then I did the same for Mr. Demir's radioactivity teaching. The same process was followed for Mrs. Ertan's electrochemistry and radioactivity teaching. To sum up at the end of this step, I had 16 summary tables showing when, how, and why each teacher did. The comparison was made between two tables for particular component for teaching electrochemistry and radioactivity for both teachers. For instance, for Mr. Demir, summary table formed for knowledge of assessment for electrochemistry and radioactivity were compared and contrasted in order to notice the topic-specificity. The comparison was done for all PCK components for both teachers. Then, the both participants' results were compared and contrasted to check if there were any differences between them. Cross-case analysis revealed that the both teachers' teaching electrochemistry and radioactivity were quite similar. There was no major difference between them. Finally, I started to label the categories. For instance, data analysis showed that both participants assessed learners' understanding at the beginning (e.g. assessment of prior knowledge), during (e.g. assessment of to what extent they learner through quiz), and at the end of electrochemistry (e.g. unit test) by the use of both formal (e.g. quiz) and informal (e.g. informal questioning) ways. The assessment used for electrochemistry was labeled "Coherent assessment". However, assessment done in radioactivity was quite limited regarding the type, time, and purpose of it. Therefore, it was more "Fragmented assessment" in radioactivity. For labeling each PCK component, again a summary table (see Table 20) showing all labels was formed. Then, PCK A was labeled and described for teaching electrochemistry and PCK B was labeled and described for teaching radioactivity. The description of all labels was provided in the result section.

3.10.2. Data Analysis for Interplay among PCK Components

This part was based on data collected from one of the participants in electrochemistry topic. I decided not to include both teachers' data due to the complex nature of the interplays. The data of Mr. Demir who had richer PCK than Mr. Ertan was analyzed for the second sub-research question. Moreover, I also did not include Mr. Demir's data for teaching radioactivity because his SMK and PCK were not as rich as they were in teaching electrochemistry.

After finishing the data coding for the first sub-research question, I focused on the second one. Due to the fact that I was familiar with the data because of the analysis of the first part, coding this part was easy. I coded all of the interplays noticed in all data sources belonging to Mr. Demir's teaching in electrochemistry. What I meant by interplay can be explained well with an example. For instance, in one of the weekly interviews, Mr. Demir stated that due to the fact that there was an objective about teaching Nernst Equation and performing exercises about it, he added that part to his teaching. In this part, it was obvious that his knowledge of curriculum informed his knowledge of instructional strategy about teaching Nernst Equation and performing exercises. These types of relations among PCK components were coded as interplay. Then, I examined all of the coded interplays. I noticed different characteristics of them. For instance, some of the interplays were so simple that they included only two components of PCK whereas some of them were quite complicated that they had some parts (e.g. understanding, decision-making, enactment, and reflection). Through the analysis of the coded interplays, I was able to assert some points about the nature of them.

To sum up, the data analysis conducted in this study was between inductive and deductive analysis (Patton, 2002). In inductive analysis, there are no priori codes and categories whereas deductive analysis is based on the existing codes and categories.

In this study, I coded the data in light of the codes gathered from PCK model and the data collected. Moreover, I used PCK components suggested by Magnusson et al. (1999) as categories. Till this part data analysis was almost deductive. However, after that it was inductive because I tried to find out the patterns which are not existent in the literature for teaching electrochemistry and radioactivity. The similar approach was also used by Lannin et al., (2008):

> What evolved was a dialectical process in which we coded data, discussed our codes, revisited the original PCK model, recoded, and so on. In this way our final product included both *a priori* categories derived from the Magnusson et al. framework, and new categories that emerged from the data that led to the development of our revised framework (p. 10).

When the nature of naturalistic inquiry was thought, it is quite normal to face with this type of differences because there is no one correct analysis for qualitative data. Additionally, qualitative research has design and analysis flexibility (Bogdan & Biklen, 2007; Marshall & Rossman, 2006; Merriam, 2009; Patton, 2002), which is an indicator of qualitative research's richness.

3.11. Trustworthiness

Validity and reliability issues in qualitative research are different from those in quantitative research (Yıldırım & Şimşek, 2006). Due to the major dissimilarities between quantitative and qualitative approaches, unique standards for ensuring validity and reliability are required. Moreover, the standards require special names for qualitative and quantitative approaches (Lincoln & Guba, 1986). 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). Then the blend of credibility, transferability, dependability, and conformability form trustworthiness of research. In the following part, evidences for trustworthiness of the study were given.

3.11.1. Credibility

Credibility in qualitative research is related to whether the results are congruent with the reality or not (Merriam, 1998). Six strategies which are triangulation, member checks, long-term observation, peer-examination or peer debriefing, participatory or collaborative modes of research and clarifying researcher’s biases can be used to increase credibility of qualitative research. In this study, triangulation, peer-debriefing, long-term observation, and member checks were employed to ensure credibility.

Triangulation is using different data sources of information by examining evidence from the sources and using them to build a coherent justification for themes (Yıldırım & Şimşek, 2006). Patton (2002) examines triangulation under four categories which are data triangulation, investigator triangulation, theory triangulation, and methodological triangulation. In this study, data triangulation was achieved by using multiple data sources including card-sorting activity, interview transcripts, field notes from observations, and CoRe.

The investigator triangulation was achieved by inviting three colleagues of the researcher to observe both teachers’ teaching. They were purposefully selected for the observation because they are knowledgeable about PCK construct, its literature, components, and how to observe it. Totally, eight hours of participants’ teaching in different weeks and topics were observed by the researcher and three other observers. Additionally, the observation form, instruction on the parts of the form, and how to use the form were provided. After observation, we came to gather and discussed about our observations with help of the form. When we had inconsistencies, we focused on that part and tried to reach consensus. All PCK components were discussed in these discussion sessions.

Peer debriefing involves a person to review and comment on the findings (Merriam, 1998). I requested two of my colleagues who have experience in qualitative research and PCK in coding and categorizing process, and in interpreting the results.

Member check refers to make the participants of the study check the data, categories, and interpretations (Yıldırım & Şimşek, 2006). The participants were given the opportunity to react to the interpretations of the data throughout the investigation. After analyzing the data, the researcher print out the summary tables for PCK components and interplays and visited participants. They were requested to check the data, categories, and interpretations. Participants did not state any opposite interpretation. They agreed with the results and interpretations provided.

Finally, long-term observation also helped me to ensure credibility. I spent about two and a half month with the participants. Meanwhile, I observed their classes, spent time with them, and talked about teaching, learners, context, and curriculum. Due to the long term-observation, I tried to capture teachers' PCK in two different topics.

In addition to those points suggested by Merriam (1998), to increase credibility of the research, Patton (2002) recommended that "*credibility of researcher*, which is dependent of training, experience" (p.552) and "*philosophical belief in the value of qualitative inquiry*, that is, a fundamental appreciation of naturalistic inquiry, qualitative methods, inductive analysis, purposeful sampling, and holistic thinking" (italics are original, p. 552-553). As a researcher, I took a qualitative research course before starting to this research. Although it does not mean that I learned everything about qualitative inquiry, still, it provided a perspective about naturalistic approach. I had a chance to read at least three distinguished qualitative research textbooks to understand the underpinnings of this field. Furthermore, I have been conducting qualitative research since 2009, which provides me a great experience in questions to be asked, data to be collected, and analysis to be done in qualitative research. In addition to experience in this type of research, I also have had experience in teacher education field especially in PCK since 2006. I also have been studying with pre-service teachers for five years in practice teaching course to assist their PCK development. Also, the experience I had due to pilot study helped me a lot about the revisions made, points focused, and questions asked. Finally, I spent a great year in the US, University of Missouri which has a perfect graduate program focusing on teacher education. I took a doctoral seminar course, *LTC 8900 Science Teacher*

Learning, taught by Assoc. Prof. Dr. Patricia J. Friedrichsen in the spring semester of 2010 (Appendix H). I studied with Sandra K. Abell (to great honor of her), Deborah L. Hanuscin, Patricia J. Friedrichsen, Mark J. Volkmann, and Lloyd Barrow. Hopefully, these evidences helped the increase of my creditability as a reseracher.

3.11.2. Dependability

Although in quantitative research reliability refers to the replication of the findings, in qualitative results it has different meaning due to the nature of the qualitative research (Yıldırım & Şimşek, 2006). Data and investigator triangulation can be used to increase both credibility and dependability in qualitative research (Merriam, 1998). Therefore, in this study investigator and data triangulation were employed as explained above. Additional two coders who have experience in PCK, chemistry education, and qualitative research coded one of the teachers from whom data were collected. Interrater reliability was calculated to provide evidence for credibility and internal reliability. Interrater reliability was calculated as %91 through the use of formula suggested by Miles and Huberman (1994). The formula is;

$$\text{Reliability} = \text{Number of agreements} / (\text{Total number of agreements} + \text{disagreements}) \times 100$$

The inconsistencies were discussed again and consensus was reached at the end.

3.11.3. Transferability

Transferability is related to what extent the results can be generalized to different situations (Merriam, 1998). It is questionable that whether making generalization based on data gathered through a single case or some cases. Although making generalizations is not the focus of the qualitative research, there are some ways that are thick description and studying with more than one teacher to increase the transferability. In this study to increase transferability both of the strategies were implemented. The physical and cultural environment of the high schools, classrooms, and participants were described in detail. Finally, the study was conducted with two in-service chemistry teachers.

In the next part, details about how data bases were searched, role of the researcher, ethical issues, and schedule were provided.

3.12. Key Words and Databases Searched

First, the key terms related to the topic were determined with the help of the previous studies. The initial key terms identified from general to specific are PCK, in-service teachers, chemistry education, and science education.

Due to the fact that there have not been many studies related to the topic-specific nature of PCK, especially with in-service chemistry teachers, science education were used as a key word in addition to chemistry education. Topic-specific PCK studies conducted in the other fields of science also helped the researcher especially in terms of theory and methodology.

Second, general references such as Science Direct, Educational Resource Information Center (ERIC) databases, and International Dissertation Abstract were searched for the relevant primary sources. Moreover, to reach primary sources in Turkey, journals that have online access (e.g. Hacettepe University Journal of Education, Education and Science, and Elementary Online, Çukurova University Journal of Education, Kastamonu Education Journal, Gazi University Journal of Education, Eurasia Journal of Mathematics, Science and Technology Education, Eurasian Journal of Educational Research, and Educational Science: Theory and Practice) were searched.

Third, the books were searched by using determined key words in the library web-site. After completing review of the related literature, determined primary sources were obtained. They were read by noting the key points. When different sources were found during the study, they were obtained and added to the study through the time.

3.13. The Role of the Researcher

The existence of the researcher in the context where participants act has some considerations (Marshall & Roseman, 2006). Therefore, the researcher should state the degree of his/her participantness, revealedness, intensiveness, and extensiveness (Patton, 2002). The participantness has a range between full participant and complete observer. In this study, I was complete observer. I did not participate in any classroom activity, group work, or discussion. I just sat at the back of the classroom, observed the teachers' teaching and reactions to students' questions, misconceptions and difficulties, and took notes about what I observed.

Second, in terms of revealedness, teachers were informed about the purpose that was to examine teachers' PCK in two different topics at 11th grade. However, in order not to attract students' attention, the researcher was announced as a pre-service teacher who would observe their class. I preferred to be introduced like that because students in the school where the study was conducted got used to pre-service teachers. College of Education assigned pre-service teachers to high school for teaching practice courses. Therefore, students in the classes in which I did observations were not disrupted very much. Teachers were informed about my research and identity.

The third point related to researcher role was intensiveness-extensiveness that is "the amount of time spent daily in the setting and the duration of the study" (Marshall & Roseman, 2006, p. 73). Before starting to study with the participants, first, I visited them to meet and request to participate in the study. Then, I went to schools for taking their weekly schedule and got some detailed information about the participants' background. After that, I visited them again, and talked about how they teach. Finally, I called them almost every week to talk about what they were teaching in that week, how they were teaching, etc. So, before the study, we had some time to understand and trust each other.

Finally, due to the specific purpose and focus of the research, as a researcher, I think that my role was quite obvious at the very beginning of the study both for me and the participants (Marshall & Roseman, 2006).

3.14. Negotiating Entry

Before meeting the participants, I was thinking that it would be much harder to persuade experienced teachers to study with me due to my own experience. However, when I visited schools, teachers were positive about participation. They requested me to talk to their principles about the permission and IRB issues. The principles were also positive so I applied to IRB for getting permission to study with those teachers. Being honest and clear about the research purpose helped me persuade them. Additionally, because I did not force them to implement anything and change their plan, they easily agreed to study with me.

3.15. Efficiency

In qualitative studies, researchers should be efficient regarding to time and sources used (Marshall & Roseman, 2006). Keeping the research questions and pilot study in mind, I decided to observe one class of each participant teachers. Both teachers taught two 11th-grade classes in that semester. For one of the classes that they taught, I observed all class hours that they taught electrochemistry and radioactivity topics. So, observing teachers' teaching during Electrochemistry and Radioactivity topics and interviewing about their practice were reasonably guaranteed to answer research questions asked.

3.16. Ethical Considerations

In order to be able to conduct the study, first, IRB permission was taken (Appendix J). IRB approved that the study has no potential to harm participants and to the students in the classes. Anonymity of participants and the school were assured as well. For all participants, pseudonyms were used. Additionally, all participants accepted to participate to the study voluntarily and they were informed that whenever they want to quit, they could do it.

Deception of the participants, protection of the participants from harm, and confidentiality of data are three important points related to the ethics in research (Frankel & Wallen, 2006). Nobody except the researcher, her advisor, and additional coders had access the data collected for the study. Finally, participants were not deceived. An informed consent form was prepared. The purpose of the study was explained to the participants; however, all the details were not given about the research in order to not to influence their planning and teaching. At the end of the study, all details and results were shared with them.

3.17. Limitations about Trustworthiness of the Study

There are some limitations originating from the nature of the qualitative study. The first one is the existence of the researcher in the classroom. Although students did not notice that I am a researcher, still my existence in the class might influence them. In addition to effect on students, participant teachers might be manipulated by my existence, observation, and note taking. These all affected the natural setting of the classroom. However, to minimize my effect on students, I was introduced as a pre-service teacher taking her school experience course. To minimize my effect on teachers, I always stressed that I am there to observe how experienced teachers teach, how they automatically respond students' need during the instruction, understand their way of teaching rather than judging or criticizing them. Furthermore, I stated that we need to understand experienced teachers' thinking before, during, and after the instruction to benefit their experience in pre-service and in-service teacher education. Additionally, I tried to spend some time with them and talked about other topics except teaching and chemistry. It is assumed that the participants got used to me easily because they stated that they were observed by pre-service teachers all semesters. So, they did not feel bad, nervous, or stressed. In my opinion, interviews conducted before the electrochemistry topic started helped us get used to each other.

The second one is related to the generalizability of the results. This study was conducted in Turkey in which teachers generally teach didactically. They rarely do laboratory activities and demonstrations, and use different instructional and assessment methods. Teachers are mostly seen as the dispenser of the knowledge. Those characteristics of teachers' teaching may limit the generalizability of the research results. Moreover, the participant teachers may not represent other teachers' teaching in Turkey. In addition to that, only two teachers' teaching was focused in this study. In order to make generalizations, it is need to study with more teachers. However, similar to Turkey, in many Eastern cultures, the context described above was parallel, for instance, India context (Nargund-Joshi et al., 2011) and China context (Zhang, Krajcik, Sutherland, Wang, Wu, & Quiang, 2003). Therefore, the results may be comparable to the results of research conducted in Eastern Culture contexts rather than in Western one.

The third one might be related to the lack of videotaping of participants' teaching. Due to the fact that school principles did not let me do that, I could not take video with me. Therefore, it may create some problem because I might not be objective during the observation as much as expected. Other researchers might observe different things, however, to minimize this limitation I requested three researchers to come and observe with me. They were PhD candidate in chemistry education. Before going to observation, first, we talked about what we were looking for, what can be observed, and what can be an indication of teachers' PCK, etc. The reasons why I selected those three were that they knew what PCK is, components of PCK, and they conducted research on PCK. Two of them participated to PCK seminar related to PCK models, sources of PCK, and research in PCK field. Two of them observed two class periods in electrochemistry and the third one observed four class periods both in electrochemistry and radioactivity. After the observations, we came together, and compared and contrasted our field notes. Then we talked about what we observed, which part of the notes were related to PCK components, how the teacher instructed, assessed, and respond to students. Therefore, with those precautions, I tried to decrease the limitation of lack of video-taping as much as I can do.

3.18. Time Schedule

Data were collected from two experienced chemistry teachers working in private high school in Ankara. Table 6 shows the timeline of the research.

Table 6. Timeline for the research

Date	Events
January 2010-May 2010	Design of the study
June 2010- August 2010	Development of the interview questions and other necessary instruments for data collection
August 2010-October 2010	Pilot study in the US
November 2010 – December 2010	Data analysis of pilot study, and revision on the instruments in light of the pilot study, and preparation last version of instruments,
January 2011- March 2011	Translation of instruments into Turkish and getting expert opinion on them, selection of the participants, meeting with participants, and getting IRB permission
April 2011-June 2011	Data collection & Preparing data for analysis (transcription, organizing field notes, etc.)
August 2011 – December 2011	Data analysis
January 2012 -April 2012	Writing results, conclusion, and discussion section

Finally, assumptions about the nature of PCK and the participants were given.

3.19. Assumptions about PCK and the Participants

- PCK is transformation of knowledge bases (SMK, PK, etc.) for teaching,
- Teaching experience is one of the major sources of PCK, therefore, experienced teachers have a solid PCK,
- Experienced teachers use different components of PCK (e.g. learner, curriculum, etc.) effectively and simultaneously in order to make teaching more efficient,
- SMK is essential for developing robust PCK but not the only knowledge base forming PCK,
- Participant teachers have solid SMK for both topics focused on,
- Participants have a rich repertoire of instructional and assessment strategies.

CHAPTER 4

RESULTS

In this section results were provided. Detailed results were presented for electrochemistry and radioactivity for each PCK aspects, namely, orientation to science teaching, knowledge of instructional strategy, curriculum, learner, and assessment. Under the each component of PCK, first, the categories formed were described in detail. Then, for each topic, the detailed explanation of both teachers' use of the components was summarized with the examples taken from both the interviews and observations. Furthermore, a brief table for each component was formed to help the readers to see the whole picture and to follow the results easily. In addition to that results for both participants' were presented together because there were no major differences between the participants' teaching topics.

After providing all the details about the topic-specific nature of PCK, the interplay among the PCK components were summarized.

4.1. Introduction of the Participants

4.1.1. Mr. Demir

Mr. Demir has about 15-years teaching experience in high school chemistry. He has been teaching in a private high school in which all fields have their groups including a chair and other teachers. Mr. Demir is the chair of the chemistry group and working with two other teachers in the school. He graduated from a vocational high school and worked in industry as an electric technician. Then, he went to college to become a chemistry teacher. He is interested in preparing students to participate in science competitions and fairs. Moreover, he has been participating in different in-service trainings (e.g. introduction of new high school chemistry curriculum) and educational conferences to present his research (e.g. participation to 2nd National Chemistry Education Conference, to present his work on mentoring pre-service teachers during practicum). Finally, he is interested in researching new activities, experiments, and in learning scientific knowledge gathered recently.

4.1.2. Mrs. Ertan

Mrs. Ertan has a master's degree in secondary science education and has been teaching high school chemistry for 8 years in private high schools. She is one of the three chemistry teachers working at the same school. She graduated from a top college in Turkey. Before starting to teach in high school, she tutored high school students for university entrance exam. Similar to Mr. Demir, she participated in professional development activities (e.g. Performance-based assessment, Introducing new chemistry curriculum, Science and Science education, New trends in chemistry education) in Turkey. She also went to Greece to participate a workshop on planning science activities. She is also interested in enriching her teaching with different activities and representations whenever possible.

4.2. Results for the Topic-specific Nature of PCK

4.2.1. Orientation to Science Teaching: Mr. Demir and Mrs. Ertan

Both teachers' orientation to science teaching was didactic in nature. Magnusson et al., (1999) described teachers' didactic orientation whose purpose is to transmit the content knowledge to learners. Their teaching was generally based on lecturing. However, they both enriched the lectures with demonstrations, analogies, and activities. To get idea about their orientation to science teaching, data gathered through card-sorting activity, observations, and interviews conducted after observations were used. Analysis of data sources showed that both Mr. Demir and Mrs. Ertan had conflicts between their own purposes and the realities of Turkish Education System. Moreover, data collected through card-sorting activity and through observations indicated some differences and similarities. Even during the card-sorting activity, they mentioned the discrepancies existing. Therefore, teachers' both ideal view and real practice were summarized below (Table 7).

Table 7. Results from card-sorting activity

Participants	Scenarios[1]: Agreed	Scenarios: Not agreed at all	Scenarios: Not sure
Mr. Demir	2, 3, 4, 7, 8, 9, 14	1, 11, 12	5, 6, 10, 13
Mrs. Ertan	2, 3, 4, 7, 8, 9, 13, 14	1, 11, 5, 12	6, 10

With help of the card-sorting activity, both participants' ideal central and peripheral purposes were determined (Table 8).

Table 8. Participants' ideal and working ideas from card-sorting activity

Participant	Purpose type	Purpose
Mr. Demir' ideal Purposes	**Central purposes**	To relate chemistry to daily-life, To help learners discover rather than providing knowledge, To develop science-process skills,
	Peripheral goals	To facilitate learners' interest in chemistry, To develop consciousness in terms of environment, To provide knowledge about history of development of concepts
Mrs. Ertan's ideal Purposes	**Central purposes**	To develop higher order thinking skills (e.g. critical thinking), To relate chemistry to daily-life, To develop scientific literacy
	Peripheral goal	To facilitate learners' interest in chemistry

[1] Details for the orientations: 1: didactic teaching, 2: Activity driven, 3: Discovery, 4: Conceptual change, 5: Academic rigor, 6: Guided inquiry, 7: Scientific skill development, 8: Curriculum goal: History of development of concepts, 9: Curriculum goal: developing conscious in terms of their relation to environment, 10: Curriculum goal: Terminology, 11: Reality of Turkish education system, 12: Curriculum goal: STS, 13: Curriculum goal: Environmental ethics, 14: Affective domain,

Through the end of the card-sorting activity and during the data collection period, I realized that there were some alterations in participants' purposes. Table 9 showed their purposes which were identified through observation of their teaching for two and a half months.

Table 9. Participants' purposes concluded from their practices observed

Purposes	Purposes	Participants
Central Purposes	To provide necessary knowledge to learners,	Both
	To prepare learners for university entrance exam,	Both
	To relate chemistry to daily-life,	Both
Peripheral Goals	To facilitate learners' interest in chemistry,	Both
	To develop consciousness in terms of environment,	Mr. Demir

As can be seen from the table 8 and table 9, although some similarities between ideal and observed purposes existed, main differences were also detected. Regarding to similarities, "to relate chemistry to daily-life" was one of the central purposes observed in both teachers' teaching. Due to Mr. Demir's background in vocational high school and in industry, he said that he links daily-life and chemistry (**Card-sorting activity**). Mrs. Ertan stated that due to her boring experience in high school with her chemistry teachers, she decided to relate chemistry to daily-life. Her teachers did not link the topics in chemistry to life (**Card-sorting activity**). Whenever, possible, they both mentioned where and how we use the phenomena taught in the class. Another reason of pursuing with it may be the stress made in the curriculum regarding to relating chemistry to daily-life. In addition to use of daily life, some of the other ideal and observed peripheral goals overlapped. For instance, to facilitate learners' interest in chemistry and to develop consciousness in terms of environment were both stated by Mr. Demir in the card-sorting activity and observed by the observer. For Mrs. Ertan, there was a consistency in her peripheral goal, to facilitate learners' interest in chemistry, stated in the card sorting activity and observed in here class.

However, some discrepancies were observed between their ideal purposes and purposes observed in real practices (Table 8 and 9). For instance, Mr. Demir stated that one of the central goals was to help learners discover rather than providing knowledge to them during the card-sorting activity; however, he provided knowledge in most of his classes. In other words, rather than letting learners to discover, he supplied necessary knowledge to them. For instance, he used a lab activity for determining relative reactivity of metals in electrochemistry. It was a good lab activity; however, he gave the purpose of the lab activity, the procedure, and how to do it. The only thing that learners should do was putting a piece of metals into different solutions. Although he stated that he want to use discovery strategy in his class, he did not focus on discovery strategy. He just tries to provide the necessary content to learners with help of hands-on lab activity. Due to the fact that he provided purposes, design, and procedure to learners, his other central goal that was to develop science-process skills formed another inconsistency detected.

Yet another example related to discrepancies was about teaching didactically. Mrs. Ertan put the “didactic teaching” scenario to ‘not agree’ category.

> **Scenario-1:** A good way to effectively teach students about fusion and fission is by lecturing and using the blackboard to draw sample reactions and tell the students the differences between fusion and fission reactions.

However, I observed that she taught fission and fusion reactions exactly the same way stated in the scenario-1. She taught fission and fusion didactically in two days and in the last day of that week, she used domino activity to show how fission used in atomic bomb and nuclear reactor. The activity was used after providing the knowledge traditionally (**Field Notes, week-3**).

Finally, in terms of peripheral goals, Mr. Demir stated that it is important to provide knowledge about history of development of concepts in card-sorting activity; he did not mention it at all. When asked about them, he explained the possible reasons of the discrepancies:

> Curriculum is too loaded. It is stated that learners should learn by doing, though making projects and research. However, it is impossible to do that because of the curriculum load. If used all of them, I think, I would teach one third of the 11th grade curriculum…..Although we focus on mandated objective in the curriculum, we do not know whether questions will be asked from all of them in the exam [university entrance exam]. We do focus on objective, but after the university entrance exam, parents will complain about our teaching and want us to teach for that exam….So, it seems the purpose is not preparing learners to link chemistry and daily-life, rather, preparing them for the exam **(Card-sorting activity, Mr. Demir, p. 2-3)**.

In light of the data gathered, it seems that they both have a didactic orientation for 11th grade chemistry course for science majors. However, it is not purely traditional. By the use of hands-on activities, analogies, animations, and discussions on environmental issues, their traditional teaching was supplemented. They stated that due to time limitation caused by loaded curriculum and university entrance exam, they had to shift their ideal focus to real one which helps them to handle with reality of the Turkish education system.

4.2.2. Knowledge of Instructional Strategy

When the data were analyzed, we came up with two instruction types used by the Mr. Demir and Mrs. Ertan in electrochemistry and radioactivity. One of them is '*content-based and teacher-centered instruction*' and the other was '*less teacher-centered instruction enriched with implicit NOS and discussion on Science-Technology-Society-Environment (STSE)*'. First, the description of the both categories was provided, and then the summary table showing the features of them were given. Finally, examples taken from the teachers' instruction were presented to make what I meant with the instruction types.

First, "*Content-based and teacher-centered instruction*" refers to the instruction in which teacher is the source of knowledge. They did not share the responsibility with learners. Content, algorithmic calculations and concepts were the aspects stressed in this type of instruction. These aspects were delivered by the use of didactic teaching, representations, teacher demonstrations, hands-on activity, daily-use of the topic, performing exercises, and comparison of concepts.

In this type of instruction, teachers always presented the content through didactic teaching at the very beginning (Table 10). After that, they provided an exercise to apply the knowledge presented. They always performed the first exercise and stressed the important points that learners should be careful about. Then, they made students perform others on the board. Finally, following teaching and performing exercises, they implemented activity to attract learners' attention and to help learners remember the topic. The laboratory activity used was structured cookbook lab activity in which all procedure was provided.

Representations enriched didactic teaching to make the content more concrete and visual. The teacher demonstrations were also employed both at the beginning and at the end of the topic. To inform learners about daily-life, daily use of the topic was offered by teachers after teaching the topic. Finally, to help learners to discriminate the confusing concepts, comparisons of concepts were carried.

Second, *"less teacher-centered instruction enriched with implicit NOS and discussion on STSE"* refers to the instruction during which teachers mentioned NOS very implicitly, made discussion on energy and environmental issues in addition to content, daily use, and concepts. Teachers drew on didactic teaching, representations, activities, daily use, and comparing and contrasting concepts. However, in this type of instruction, teacher had less control on the learning process than they had in the former instruction type. Discussions regarding to effectiveness, cost, and effect of nuclear energy on environment, people, and society made learners active participants rather than passive listeners.

Didactic teaching was used at the very beginning of the topic with the same purpose; to provide necessary knowledge. Additionally, discussions which were held to satisfy learners' curiosity and to provide scientific-view regarding to energy made the teaching less teacher-centered and increased learners' participation. Teachers implied *'scientific knowledge is subject to change'* point during teaching in this type of instruction very implicitly. Different than the former instruction, there was no algorithmic calculation here. Representations supplemented teachers' teaching regarding to visualization. Hands-on activity was employed to help learners remember the content after teaching the topic. The concepts making learners confused were compared and contrasted as well. Finally, to notify learners about the daily use of the topic, teachers mentioned how we use them in our life after teaching the subject matter.

Table 10 shows the summary of both types of instruction.

Table 10. Two types of instruction labeled and their properties

<table>
<tr><th rowspan="2">Aspects stressed during the instruction</th><th colspan="4">LABEL: CONTENT-BASED AND TEACHER-CENTERED INSTRUCTION</th><th colspan="4">LABEL: LESS TEACHER-CENTERED INSTRUCTION ENRICHED WITH IMPLICIT NOS AND DISCUSSION ON STSE</th></tr>
<tr><td colspan="2">The way of delivering (How)</td><td>Time for the use (when)</td><td>Purpose of the use (why)</td><td colspan="2">The way of delivering (How)</td><td>Time for the use (when)</td><td>Purpose of the use (why)</td></tr>
<tr><td rowspan="5">Content</td><td colspan="2">Didactic Teaching</td><td>At the beginning of the topic</td><td>To provide knowledge necessary to learn the topic</td><td colspan="2">Didactic Teaching</td><td>At the beginning of the topic</td><td>To provide knowledge necessary to learn the topic</td></tr>
<tr><td colspan="2">Representations and analogies</td><td>During teaching</td><td>To make more concrete and visual</td><td colspan="2">Representations</td><td>During teaching</td><td>To ask question and make students think on the reactions, to make more concrete</td></tr>
<tr><td rowspan="2">Activity</td><td>Teacher demonstration</td><td>Before and after teaching the topic</td><td rowspan="2">To attract attention and to help learners remember</td><td rowspan="2">Activity</td><td>Teacher demonstration</td><td>-----</td><td rowspan="2">to help learners remember</td></tr>
<tr><td>Hands on activity</td><td>After teaching the topic</td><td>Hands on activity</td><td>After teaching the topic</td></tr>
<tr><td colspan="2">Daily use of electrochemistry</td><td>After teaching the topic</td><td>To relate chemistry to daily-life</td><td colspan="2">Daily use of radioactivity</td><td>After teaching the topic</td><td>To relate chemistry to daily-life</td></tr>
</table>

Table 10 (continued)

Algorithmic Calculations	**Performing exercises**	After providing the necessary information didactically	To make them use the knowledge given, to help them learn the knowledge taught, to talk about the important points	**Not mentioned**	-	-
Comparison among the concepts confused	**Comparing and contrasting them verbally and/or by the use of a table**	At the beginning of the topic and during teaching it when necessary	To prevent learners to confuse them	**Comparing and contrasting them verbally and/or by the use of a table**	At the beginning of the topic and during teaching it when necessary	To prevent learners to confuse them
Implicit NOS Teaching	**Not mentioned**	-	-	**Implicit, mention didactically**	During teaching the topic	To help learns to think that scientific knowledge is subject to change
STSE	**Not mentioned**	-	-	**STSE**	During teaching the topic	To satisfy learners' curiosity, to provide scientific- view regarding to nuclear energy

Table 11. Types of instructions used in electrochemistry and radioactivity

Participants	**Electrochemistry**	**Radioactivity**
Both Mr. Demir and Mrs. Ertan	Content-based and teacher-centered instruction	Less teacher-centered Instruction enriched with implicit NOS and discussion on STSE

Data analysis showed that both teachers used a ‘Content-based and teacher-centered instruction’ to teach electrochemistry whereas used a ‘Less teacher-centered instruction enriched with implicit NOS and discussion on STSE’ in radioactivity (Table 11). Below, the details of teachers’ instruction in both electrochemistry and radioactivity were summarized by the use of the data collected through multiple data sources (e.g. interviews and observations).

4.2.2.1. Content-based and Teacher-centered Instruction in Electrochemistry

4.2.2.1.2. Subject-specific Instructional Strategy

None of the teachers used subject-specific strategy (e.g. 5E, inquiry, etc.) during teaching electrochemistry.

4.2.2.1.3. Topic-specific Instructional Strategy

Topic-specific strategies implemented by teachers were summarized under to sub-titles, namely, activities and representations.

Both Mr. Demir and Mrs. Ertan employed content-based and teacher-centered instruction in order to teach electrochemistry. In other words, their instruction was mainly based on transmission of knowledge to students. For example, after taking students’ ideas about electrochemical cell, Mr. Demir provided the knowledge directly: started the electrochemical cells with a question:

> Mr. Demir: What is an electrochemical cell?"
> Student-1(Std): Cells containing chemicals.
> Std-2: It is producing energy during a chemical reaction.
> Mr. Demir: If we can produce electricity because of a reaction, it is electrochemical cell. So, how can we get it? (**Field notes, week-4, p.32**).

After taking students' ideas about it, he provided the knowledge directly:

> If we want to produce electricity, the electrons should be moved from one part to other. In here [redox reaction occurring in a beaker] electron transfer occurs in the solution. It should be transferable if we want to get electricity. Here, there is no electricity because oxidation and reduction occur in the same container and simultaneously. If we do it in separate containers, we can get it **(Field notes, week-4, p. 33)**.

Then, he showed a video providing the information that students were supposed to learn (e.g. how to determine anode, cathode, and the direction of the flow of electrons, etc.). In the next day, he drew a zinc-cupper (Zn-Cu) cell on the board and started to teach it in detail. Later, he performed exercises related to electrochemical cells, how to determine anode and cathode, and calculations of potentials of cells on the board. For example, he performed the Zn-H_2 and Cu-H_2 cells on the board and then they performed the others together. Finally, at the end of the cells topic, teacher's demonstration related to Zn-Cu cell was employed by Mr. Demir. He showed how to make an electrochemical cell by the use of Cu-and Zn electrodes, $Zn(NO_3)_2$ and $Cu(NO_3)_2$ electrolytes, and salt bridge filled with KNO_3 solution. He mentioned oxidation of zinc electrode from zinc atom (Zn^0) to zinc ion (Zn^{2+}) and the reduction of cupper ion (Cu^{2+}) to cupper atom (Cu^0). Learners were standing around the bench on which he was demonstrating and observing him. The instance provided above from electrochemical cells was a highly representative example of both Mr. Demir and Mrs. Ertan's teaching in electrochemistry.

During electrochemistry, they used two teacher demonstrations and one hands-on activity. One of the teacher demonstrations was implemented to show the color change during redox reactions between Zn metal and $Cu(NO_3)_2$ electrolyte at the beginning of the topic. The second one was demonstrated after teaching electrochemical cells (Zn-Cu cell). The purpose of the demonstrations was again to make the topic more concrete and to help learner remember it later. The only laboratory activity they implemented in electrochemistry was *'Reactivity of Metals'* employed after teaching reactivity of metals didactically. The activity was structured, and the purpose and the process that learners should follow were given in the hand out. They were supposed to sequence of metals (e.g. Zn, Cu, iron (Fe), Magnesium (Mg) and Hydrogen ion (H^+) with help of their observation of reactions among them.

Second, in addition to demonstration and laboratory activity, teachers also used many representations for teaching the different sub-sections of electrochemistry. Symbolic representation of the reactions and macroscopic drawings of cells were always provided to learners. Sub-microscopic representations of redox reactions were overlooked a bit when it was compared to macroscopic and symbolic levels. Sub-microscopic level was mentioned during the animation used for electrochemical cells topic (**Field note, week-4, p.34**). Furthermore, a video related to cell formation and cell components were shown to make the topic more concrete. Yet another type of representation put into practice was analogy. For instance, Mrs. Ertan used a waterfall analogy in order to tell the spontaneity of the reactions occurring in the electrochemical cells. She stated: "As in waterfall, there is a flow from high potential to low one. The direction of electron flow is from anode to cathode. Then, the potential of anode is higher than that of cathode." **(Field note, p.36)** When asked the reason of use of analogy during the interview, she said:

> …to help learners understand that the reactions focused in the cells are spontaneous, which is similar to movement of water from higher point to lower one. The electrons move from electrode with higher potential to other with lower potential. They can visualize it better with the analogy **(interview 1-5, p.1).**

Similar to analogies, both participants developed varying representations to help learners understand the topic. For instance, Mr. Demir and B used a representation (Figure 14) in which an arrow to help learners understand whether an atom and/or ion was oxidized or reduced during the reaction. Learners had difficulty in determining the oxidized and reduced species in the cell.

Mr. Demir	**Mrs. Ertan**
Fe: (+3) $\longrightarrow$ (0)	Mn: +7 $\longrightarrow$ +4 (reduced)
Zn: (0) $\longrightarrow$ (+2)	C: +3 $\longrightarrow$ +4 (oxidized)

Figure 14. Representation used to indicate the changes in oxidation number

Both teachers focused on the whether the species received or gave electron. They stressed that if electron is received, there is a decrease in the oxidation number as in the Fe^{+3} ion. It received three electrons, which resulted in a decrease from (+3) to (0).

Yet another representation used in the electrochemistry was related to Standard Hydrogen electrode (SHE). Mr. Demir tried to tell the relative potentials determined by the use of SHE and stressed:

> We select Hydrogen electrode as a reference point and we determine the others' potentials relatively to Hydrogen electrode's potential. (**Field notes, week-5, p.39)**

He related the height difference among the lines in the representation (Figure 15) and how SHE is used in chemistry. He stated that the values given for oxidation or reduction potentials are not absolute values rather they are the relative values. SHE is used as a reference point **(Field notes, week-5, p.39, interview 1-5)**

Zn 0.76 V

H_2 0.0 V

Cu -0.34 V

Figure 15. Representation of relative oxidation potential of Zn, H_2, and Cu

Another important aspect of their instructional strategy was the comparisons that they made between the concepts that confused students. Whenever necessary they either compared them verbally or provided a comparison table showing the differences and similarities between them. For instance, Mr. Demir stated that students have difficulty in discriminating electrochemical and electrolytic cells in the

CoRe interview (**p.2**). Then, he provided a table comparing and contrasting electrochemical and electrolytic cells at the beginning of the electrolytic cells (Table 12) (**Field Notes, Week-6, p.51)**

Table 12. Comparing and contrasting electrochemical and electrolytic cells

Relationship between Cell Potentials, E, and Free-Energy Changes, ΔG			
Reaction Type	**E**	**ΔG**	**Cell Type**
Spontaneous	+	-	Galvanic
Nonspontaneous	-	+	Electrolytic
Equilibrium	0	0	Dead battery

He also stressed the differences verbally.

> Last week we said that redox reactions can be spontaneous and non-spontaneous. If it is spontaneous, it produces energy whereas if it is non-spontaneous, it requires energy to proceeds….The biggest difference between them is that energy is produced electrochemical cells which are spontaneous reactions. However, reactions occurring in electrolytic cells are non-spontaneous and necessitate energy to proceed. The same events [in terms of the place where oxidation and reduction reactions occur] occur in the anode and cathode of both cells. The only difference regarding to the half cells are the signs of them [sign of anode and cathode]" (**Field Note, Week-7, p.53)**

Mrs. Ertan also utilized the same comparison table in her class:

> We finished electrochemical cells. And now we are starting electrolytic cells. Is there any difference between them? Why do we separate them?" One of the students said that electrochemical cells include two containers but electrolytic cell has only one. Then she started to tell the differences. She added the signs of electrodes, use of production of electricity to the comparison table (**Field Note, p.50).**

Finally, they mentioned the daily use of electrochemical and electrolytic cells. They provided electrochemical cell types used in daily life, for instance, dry cell, Nickel-Cadmium (Ni-Cd) cells, watch cell, etc. Some knowledge related to cell ingredients and photo of the different types of cells at macroscopic level were given by the use of PowerPoint slayts. Moreover, Mr. Demir taught how cathodic protection is used to protect ships and other metal materials from corrosion didactically (**Field notes, week-6, and p.50-51)**. In the interview conducted at the end of the week, the reason of teaching daily use of cells and cathodic protection was asked:

> **Researcher (R):** You mentioned daily use of cells and try to relate the topic to daily-life. Could please tell me about its importance for students and for you?
>
> **Mr. Demir:** It would be more permanent. It is especially related to my personal…I am interested in those kind of stuff so I always relate the topic to daily life. I try to give examples of the use of them. It makes the knowledge more permanent (**Interview, 1-5, p.1-2**).

Similar point was stated by Mrs. Ertan as well:

> The learning is more permanent if we relate the topic to daily life. We talked about the car batteries….And also to help them to learn the working principles of the stuff used in life **(Interview, 1-5, p.6)**.

To sum up, both Mr. Demir and Mrs. Ertan's instruction was similar mostly depending on transition of knowledge from teacher to learners. They mostly focused on the content.

4.2.2.2. Less teacher-centered Instruction Enriched with Implicit NOS and Discussion on STSE in Radioactivity

4.2.2.2.2. Subject-specific Instructional Strategy

None of the teachers used subject-specific strategy (e.g. 5E, inquiry, etc.) during teaching radioactivity.

4.2.2.2.3. Topic-specific Instructional Strategy

First, in the radioactivity part, both teachers started with the nucleus of the atom and reminded students what nucleon is, sub-atomic particles forming the nucleus, and atomic and mass number of the atom. Then, they started to teach the Standard Model didactically. However, in radioactivity, the way of participants' didactic teaching was somewhat different than that of teaching electrochemistry. For instance, they implicitly addressed one aspect of nature of science (NOS), that is, science is subject to change. In Mr. Demir's class, students had confusion when they were talking about quarks and leptons in Standard Model. One of the students asked whether quarks and leptons have sub-particles or not.

> **Mr. Demir:** We do not know yet. Before those [leptons and quarks], we just had known proton and neutron. There may be others. Later with help of new technologies….We could not explain how protons and neutrons were holding in the past but now we can do that.
> **Std:** So, did they [scientists] deceive us? Were they all lies?"
> **Mr. Demir:** Before the recent research, we had not known them (**Field Note, week-1, p. 63-64**).

When asked in the interview, he said:

> [Scientists] do not say that [leptons and quarks] do not have sub-particles. They do say that these are the things that we know now. It is a theory used to explain the phenomena. In near future, scientists may refute it. But it is hard for learners to understand it (**Interview, 2-1, p. 1**).

Correspondingly, Mrs. Ertan introduced the same point in her class implicitly. After mentioning the prior knowledge the learners learned in the previous grades, she added:

> A short time ago scientists thought that proton, neutron, and electron were the smallest particles of the atom. However, recent research, you remember we talked about research has been conducted in CERN [The European Organization for Nuclear Research], showed that there are sub-atomic particles smaller than those (**Field notes, p.64)**.

Then, one of the learners asked whether it is possible to convert a proton into a by changing the quarks that proton has. Mrs. Ertan said that she does not know it and added scientist may not be able to do it now but they may be able to achieve it in near future. Through the teaching of radioactivity, both teachers mentioned constantly that in light of the results gathered from continuing research, the knowledge we know now may be replaced with the new one. However, they did not explicitly say that science is subject to change or engage students in discussion or reflection on this idea.

Another characteristic of this style of teaching was increasing amount of dialog between learners and the teachers. Especially, questioning and discussions were integrated to teaching fission, energy issues, and effects of radioactivity sub-topics.

Mr. Demir: How do we benefit from fission reactions?
Stds:….
Mr. Demir: Where?
Std-1: To make Atomic Bomb.
Mr. Demir: And?
Std-2: Hydrogen Bomb?
Mr. Demir: No, it is fusion reaction….A huge amount of energy is released during fission reactions. If the energy released is controlled, it is nuclear power plant. How is it controlled in nuclear reactors?
Std-3: We can make it in thick lead blocks.
Mr. Demir: How can you control energy with lead block?
Std-4: They use cold water in reactors.
Mr. Demir: It is used for energy transfer. What I want to ask is that how we can use the atomic bomb reaction in the reactor? It is a huge amount of energy but it is not released all of a sudden. How can scientists achieve it?
Std-3: We can use less amount of Uranium. If we use less Uranium, the energy released would be less too.
Std-5: We can use isotopes of Uranium.
Std-4: The neutrons produced have to be caught.
Mr. Demir: The thing that you should do is catching the neutrons produced in order to impede them to collide with other Uranium atoms.
Std-3: It is decreasing the amount of energy released.
Mr. Demir: To do it, control rods are used (**Field note, week-3, p.80-81)**.

In addition to dialog and questioning, they discussed energy produced, effectiveness of nuclear power plants, and environmental issues.

Std-3: Why does the reactor warm up?
Mr. Demir: Energy is produced and heats the reactor.
Std-3: How do they cool it?
Mr. Demir: They use water. That is the reason why they build them near to river and lake. But the water cooling system has a bad effect on the environment.
Std-1: Radioactive waste may contaminate the river or lake.
Mr. Demir: Yes, possible. Second, when you heated the water, what would be the amount of oxygen dissolved in that water?
Stds: would decrease.
Mr. Demir: It threatens life of fish and other living organism in the river and lake.
Std-4: Is not it also expensive to build nuclear reactors?
Mr. Demir: Initial cost is expensive but then it is not.
Std-5: We can use wind power.
Mr. Demir: It is not efficient. Actually, analysis of energy need should be conducted for Turkey. How much energy do we need in 10 or 20 years? How much of that energy need can be supplied from wind power and hydroelectric

power plant. We buy natural gas from Russia to heat water in hydroelectric power plant. Neither is it efficient.
….
Std-5: How many percent of the energy need of the country is produced in a hydroelectric power plant?
Mr. Demir: I do not know but may be about 3%.
Std-5: If we compare the energy produced in a power plant with that of Ataturk hydroelectric power plant?
Mr. Demir: It may not be.
Std-5: Then, we should build hydroelectric power plant.
Std-6: But hydroelectric power plant has a life time because of the soil fills it.
Mr. Demir: Ok. They all have both advantages and disadvantages. So, the evaluation of them should be done carefully (**Fields notes, week-3, p. 83-84)**.

In the same way, Mrs. Ertan and the learners in her class also discussed the same points. She realized that learners were very interested in nuclear energy and atomic bombs, and their effect on people and environment. One of the learners asked permission to make a presentation on World War II (WW-II), the atomic bomb, and the Chernobyl accident. She allowed him to make the presentation lasting about 40 minutes in the next week. The learner mentioned historical, political, and social aspects of WW-II atomic bomb, and gave some numbers about how many people died and how long the effect of it lasted. Furthermore, about Chernobyl accident he provided information about the places that were affected by the accident, the reason of it, and finally he compared the Fukushima disaster occurred in Japan because of Tsunami in 2011. At the end of the presentation, Mrs. Ertan and learners made a summary together.

In addition to discussions and comparisons, both Mr. Demir and Mrs. Ertan implemented an activity after teaching the topic. The activity was *"Domino Activity"* for helping learners understand how fission reactions are different for atomic bomb and nuclear reactors. After the fission and fusion reactions, they provided information about how learners do the activity. First, they were supposed to build a straight line of dominoes and then knock them down. During the process, they measured the time necessary for knocking down all the dominoes used. Second, with the same number of dominoes, they would build another shape shown below (Figure 17).

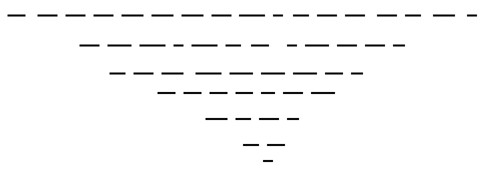


Figure 16. The shape of the dominoes for representing fission in atomic bomb

They would knock down the dominoes and measured the time. Teachers asked them to compare the times measured for both arrangements of dominoes. Learners did the activity in groups of four or five learners. The time for straight line arrangement was shorter than the other. At the end of the activity, Mr. Demir asked which one is atomic bomb and which one is nuclear reactor. They stated that the first one represents nuclear reactor whereas the second one is atomic bomb. When asked in the interview, he stated that the purpose was not to teach new knowledge rather making the knowledge taught permanent.

> It was to show that what chain reaction is and they can occur in different ways. It was for those purposes. I had taught that they can occur in different ways before so it was for making the knowledge more permanent. I believe that now it is more permanent (**Interview, 2-3, p.3**).

Mrs. Ertan started the activity by reminding the two uses of fission reactions to make atomic bomb and to produce energy in reactors. After the instruction about how to do the activity, learners did it. At the end, they talked about which one represented atomic bomb and which one represents nuclear power plant.

Yet another feature of the instruction used in radioactivity was lack of algorithmic calculations. Although they spent much time on performing exercises and making students perform them in electrochemistry, in the radioactivity topic, that time was spent for questioning and discussions related to the topic.

Second, in this type of instruction, representations at different levels were applied commonly. In terms of the number, more representations were used in the radioactivity than that of in electrochemistry. In radioactivity, the representations employed were generally symbolic representations of all nuclear reactions mentioned, sub-microscopic representations of fission and fusion reactions with colorful circles showing neutrons and protons, and pictures of a nuclear power plant built near to river, control rods used in nuclear reactors to keep neutrons produced during fission reactions. Moreover, they used some of the representations during the questioning and discussion.

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow [^{236}_{92}U] \text{ (unstable)}$$

$$^{236}_{92}U \longrightarrow ^{90}_{38}Sr + ^{143}_{54}Xe + 3\ ^{1}_{0}n$$

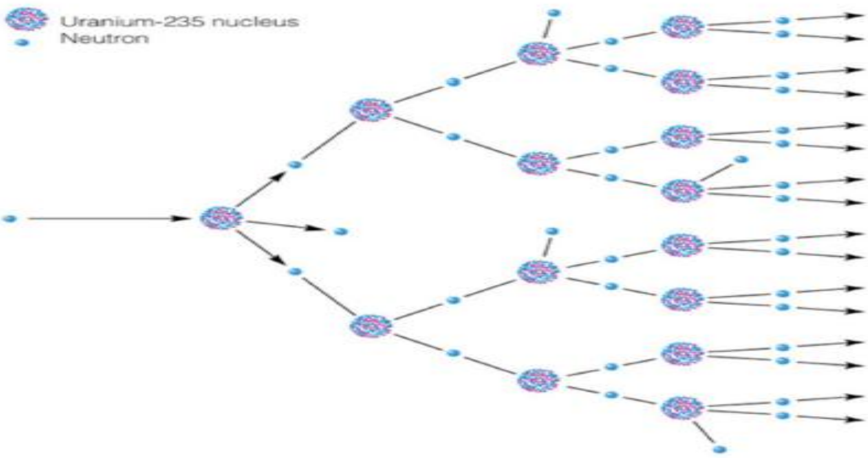


Figure 17. Representation at symbolic and sub-atomic levels used to show fission reaction

For instance, Mr. Demir showed the chain reaction's symbolic and sub-microscopic representations to ask how the energy released during fission reaction can be controlled in nuclear power plants. They talked on the representations showing the reactants and products of the fission reaction (Figure 16). Although he utilized representations to make the topic more concrete in electrochemistry, he used representations to make discussions on them as well as to make the topic more concrete in radioactivity (Figure 16).

Regarding to representations, Mr. Demir and Mrs. Ertan did not use any analogy in teaching radioactivity.

In radioactivity, comparisons of concepts verbally and/or with help of a comparison table was employed and this helped learners distinguish them. Comparison of chemical and nuclear reactions and stressing the differences were done at the beginning of the Radioactivity. Mrs. Ertan, compared and contrasted them in terms of energy released during the reactions, the nature of the products produced, the effect of temperature and pressure on them, and the isotopes' reactivity in chemical and nuclear reactions (**Field Note, p. 73)**. Similarly, Mr. Demir also compared and contrasted them. When asked the reason of the comparison:

> To hinder students from relating chemical and nuclear reactions… They are quite different from each other. Sometimes they think that if pressure changes, nuclear reaction will change too. In chemical reactions they know that pressure affects on reaction. Here, they have a tendency to think in a similar way (**Interview, 2-1, p.1**).

Summary tables were also used to show quarks and their properties (symbol, flavor, charge, etc.) (Table 13), and the types of decays, their penetrating effect, and energy.

Table 13. Summary table used by teachers for properties of quarks

Quark	**Symbol**	**Flavor**	**Charge**	**Mass (MeV)**
Up	u	I_z=+1/2	+2/3	1.5 to 4.0
Down	d	I_z= - 1/2	-1/3	4 to 8
Strange	s	S= - 1	-1/3	80 to 130
Charm	c	C= 1	+2/3	1150 to 1350
Bottom	b	B'= - 1	-1/3	4100 to 4400
Top	t	T= 1	+2/3	171400 ±2100

They also underlined the similarities and differences between the fission and fusion reactions. Moreover, fission reactions used to make atomic bomb and used to produce energy in nuclear power plants were also compared and contrasted by both teachers verbally.

Like in electrochemistry, both teachers mentioned the daily-life use of radioactivity after teaching the topic. The use of radioactivity regarding to X-ray in medicine, food irradiation, external radiation therapy, radiocarbon dating in archeology, and nuclear power plants were mentioned.

> Gamma Rays given off by the radioactive isotope of ^{60}Co are directed at the tumors because Gamma Rays can penetrate into the deepest cells in the body and kill them by breaking covalent bonds in proteins and DNA, carefully controlled and focused doses of gamma radiation can destroy cancer cells **(Mrs. Ertan, Field notes, p. 92)**.
>
> It is [food irradiation] used in order to destroy the bacteria existing in food. So, shelf-life is increased for food. The dose of radiation exposed to food is low for preventing the damage on people **(Mr. Demir, Field note, p. 88)**.

4.2.3. Knowledge of Curriculum

Related to knowledge of curriculum use, two categories were formed, namely, "n*etwork of topics*" and "*limited network of topics*". The characteristics of both groups were given in the following part.

"*Network of topics*" refers to the use of curriculum knowledge by relating the topic to the other topics taught in previous grades (vertical relations), topics taught earlier in the same grade (horizontal relations), and topics taught in other courses (e.g. physics). The purposes of forming networks were to make learners remember the previous topics learned, to help them relate new and previous ones, and to make them to look over the previous topic. The vertical relations were achieved through mentioning the previous topic, asking questions that help learners to understand the relation, and stating that they already learnt it and need to go through it especially at the beginning of the instruction and/or activity. Horizontal relations to previous topics in the same grade were realized to make learning the new topic easier.

Teachers taught the new topic by using the previous one as a base for the subsequent one.

In addition to links to prior topics, teachers having network of topics curriculum knowledge, criticized the sequence of the sub-topics and altered the sequence of them in order to eliminate learners' difficulty in understanding the topic.

Finally, teachers were aware of the purposes and goals stated in the national curriculum and taught the topic as indicated in the program. They paid attention to follow all warnings and limitations related to what extent the topic should be taught.

In this type of curricular knowledge use, teachers made some links to topics taught in previous grade (vertical relation), and to the topics taught in physics. However, the amount of connection between topics was quite limited when it is compared to those made in the previous category. Furthermore, the explanation provided during relating the topics were also highly superficial in this type of curriculum use. In contrast to first category, no horizontal relation to the topics previously taught in the same grade was observed. Additionally, although teachers made some changes in the sequence of sub-topics in the previous category, no critic on the sequence was observed here. Finally, teachers paid attention to goals and objectives, and reflected the limitations and suggestions given in the curriculum. Table 14 shows the summary of both use of knowledge of curriculum.

Table 14. Use of knowledge of curriculum for teaching

<table>
<tr><th>Topic</th><th colspan="2">The way of using curricular knowledge</th><th>Purpose</th><th>How</th><th>When</th><th>LABEL</th></tr>
<tr><td rowspan="4">ELECTRCHEMISTRY</td><td rowspan="2">Relating to other topics</td><td>Vertical relation to topics taught in previous grades</td><td>to make learners remember the topics learned,
to help them relate new and previous topics, and
to warn them to look over the previous topic that will be used now</td><td>Mentioning the related previous topic
Asking questions that help learners to get the relation
Stating that they already learnt it and need to go through it</td><td>At the beginning of the instruction and/or activity</td><td rowspan="4">NETWORK of TOPICS</td></tr>
<tr><td>Horizontal relation to topics taught earlier in this year</td><td>to make learning the new part easier</td><td>Explaining the events occurring in the new part by the use of information provided in the previous units didactically on examples</td><td>During teaching</td></tr>
<tr><td>Relating to other disciplines</td><td>Relation to physics</td><td>To help them remember the knowledge learned

To explain a part which creates a conflict</td><td>Asking questions that help learners to get the relation

Explaining the confusing point</td><td>During the activity
At the beginning of the topic</td></tr>
<tr><td colspan="2">Altering the curriculum</td><td>To solve learners’ difficulty in the latter topic due to the requirement use of some parts in the latter during teaching the former one</td><td>Changing the sequence of the and starting with the latter one</td><td>After realizing the learners’ difficulty</td></tr>
</table>

Table 14 (continued)

	Paying attention to the objectives and the specific warnings stated in the curriculum		To teach the topic as indicated in the national curriculum	Obeying the all warnings provided and Checking the objectives all the time	During teaching Before teaching, during planning	
RADIOACTIVITY	The way of using curricular knowledge		**Purpose**	**How**	**When**	**LABEL**
	Relating to other topics	Vertical relation to topics taught in previous grades	To make learners remember the topics that they learned and	Relating previous topic and giving some explanations	During teaching	**LIMITED NETWORK of TOPICS**
		Relation to physics topics	To help them remember the knowledge learned in physics to use in radioactivity	Mentioning the related part	At the beginning of the topic	
	Altering the curriculum		---	---	---	
	Paying attention to the objectives and the specific warnings stated in the curriculum		To teach the topic as indicated in the national curriculum	Obeying the all warnings provided, Checking the objectives all the time	During teaching Before teaching, during planning	

Table 15. Types of curriculum knowledge use by Mr. Demir and Mrs. Ertan in electrochemistry and radioactivity

Participants	**Electrochemistry**	**Radioactivity**
Both Mr. Demir and Mrs. Ertan	Network of topics	Limited network of topics

In light of the data collected, teachers' use of curriculum knowledge was categorized. Both teachers' curriculum knowledge use in electrochemistry was placed in" Network of topics" category whereas it was placed in "limited network of topics" category for teaching radioactivity (Table 15). Below, both categories were elaborated with the examples from both participants' applications.

4.2.3.1. The network of Topics in Teaching Electrochemistry

Analysis of the data showed that Mr. Demir and Mrs. Ertan connected electrochemistry to the topics taught in previous years (e.g. types of reactions, how to assign oxidation number, etc.), to topics taught earlier in the academic year (e.g. spontaneity of chemical reactions, chemical equilibrium, spectator ions etc.), and to topics taught in physics (e.g. electricity). It was obvious that teachers used knowledge previously taught in chemistry and in physics.

4.2.3.1.1. Vertical Relations

First, at the beginning of the topic, Mrs. Ertan asked:

> If we turn back to 9th grade…You learned redox reactions. What are they? What did you learn? (**Field notes, p.1**)

She took learners' ideas. After taking their ideas, she stated that they would learn more about redox reactions and cells. When asked the reason of relating the topics in chemistry curriculum vertically, she stated:

> First of all, it helps learners to remember. Moreover, the links to the related topics help learners to see the how they are interrelated **(Interview, 1-1, p.1)**.

In addition to helping learners, another purpose of using curricular relations was to warn learners about their shortcomings in previous topics. For instance, to be able to learn electrochemical cells, learners are supposed to know redox reactions, and oxidizing and reducing agent. Mr. Demir mentioned that redox reactions were taught in 9th grade-chemistry. However, his observations noticed him that learners could not remember them well. Therefore, he stated that they already learned them in 9th grade and warned them about the difficulty that they would face with in learning electrochemical cells.

4.2.3.1.2. Horizontal Relations

Second, they made links to the previous topics in 11th grade chemistry curriculum as well. For instance, during Nernst Equation used for calculation of cell potentials for non-standard conditions, both participants associated the topic with Le Chatelier's Principle in chemical equilibrium. The part provided below was taken from Mrs. Ertan's class observed:

She wrote the reaction between Zn and Cu^{+2} ion:

$$Zn\ (s) + Cu^{+2}\ (aq) \rightleftharpoons Zn^{+2}(aq) + Cu\ (s)$$

Then, Mrs. Ertan asked:

> When I thought the cell reaction as equilibrium, how can I write the equilibrium constant, K?

They together wrote the constant:

$$K= [Zn^{+2}] / [Cu^{+2}]$$

They talked about the changes made on the equilibrium and the cell potential. One of students said that they should increase the concentration of Cu^{+2} ion **(Field note, p.**

45). During the interview, she stated that the link of chemical equilibrium to cell potential for non-standard conditions would make learning the new knowledge easier:

> If the cells at non-standard conditions are taught by the use of Chemical Equilibrium, it is so simple to understand. If not, students try to memorize everything about it. Because they already know equilibrium, they do not have difficulty in understanding the cells at non-standard conditions **(Interview-1,5, p.4-5)**.

4.2.3.1.3. Relation to Other Disciplines

Participants also interconnected electrochemistry to the physics topics taught. For instance, during the calculations in Faraday's Law in electrolytic cells, there were electrolytic cells connected in series. The question was: 0.05 F electricity is passed through solutions of $AgNO_3$ and $CuSO_4$ arranged in series. How many grams of metallic silver and copper are produced in the system? Mr. Demir drew the system on the board (Figure 18).

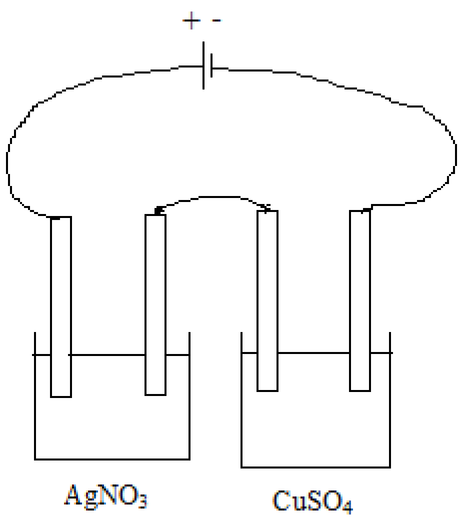


Figure 18. Electrolytic cells connected in series

> **Mr. Demir:** What are the properties of series circuits? Remember from Physics class. The same amount of current goes through the circuit, right? Therefore, if the 0.06 moles of electron passes through the first container, how many moles of electrons would pass through the second one? It would be the same.

> **Std-1:** What about parallel arrangements?
> **Mr. Demir:** In those systems, the voltage is constant, it is the same; however, the current is not. It changes. In serial arrangements, on the contrary, the current is the same (**Field note, week-7, p.61**).

He also mentioned the circuits connected in parallel and series during the teacher demonstration in electrochemical cells in the same way he did above **(Field notes, week-6, p.49)**.

Another example of mentioning physics topic was observed during electrochemical cells. In Physics, students learned that the electricity flows from (+) terminal to (-) one. In chemistry, however, Mr. Demir stated that electrons flow from anode signed (-) to cathode signed (+). So learners asked the direction of the flow:

> Here, we are talking about the electron flow not about current flow. Before the discovery of electron flow, early physicists described it from (+) to (-). Later it was realized that it is not the case for electron flow **(Field notes, week-4, p. 34)**.

To sum up, he used Physics knowledge to explain a part creating conflict between chemistry and physics.

4.2.3.1.4. Altering the Curriculum

In addition to connections to the topics in chemistry and physics high school curriculum, Mr. Demir and Mrs. Ertan used their curriculum knowledge to make change the sequence of the sub-topics in Electrochemistry. For instance, Mr. Demir decided to teach “oxidation number” first and then “competition for electron” topic later in contrast to curriculum. The reason of the change in the sequence was asked in the interview 1-2.

> The reason is learners’ difficulty in remembering the oxidation numbers. We assume that they had already known the oxidation numbers and mention them after competition for electron part. However, because I realized that students have big problems related to assigning oxidation number, so, I decided to teach it first. After they learn it completely, I continued with competition for

> electrons. There was no problem in the flow of the lesson because of the decision that I took. Actually, it helped me so there is no regret to make it change **(p.1)**.

Similarly, both participants altered the sequence of “Calculations in Faraday’s Law” part after teaching the electrolytic cell rather than teaching at the beginning as suggested in the curriculum. They both stated that it does not make sense to teach it before teaching cells because they would eventually teach cells. Therefore, teaching the cells first and then preceding with the Faraday’s Law and its calculations made more sense to them.

4.2.3.1.5. Goals and Purposes, and Knowledge of the Program

Finally, Mr. Demir and Mrs. Ertan were knowledgeable about the chemistry curriculum. Moreover, they also paid attention to the objectives and the specific warnings stated in it. In the national high school chemistry curriculum, objectives and restrictions regarding amount of knowledge provided to learners are offered to all chemistry teachers. Participants were aware of all the objectives and suggestions about the limitations mentioned in the program. For instance, it was suggested to use of reduction potentials to determine anode and cathode in an electrochemical cell or to predict whether a reaction occurs between two species. They were aware of it before teaching. Therefore, they both always used reduction potentials in his teaching and exercises.

> Another example was providing daily life examples regarding to cells. Learners should be able to give examples of electrochemical cells **(NME, 2011, Objective 3.2, p. 65)**.

Both teachers provided examples of cells used in daily life (battery used in watch and remote control, and car battery), photos of them on the PowerPoint slayts, and some knowledge related to cell ingredients **(Field notes)**.

4.2.3.2 Limited Network of Topics in Teaching Radioactivity

In Radioactivity, Mr. Demir and Mrs. Ertan's curriculum knowledge was labeled with *limited network of topics* **(**Table 14). Results revealed that there were not as many vertical and horizontal connections to other chemistry topics as were in Electrochemistry. Mr. Demir formed links between Radioactivity-Atom and its Structure, and Radioactivity-Electromagnetic Radiation taught in chemistry in previous years. Mrs. Ertan related the topic only to Atom and its Structure topic. Moreover, both of them were aware of the objectives and limitations stated for shaping the instruction of Radioactivity in the curriculum.

4.2.3.2.1. Vertical Relations

First, both Mr. Demir and Mrs. Ertan the started introduction of the Radioactivity with atom, its structure, and sub-components. They picked and atom (e.g. Carbon-12) and made students remember atomic number, mass number, nucleon, and how to represent of all them (Figure 19). Mr. Demir mentioned all of them on C-12:

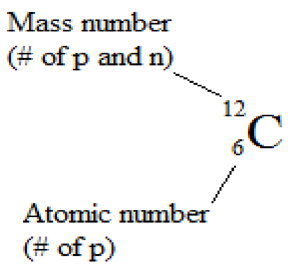


Figure 19. Atom, its structure, and sub-components

Another vertical link was identified when learners asked whether they are able to see the radioactive decays of uranium or not. Mr. Demir needed to talk about the 'Electromagnetic Radiation' taught in 10^{th} grade in 'The Structure of the Atom' topic in chemistry.

> Can you see radio waves or other waves? They are not visible. We mentioned that when we were talking about electromagnetic radiation. Please remember it from last year. You cannot see them **(Field Notes, Week-3, p.88)**.

When we talked about it, he said:

> Although they learned it, sometimes it happens. They always try to make it more concrete. In the structure of the Atom topic, they learned that the only part that can be seen is visible part in the spectrum. They also learned that although we cannot see the other parts of the spectrum, they exist. In this case, he could not make the relation between those two **(Interview, 2-3, p.2)**.

4.2.3.2.2. Horizontal Relations

In addition to vertical links to topics taught in previous years, analysis was done to check whether they made relations between radioactivity and previous topics taught in the 11th grade. However, no link was detected.

4.2.3.2.3. Relation to Other Disciplines

A link made to Physics curriculum was observed at the beginning of 'Basic Forces' topic. At the beginning of 'Basic Forces', in order to help learners remember the knowledge learned in physics, Mr. Demir just stated that they learned it Physics in 9th grade. However, no details were given regarding to how learners should link the topics. Similarly, Mrs. Ertan made a link to Physics during teaching types of radioactive decay. She stated that they learned them in physics without any explanation.

Second, in terms of debating the sequence offered in the curriculum and making changes on it, no example was detected (Table 13). In contrast to Electrochemistry, sequence of the topics was followed in Radioactivity.

4.2.3.2.4. Altering the Curriculum

No example of altering the sequence of sub-parts in radioactivity was observed.

4.2.3.2.5. Goals and Purposes, and Knowledge of the Program

Finally, regarding to being aware of the goals and objectives stated in the curriculum, similar to Electrochemistry, they were well-informed about them. Before they started to Radioactivity, they read objectives carefully and focused on the limitations mentioned in the curriculum document. For instance, there was an objective in the curriculum:

> Students should be able to discuss nuclear energy in teams of social, economic, and environment" (**Objective 2-5, p. 77, NME, 2011**).

During teaching the topic, whenever suitable, they discussed the nuclear energy regarding to different aspects mentioned in the curriculum such as economy or environment. During the discussion, they avoided to direct learners' ideas about nuclear energy. They provided scientific knowledge to them and stressed that it was an issue which should be taught from different perspectives (**Fields notes)**. (Discussion was provided under Instructional strategy part of the result chapter). Another example was observed in the writing equations for nuclear reactions. In the curriculum it was stated:

> The real examples are used in the calculations of atomic and mass numbers during nuclear changes and hypothetical examples of nuclear changes are not used in assessment **(NME, 2011, explanation for objective 2-1, p.77)**.

Therefore, both of the participants used real examples of nuclear reactions when teaching γ, β and α rays, and fission and fusion reactions. The purpose of the explanation provided in the curriculum was to prevent teachers from writing unreal equations to represent nuclear changes while teaching radioactivity. Moreover, some teachers wrote equations by the use of X, Y and Z to represent elements in the nuclear reactions rather than real radioactive elements such as U, Po, and Th. Mr. Demir and Mrs. Ertan used real nuclear elements during teaching radioactivity and in the test to assess students' learning. To sum up, they were aware of the objectives and suggestions provided in the curriculum.

4.2.4. Knowledge of Learner

The third PCK component focused on was the knowledge of learner. Results indicated that two types of knowledge of learner, namely, "*satisfactory knowledge of learner*" and "*deficient knowledge of learner*" were labeled. In this part, first, the characteristics of both types of knowledge of learner were presented (Table 16). Then, participants' knowledge of learner and how they used it in their teaching were summarized. Knowledge of learner component was examined under three sub-components that are learners' difficulties, misconceptions, and pre-requisite knowledge to learn the topic.

"Satisfactory knowledge of learner" refers to the awareness of difficulties, misconceptions, and pre-requisite knowledge that learners should have before learning the new topic (Table 16). Teachers in this category were conscious about the difficulties to eliminate them. Teachers sometimes used knowledge of learner before the difficulty occurred by alarming learners that previous learners had difficulty related to a particular point. Also, they used it after difficulty was observed by re-explaining the point creating the difficulty. In terms of misconceptions, teachers were aware of some of them. To address the misconceptions, they acted after they realized that learners had the misconceptions. When they noticed that learners had misconception, they provided the correct explanation and asked questions to create dissatisfaction with the misconception. Regarding to pre-requisite knowledge, teachers actively used this knowledge to make the learning of the new topic easy during teaching and to make learners remember the pre-requisite knowledge at the beginning of the topic. The methods of integrating the pre-requisite knowledge were teaching the new topic through the use of previous one, re-teaching the pre-requisite

knowledge when learners could not remember, and mentioning the old one superficially.

Another type of knowledge of learners identified was "*deficient knowledge of learner*" (Table 17). In this type, teachers were partially aware of difficulties and misconceptions that learners may have, and the pre-requisite knowledge. In contrast to the former category of knowledge of learner, it was not comprehensive. Moreover, they sometimes missed learners' difficulties and misconceptions. The major difference between the two categories was the quality of knowledge of learner that they have. Teachers used more or less the same strategies to eliminate difficulties and misconceptions. For instance, they provided the correct explanation and taking learners' attention to the point before difficulty occurred. Or, when they realized that learners had difficulty, to assist learners' understanding, they asked questions to help learner solve the difficulty. Regarding to pre-requisite knowledge, they only mentioned the pre-requisite knowledge, which far less that they did in the former category.

Table 16. Knowledge of learner for teaching different topics

Topic	Sub-components	Awareness	Purpose of use	Time	The way of using/handling	Label
ELECTROCHEMISTRY	**Difficulties**	**Complete awareness**	To eliminate the possibility of occurring the difficulty observed in previous learners and to assist learners' understanding	Before and after difficulty observed	Alarming and re-explaining the confusing point	**SATISFACTORY KNOWLEDGE of LEARNER**
			To eliminate the possibility of occurring the difficulty To provide explanation and to assist learners' understanding	Before and after difficulty observed	Providing explanations supported by the use of additional strategies/ materials (e.g. summary card, purposeful postpone of using the confusing parts, analogy, and representation	
	Misconceptions	**Partial awareness**	To eliminate the misconception	After misconception observed	Providing the correct explanation Asking questions to create dissatisfaction with the misconception	
	Pre-requisite knowledge	**Complete awareness**	to make the learning of the new topic easy and to make them remember the pre-requisite knowledge	At the beginning of the topic	Teaching the new one through the use of previous one and mentioning the old one	

Table 16 (continued)

Topic	Sub-components	Awareness	Purpose of use	Time	The way of using/handling	Label
RADIOACTIVITY	**Difficulty**	**Partial awareness**	To eliminate the possibility of occurring the difficulty observed in previous learners	At the beginning of the topic (before teaching)	Providing the correct explanation and taking learners' attention to the point	**DEFICIENT KNOWLEDGE of LEARNER**
			To assist learners' understanding	During teaching the topic	Providing the correct explanation and Using questioning technique to help learner find the answer	
	Misconception	**Partial awareness**	To eliminate the misconception	During teaching the topic	Providing the correct explanation	
	Pre-requisite knowledge	**Partial awareness**	to make them remember the pre-requisite knowledge	At the beginning of the topic	Just mentioning the old one	

Table 17. Types of knowledge of learner used in electrochemistry and radioactivity

Participants	Electrochemistry	Radioactivity
Both Mr. Demir and Mrs. Ertan	"satisfactory"	"deficient"

Both participants' knowledge of learner use in electrochemistry and radioactivity was presented in the following part.

4.2.4.1. Satisfactory Knowledge of Learner in Teaching Electrochemistry

Both Mr. Demir and Mrs. Ertan had satisfactory knowledge of learner in teaching electrochemistry. Knowledge of learner was presented in three parts, namely, difficulties, misconceptions, and pre-requisite knowledge.

4.2.4.1.1. Difficulties

When asked in the CoRe-1 interview before they started to teach Electrochemistry, both teachers stated possible difficulties that learners faced with in the topic. For instance, Mr. Demir specified that learners generally have difficulties in balancing redox reactions due to the obligation of following plenty of rules. Additionally, they had difficulty in understanding the reason why scientists needed to define and use a reference electrode. Mrs. Ertan indicated that learners find it hard to learn the sign of anode and cathode in electrochemical cells and electrolytic cells (**CoRe-1, p. 2**). All of the difficulties identified by them during the CoRe-1 interview were observed in the class. Furthermore, they were conscious about the possible reasons of the difficulties. For example, learners were taught in physics that electricity flow is from (+) to (-) electrodes. When they start to learn that electron flow is from anode (-) to cathode (+) in electrochemistry, they have difficulty to understand and start to ask question.

As Table 16 shows, Mr. Demir and Mrs. Ertan basically used two tactics to deal with difficulties which learners may have and/or they had. The first one was alarming and re-explaining the confusing part, and the second one was re-explanation supported by additional strategies/ materials. First, they usually warned learners about the specific points at which their previous learners experienced challenge. To eliminate the possibility of occurring them in this year, they cautioned learners to be careful about the point specified and provided explanations. For instance, Mr. Demir realized that learners had difficulty in discrimination of charge and oxidation number. So, with help of his prior experience, he warned learners about the point which other learners had problem.

Some learners summed oxidation numbers when they calculate the charge of compound:

> In $CaCl_2$ example, the oxidation number of Ca is (2+) and of Cl is (1-). But the total charges come from Ca is (2+) and from Cl is (2-) due to the multiplication of the oxidation number by the number of Cl in the substance (**Field notes, p.6, Week-1**).

Before some learners had a problem related to the point, he had warned them to be careful about it and provided the necessary explanation.

In addition to alarming learners about the possible difficulties, they also used providing explanations when the difficulty was detected in the class. For example, after teaching how to determine anode and cathode in electrochemical cells, Mrs. Ertan noticed that some learners had difficulty in understanding it. Then, she needed to re-stated how to determine anode and cathode in electrochemical cells and again warned them to be careful about the half cell potentials given (**Field notes, p.35**)

Second, they also used some methods and materials to handle with the difficulties (Table 16). Some of them were utilized before the difficulty observed this year. Due to their experience with previous learners, they know that learners had difficulties in following the rules stated in both oxidation number and half-reaction methods in order to balance redox reactions. Therefore, to eliminate the possibility of occurring it, they had prepared a card summarizing the all steps of oxidation number method on one side and the steps of half reaction method on the other side. They distributed the cards to learners and asked them to use the card to get used to following the sequence of steps (**Field note**).

Similar to preparation of summary cards, Mr. Demir also tried to eliminate possibility of another difficulty through postponing the confusing parts purposefully. He knew that learners had difficulty in learning the signs of anode and cathode in electrochemical and electrolytic cells. Learners have difficulty because although the events occurring in the anode and cathode do not change, the signs of anode and cathode do change. Thus it causes a difficulty in learning them. In light of the previous experience, he purposefully postponed the use of the signs of anode and cathode when he was teaching the electrochemical cell. Then, when he started to teach the electrolytic cells, he focused on the signs, and compared and contrasted all properties that both cell types have.

Contrary to two examples provided above, they also tried to handle with the difficulties after they were observed in the class (Table 16) For example, Mrs. Ertan observed that learners had difficulty in identification of the reduced and oxidized species in the reaction. After diagnosing the difficulty, she used a representation shown in figure 19.

Mn: +7 $\longrightarrow$ +4 (reduced)

C: +3 $\longrightarrow$ +4 (oxidized)

(Field note, p.15)

Representation of oxidized and reduced species

In this representation, she explained that the charge of Mn ion changed from (+7) to (+4). She added that Mn received electron so it is a reduction reaction. Then, the C^{3+} ion gave an electron so it was oxidized. With help of the simple representation and talk about the changes in the charge regarding to electron receiving and giving, she could teach how to determine oxidized and reduced species. Similar representation was used by Mr. Demir for Fe-Zn example.

Finally, they used analogies to overcome the difficulties both before and/or after they occurred. As mentioned above, it was complicated for learners to follow the rules in balancing redox reactions. Although they took precaution to get over it through the use of the summary card at the beginning of the topic, some learners were still complaining about them. Therefore, Mr. Demir used an analogy through which he related the rules followed in balancing redox reactions to the address description for finding a place that you have not been before. He said that when people try to find a place where they do not know, at first, they follow the exact instruction provided. After sometime, when they learn the place, they may develop new strategies. He forced them to follow the rules. He suggested that when they learned the rules, they might find short ways to balance them.

4.2.4.1.2. Misconceptions

The participants' knowledge of misconceptions in electrochemistry was not as good as their knowledge of learners' difficulties in the same topic. No misconception was stated by them in the CoRe interview conducted before they teach the topic. During teaching, Mr. Demir realized some of the misconceptions and missed some others. For instance, when Mr. Demir was talking on the Al-Fe cell, and telling the events occurring at anode and cathode, one of the learners stated that Aluminum electrode was melting. Some of the learners confuse melting with ionizing. Although it is true for salts including ions (e.g. NaCl), it is not true for ionization in aqueous solutions. Mr. Demir did not realize it **(Field notes, p.44)**.

Similarly, Mrs. Ertan missed some of the misconceptions. For instance, during teaching the electrochemical cells, she drew a Sc-Ag cell on the board. One of the students asked: "Which container includes reactants and which one includes products?" Most probably, the learner thought that reactants and products are in separate containers. Mrs. Ertan said that Sc^{3+} ion is reduced in anode and Ag is oxidized in cathode. When asked in the interview, Mrs. Ertan said:

> She [the student] could not understand that half reactions occur in different containers. Indeed, she could not understand anything." (**Interview, 1-4, p. 4**).

Although Mr. Demir and Mrs. Ertan could not state any specific misconception during CoRe-1 interview, they realized some of the misconceptions that learners had during teaching. When they noticed them, they almost always provided the scientific knowledge (Table 16). For example, they were studying on electrochemical cells through performing exercises. Mr. Demir read the question and drew the cell figure on the board (Figure 20)

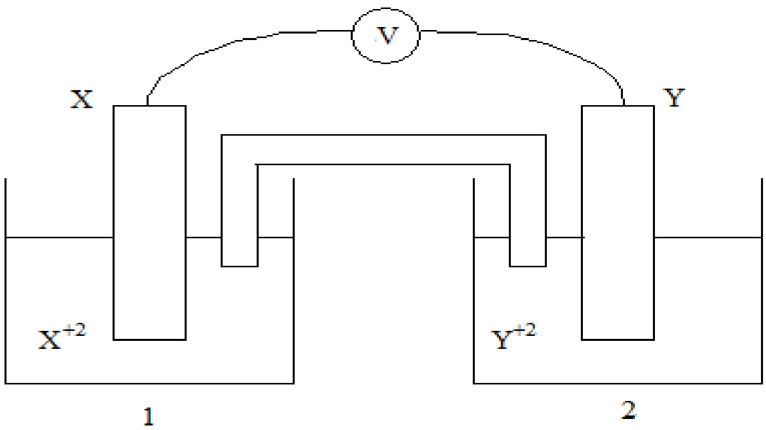


Figure 20. Drawing of electrochemical cell including X and Y electrodes and their solutions

> **Std:** The first one is anode, right?
> **Mr. Demir:** No, it is not. There is no rule like that. It is only in the writing the [short-hand] cell notation (**Field notes, week-5, p. 44)**.

The misconception detected and reported by Sanger and Greenbowe (1997a) was that many learners think that the first half cell is always anode and the other is the cathode. The same misconception was observed in Mrs. Ertan's class as well. When asked in the interview, Mr. Demir stated that he detected it in previous years as well. He thought that learners had it because we always say "oxidation and reduction", therefore, they think that oxidation is first so is anode. Moreover, he stated that they probably faced with many questions in which anode is the first container (**Interview, 1-5, p. 4**). The same event was observed in Mrs. Ertan's class. Similar to Mr. Demir, she also stated that anode does not have to be on the left **(Field note, p.33)**. She warned learners not to focus on the physical placement of electrodes.

A similar example was seen in the electrochemical cell part. It was the initial part of the topic and Mr. Demir was teaching what anode and cathode is, and what happens at anode and cathode electrodes. Suddenly, one said: Anode should be positive because it loses electrons. Mr. Demir stated:

> We do not decide where oxidation and reduction occurs through looking at the signs of the electrodes **(Field Notes, week-4, p.35)**.

This misconception was also stated in the literature by Sanger and Greenbowe (1997a).

In addition to providing the correct explanation to learners, they also tried to eliminate them through asking questions to learners, which makes them think on the point and creates dissatisfaction with their conception (Table 16). An instance was observed when Mr. Demir was demonstrating the redox reactions occurring between Zn solid and $CuSO_4$ solution. Most probably because they waited till next day to observe what happened in the beaker, one of the learners stated:

> **Std:** Redox reactions are slow ones, right?
> **Mr. Demir:** What are the factors affecting the rate of reactions?
> **Stds:** Temperature and concentration….
> **Mr. Demir :** So, can we state that redox reactions are slow?
> **Std:** No **(Field note, week-1, p.2).**

Although he did not provide any explanation here, the learner understood what Mr. Demir meant and did not pursue with his misconception. During the interview, he stated that because they waited to see the changes, he had misconception about the rate of redox reactions. He had used magnesium and put it into HCl earlier years, which was very fast one **(Interview, 1-2, p.2)**. However, Mr. Demir did not use that demonstration to eliminate the learners' misconception. Rather, he preferred to ask a question.

4.2.4.1.3. Pre-requisite knowledge

Mr. Demir and Mrs. Ertan forecast well about the pre-requisite knowledge that learners would need in learning electrochemistry in the CoRe interview. They stated that learners need to know chemical reactions, chemical calculations, oxidation number, rate and heat of reactions, and chemical equilibrium.

As can be seen from table 16, they used their knowledge of pre-requisite knowledge either to make the learning of new topic easy or to make learners remember the pre-requisite knowledge. For instance, at the beginning of teaching Nernst Equation, sub-topic under electrochemical cells, both teachers preferred to teach it by using Chemical equilibrium topic as a basement. Nernst Equation is used to calculate the potential difference (E) of the cells that are at non-standard conditions. Therefore, changes in the conditions result in change in the standard potential difference of the cell (^0E). Although the use of equation gives the value of the E, Mr. Demir focused on the interpretation that can be done by using Le Chatelier's principle. He wrote the symbolic equation of the Zn-Cu cell and told the basic points:

$$Zn\ (s) + Cu^{+2}\ (aq) \rightleftharpoons Zn^{+2}(aq) + Cu\ (s)$$

Mr. Demir: We start with 1 M of solutions. How can we write the constant of equilibrium?

Students stated;

$$K = [Zn^{+2}] / [Cu^{+2}]$$

> **Mr. Demir**: At t=0, there is no equilibrium here. Through the time, the concentration of Zn^{+2} ions increases whereas that of Cu^{+2} ion decreases in the

system. After some time, it reaches the equilibrium and then cell potential will be zero. At equilibrium;

$$\text{Rate}_{\text{forward reaction}} = \text{Rate}_{\text{reverse reaction}}$$

$$K= Q \quad \text{and} \quad E_{cell}= 0\ V \qquad \text{[Q is reaction quotient]}$$

(Field Notes, week-5, p.44)

They also used their knowledge to make learners remember the previous topic taught before. They mentioned the pre-requisite knowledge with one or two sentences. For instance, in electrolytic cells, they talked about the spectator ion, which does not react with the species. It is necessary to know while determining which species would be oxidized and reduced in the cell (**Field note**).

4.2.4.2. Deficient Knowledge of Learner in Radioactivity

Although teachers had robust knowledge of learner in electrochemistry, they were clearly weak in radioactivity topic. Knowledge of learner was summarized here under the difficulties, misconceptions, and pre-requisite knowledge.

4.2.4.2.1. Difficulties

When asked in the CoRe-2 interview before they started to teach radioactivity, Mr. Demir stated that the learners generally cannot visualize particles in their mind, therefore, have difficulty in understanding the relations between particles. He added that he realized the same difficulty in teaching atom topic. He attributed the difficulty to abstract nature of the topic. Second, he mentioned another difficulty caused by the nature of the radioactivity topic. It is an algorithmic-calculations free topic, which makes it difficult for learners to learn because they get used to performing algorithmic-calculations in other topics. Even without conceptual understanding, learners can perform exercises due to the familiarity with the types of questions (**CoRe-2, p. 2)**. Mrs. Ertan stated that:

> Indeed, radioactivity is a simple topic. The points that they have difficulty…Oh, they have difficulty in discriminating artificial and natural radioactivity. This is the only one I guess. They most probably think that when there is specie on the left side of the reaction equation, they think that it is natural one. However, when there is more than one species, it is artificial one **(CoRe-2 interview, p. 2)**.

As Table 16 shows, both teachers tried to handle with difficulties before and after they emerged. First, to eliminate the possibility of emergence of the difficulty, they took learners' attention to the point that they would have difficulty about and stress the important points. For instance, both teachers knew that they would experience difficulty in discriminating chemical and nuclear reactions. Therefore, at the beginning of the topic, he stressed the differences between the two in terms of how they occur, energy change, particles taking role, etc. Mrs. Ertan stressed the differences between chemical and nuclear reactions in terms of conservation of mass, energy required and released, and conservation of number of proton, neutron and electron (**Field note, p. 62)**. When asked the reason for this in the interview, she stated:

> Till now they learned chemical reactions. But from now on they will learn nuclear ones. They are really different from each other. Atoms and mass are saved during chemical reactions but not in nuclear ones. To help them understand **(Interview, 2-1, p.1)**.

Contrary to their style in electrochemistry, they did not warn learners rather they stressed the differences between the two here. However, taking precaution before it occurs is the similarity observed in terms of time mentioned in both topics.

Second, they tried to help learners to understand the points on which they had difficulties, in other words, after the difficulty already arose. Contrary to their way of handling difficulties in electrochemistry (e.g. providing explanations supported by the use summary card, analogy, and representation) (Table 16), to handle with them, they either directly provided the correct explanation or used questioning technique to help learner handle it. For instance, Mr. Demir used questioning technique to help learners in handling the difficulties that they faced with. One of the examples of it was observed when he taught artificial radioactivity and provided two examples of artificial nuclear reactions achieved by Madam Curie and Ernest Rutherford:

$$\text{Rutherford: } {}_{7}^{14}N + {}_{2}^{4}He \longrightarrow {}_{8}^{17}O + {}_{1}^{1}p$$

$$\text{Curie: } {}_{13}^{27}Al + {}_{2}^{4}He \longrightarrow {}_{15}^{30}P + {}_{0}^{1}n$$

> **Std:** I cannot understand that how those are changed into new matter?
> **Mr. Demir:** OK. Let me ask something to you. When I say oxygen atom, how can I understand that it is oxygen?
> **Std:** From its chemical properties.
> **Mr. Demir:** Chemical properties... What is the basic point you focus on when you say chemical properties?
> **Std:** Atomic number.
> **Mr. Demir:** What is atomic number?
> **Std:** Number of protons.
> **Mr. Demir:** If the number of protons changes in the reaction, it does in nuclear reactions…(**Field notes, week-3, p.77)**

Rather than providing the scientific explanation to the learner, he preferred to ask questions and tried to help her to get the point.

4.2.4.2.2. Misconceptions

Similar to their knowledge about learners' misconceptions in the previous topic, Mr. Demir and Mrs. Ertan were partially aware of them in radioactivity. Only one misconception was stated by Mr. Demir in the CoRe-2 interview before he started to teach the topic. Moreover, he thought that learners generally have difficulties rather than misconceptions in radioactivity. The misconception that learners may have was that "Radioactivity is bad and dangerous" The misconception was observed during the observation period. To eliminate the misconception, Mr. Demir provided different use of nuclear reactions in medicine, energy, and age dating in archeology through the topic.

In addition to that, it was observed other misconceptions by the observer. For instance, students thought that alpha particle is Helium atom rather than Helium ion.

During teaching Mr. Demir was talking about alpha decay and a student, simultaneously, said Helium. Mr. Demir stressed:

> Helium without electrons or Helium's nuclei **(Field notes, p.70, week-2)**.

Moreover, the observer realized that they might have more misconceptions than Mr. Demir expected. An example was observed when they were talking about the nuclear waste. Mr. Demir asked why nuclear wastes are dangerous. One of the learners stated that they are poisonous. Because Mr. Demir did not want him to explain his idea in detail, it is better not to code it as a misconception, however, it might be. In the literature, "Ionizing radiation is confused with other environmental hazards; e.g. chemical pesticides and electric fields " (Henriksen & Jorde, 2001, as cited in Colchough, 2007, p.63). Therefore, it can be said that he may confuse them with chemical pesticides. Mr. Demir could not catch it so it is unknown what he meant by 'poisonous'. Poisons are chemicals which have harmful effects on body and the environment. It should have been focused the learner's idea and tried to be understood whether he had a misconception detected in the literature or not. As mentioned above, because he thinks that learners generally have difficulties rather than misconceptions in this topic, he might miss it.

Mrs. Ertan did not provide any misconception that learners may have in radioactivity in CoRe-2 interview. However, it was observed that learners had some. For instance, she realized that learners thought:

> "Fission is natural whereas fusion is artificial radioactivity"

She also realized one more:

> "Both fission and fusion occur in nuclear reactors."

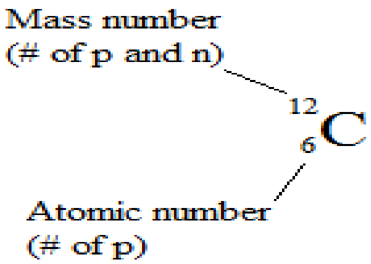
When she realized them, she gave the scientifically accepted explanation **(Field notes, p. 87)**.

The way of handling misconceptions was similar to their way in electrochemistry. In both topics, they provided the scientific explanations. Although they asked some questions to make learners dissatisfy with their idea in electrochemistry, they did not do it in radioactivity (Table 16).

4.2.4.2.3. Pre-requisite Knowledge

Mr. Demir and Mrs. Ertan were partially aware of pre-requisite knowledge necessary for learning radioactivity. They stated that they need atom and isotope knowledge to understand the topic which does not necessitate much knowledge from other topics. Although they could mention necessary other knowledge for learning electrochemistry, they were less knowledgeable in this part in radioactivity. Mrs. Ertan thought that learners only need to know atom as prerequisite knowledge during CoRe-2 interview.

Similar to their use of it in the first topic, they made learner remember the pre-requisite knowledge. For instance, Mr. Demir mentioned atom, nucleon, proton, neutron, atomic and mass number, and showed them on Carbon atom (Figure 21)



(Field observation, week-1, p. 63)

Figure 21. Presentation of pre-requisite knowledge necessary for learning radioactivity

Similarly, he made learners remember what isotope means at the beginning of the reason of instability of some nucleus. He asked “what does isotope mean” to them

(Field observation, week-2, p.68). Because learners remembered them easily, he did not have to re-teach them.

Although they could have linked radioactivity to previous topics, they could relate it to only atom and its properties. However, during the observations, it was observed that in addition to those, learners need to know about radiation, electromagnetic radiation, energy, ion, and ionization in order to learn radioactivity. For instance,

> Std: Can we see them [Alpha particles] if we are close enough?
> Mr. Demir: Can you see radio waves or other waves? They are not visible. We mentioned that when we were talking about electromagnetic radiation. Please remember it from last year. You cannot see them **(Field notes, week-3, p. 88)**.

Although they learned electromagnetic spectrum in 10^{th} grade, learners either could not remember it or could not relate it with radioactivity.

4.2.5. Knowledge of Assessment

The last component analyzed in this study was knowledge of assessment. Two types of application of knowledge of assessment were noticed, namely, "*Coherent assessment* "and "*Fragmented assessment"*. Before presenting the major attributes of the categories formed, necessary descriptions to be able to understand the categories should be given here.

First, the formal assessment is a way of assessment after which teachers have a document filled by learners, and project and/or a work done by learners. For instance, quiz is a formal assessment that teacher has a quiz paper which shows to what extent learners understand. On the contrary, informal assessment is done without use of any document (e.g. quiz and exam paper) and/or any work that learners have to do (e.g. questioning at the beginning of the topic and observing learners while they are performing exercises, etc.) Second, diagnostic assessment is used to identify the prior knowledge that learners have before starting to teach a new topic. Formative assessment is another type of assessment which is applied for taking information about how much students learn and providing feedback to learners about their level of understanding. It is done through the learning process. Finally, summative assessment is one to conduct at the end of the teaching to grade (Abell & Volkmann, 2006).

The important characteristics of the *coherent assessment* were use of multiple assessment strategies (e.g. informal questioning, quiz, observing learners' performance, and unit test), for different purposes (e.g. to elicit learners' prior knowledge, to check how much learners learn, and to grade), and through teaching the topic (e.g. at the beginning, during, and at the end of the topic). Although purpose, time, method, and type of the assessment were various, the only domain assessed was cognitive one. Among the cognitive domain, they only assessed content knowledge. In other words, assessment of learners' NOS understanding and science process skills were not assessed. The questions asked in the quiz and unit test were open-ended and multiple-choice items. Both informal and formal assessment strategies were employed throughout their instruction.

The *fragmented assessment* included limited types of assessment methods, namely, informal questioning and unit test. In other words, teachers' assessment was based on diagnostic and summative assessment results. However, the use of formative assessment was missing. The purposes of the assessment were to elicit learners' prior knowledge and to grade them. Eliciting prior knowledge was done informally whereas the grading was done formally. In these assessments, both multiple-choice and open-ended questions were used. To sum up, in fragmented assessment, teachers did not use assessment continuously through teaching the topic. Therefore, the methods, purposes, and types of assessment used were quite limited.

Table 18 shows the summary of both types of assessment.

Table 18. Knowledge of assessment for teaching electrochemistry and radioactivity

	Method of assessment	**Purpose of the assessment**	**Type of assessment**	**The way of assess**	**What is assessed**	**Types of questions used**	**Time of the assessment**	**LABEL**
ELECTROCHEMISTRY	**Informal questioning**	Eliciting learners' prior knowledge	Diagnostic	Informally	(Prior) knowledge: Cognitive	Open-ended	At the beginning of the topic	**COHERENT ASSESSMENT**
	Quiz (twice)	To check how much learners learn	Formative	Formally	Content Cognitive	Open-ended	During the topic; before from moving to next step	
	Observing learners performing exercises	To check how much learners learn	Formative	Informally	Content cognitive	Open-ended	After providing the content	
	Homework	To check how much learners learn	Formative	Formally	Content cognitive	Open-ended and multiple-choice items	During the topic; before from moving to next step	
	Unit test	To grade them	Summative	Formally	Content Cognitive	Open-ended and multiple-choice items	At the end of the topic	

Table 18 (continued)

	Method of assessment	Purpose of the assessment	Type of assessment	The way of assess	What is assessed	Types of questions used	Time of the assessment	LABEL
RADIOACTIVITY	**Informal questioning**	Eliciting learners' prior knowledge	Diagnostic	Informally	(Prior) knowledge: Cognitive	Open-ended	At the beginning of the topic	**FRAGMENTED ASSESSMENT**
	Unit test	To grade them	Summative	Formally	Content cognitive	Multiple-choice items	At the end of the topic	

Table 19. Types of assessment used in electrochemistry and radioactivity

Participants	**Electrochemistry**	**Radioactivity**
Both Mr. Demir and Mrs. Ertan	Coherent Assessment	Fragmented Assessment

In light of the data collected, teachers' assessments were categorized with help of the labels formed above (Table 19). Both teachers used a "coherent assessment" in electrochemistry and a "fragmented assessment" in radioactivity. Below, the details of teachers' assessment in both electrochemistry and radioactivity were provided.

4.2.5.1. Coherent Assessment Use in Electrochemistry

4.2.5.1.1. How to Assess and Purpose of Assessment

Through Electrochemistry, both teachers applied different assessment methods, for instance, informal questioning, quizzes, observing learners performing exercises, and unit test. They preferred to use assessment techniques to obtain information about how much learners get the ideas that they wanted to teach. Both Mr. Demir and Mrs. Ertan started the lessons to elicit learners' prior knowledge about electrochemistry. They asked what the learners know about electrochemistry and took their ideas before talking about electrochemistry **(Field notes)**. When they started to a new sub-topic, they elicited learners' prior knowledge regarding to the new part informally. A short talk before starting to the new part helped teachers to diagnose how much learners know and/or remember about the part.

In addition to the diagnostic assessment used at the beginning of the topic and sub-sections of the topic, they applied different formative assessment methods to determine to what extent learners gained till a specific point of time. For instance, after providing information about how to decide anode and cathode in electrochemical cells, and to form the cell, they made learners perform some exercises. While they were performing, teachers observed them, provided some important points that learners missed, and gave feedback about their performance **(Field notes)**. Moreover, in light of the information they gathered from this informal formative assessment, they decided to perform more exercises and stressed the points that learners had problems.

Additionally, Mr. Demir and Mrs. Ertan did two quizzes during electrochemistry. When asked the purposes of use of quizzes, Mr. Demir stated:

> I will focus on whether they learn how to balance redox reactions or not. I will ask questions related to both methods of balancing redox reactions….You can warn learners about their weaknesses before exam or you can turn back to the topic and performed exercises or new exercises to repeat **(Interview, 1-2, p. 3)**.

The first quiz was conducted after finishing balancing redox reactions and the other was after teaching the electrochemical and electrolytic cells. After being graded, quiz papers were distributed to the learners to show their work, to what extent they learned, and the mistakes that they did. For instance, in the first quiz, most of the learners in Mr. Demir's class could not balance the reactions below:

$$I_2 + HNO_3 \longrightarrow HIO_3 + NO_2 + H_2O \quad \text{and}$$

$$KCl + MnO_2\ H_2SO_4 \longrightarrow K_2SO_4 + MnSO_4 + Cl_2 + H_2O$$

He performed them on the board by talking about their mistakes. In both of the reactions, one of the problems he indicated.

Similarly, Mrs. Ertan's students had difficulties in some of the questions asked in the quiz-1. For instance,

$$KMnO_4 + H_2C_2O_4 + H_2SO_4 \longrightarrow CO_2 + K_2SO_4 + MnSO_4 + H_2O$$

She performed the question on the board by telling the mistakes that they did:

> You see H_2O in the products. Some of you deleted it and added either H^+ or OH^-. Also, many of you still have problem in assigning oxidation number… (**Field note, p. 28)**.

After the first quiz, both teachers decided to perform more exercises about how to balance redox reactions due to the difficulties that detected in the quiz papers. They applied the same strategy after second quiz done after teaching cells. They asked questions related to electrochemical and electrolytic cells. They again mentioned the most problematic items and talked on them. In addition to benefits of learners that they took from the quizzes, they also got useful information about how much students learned, and what they needed more for learning specific points in the topic.

Teachers also prepared worksheets and gave them as homework. In one of them, learners were asked to form a cell with the electrodes and electrolytes that they choose, draw the cell, calculate the cell potential, and show the electron and ions flow. They collected homework and checked whether learners had any problem or not. After the homework mentioned, both teachers performed some exercises related to cells by stressing the important points to eliminate the difficulties that learners have.

Finally, at the end of electrochemistry, they used a paper-pencil test to grade learners. To sum up, diagnostic, formative, and summative assessment were applied through electrochemistry.

4.2.5.1.2. What to Assess

Mr. Demir and Mrs. Ertan assessed the content presented to the learners through the use of all those assessment strategies. In other words, knowledge that learners were supposed to learn was focused rather than assessing other types of domains such as NOS understanding, use of electrochemistry in daily-life, and/or science-process skills. Two examples of the questions asked in the quiz were provided above. More questions were given in the next part.

The types of items used in these assessments were items requiring balancing redox reactions, forming a galvanic cell by the use of electrodes given and deciding anode, cathode and the direction of electron flow, and multiple choice items. When they need to see how the learners think and when the solution includes many steps and decisions, they used the items in which learners construct their answers such as the cell formation item mentioned above (Figure 22). In this type of galvanic cell questions, learners should decide first the anode and cathode by the use of reduction or oxidation half-cell potentials. Then they determine the electron flow, ion flow through salt bridge, potential difference between the anode and cathode, and write oxidation and reduction half-cell reactions and cell reaction.

> You cannot see what learners did with multiple-choice items, however, with the items that I used you can see that to what extent they can do and to what extent they learned. You can see the steps in their answers….If I do not know where they have problem, how can I re-teach it? But if you determine where they stick, you can do more to help them learn that part **(Mr. Demir, CoRe- 1 Interview, p.9**).

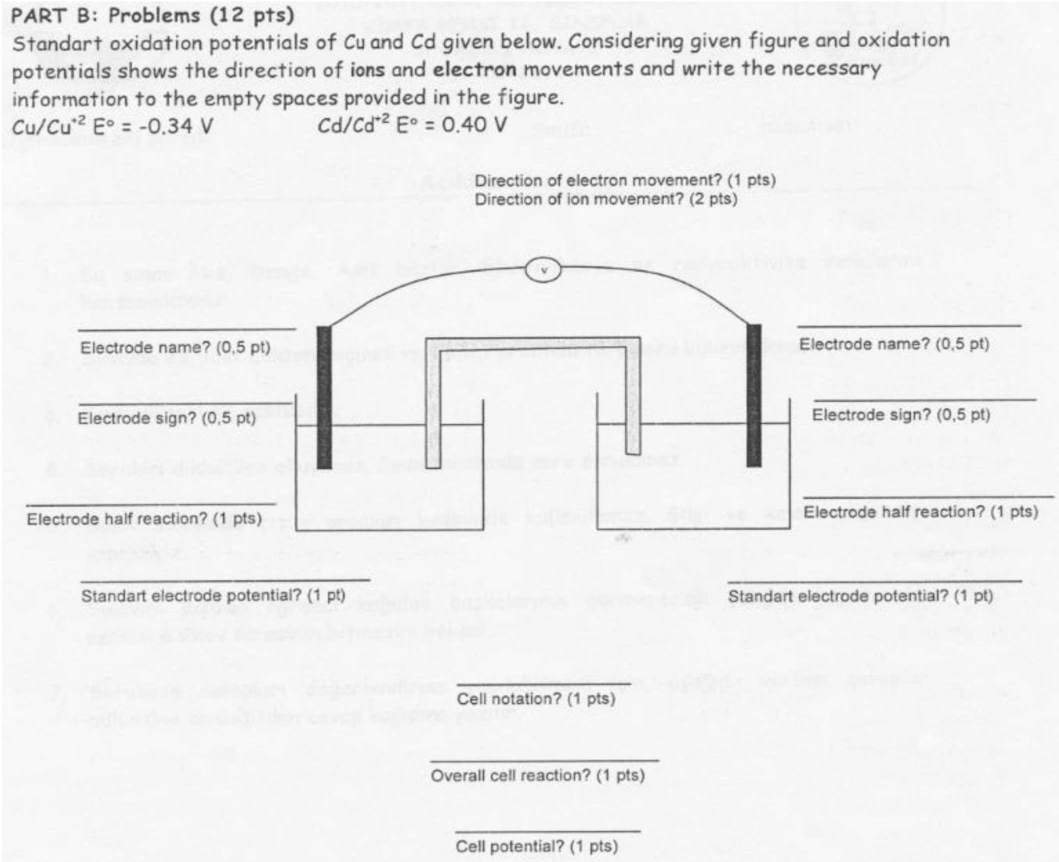


Figure 22. An example of open-ended question asked in the exam

Other than that, they preferred to use multiple-choice items to assess their understanding.

Below, an example of a multiple-choice question used in unit test was provided.

Item: A galvanic cell consists of one half-cell that contains $Ag_{(s)}$ and $Ag^{+}_{(aq)}$, and one half-cell that contains $Cu_{(s)}$ and $Cu^{2+}_{(aq)}$. Which species are produced at the electrodes under standard conditions?

$$Ag^{+}_{(aq)} + e^{-} \longrightarrow Ag_{(s)} \qquad E^{0} = +0.80\ V$$
$$Cu^{2+}_{(aq)} + 2e^{-} \longrightarrow Cu_{(s)} \qquad E^{0} = +0.34\ V$$

a. $Ag_{(s)}$ is formed at the cathode, and $Cu_{(s)}$ is formed at the anode.

b. $Cu^{2+}{}_{(aq)}$ is formed at the cathode, and $Cu_{(s)}$ is formed at the anode.

c. $Cu_{(s)}$ is formed at the cathode and $Ag^{+}{}_{(aq)}$ is formed at the anode.

d. $Ag_{(s)}$ is formed at the cathode, and $Ag^{+}{}_{(aq)}$ is formed at the anode.

e. $Ag_{(s)}$ is formed at the cathode, and $Cu^{2+}{}_{(aq)}$ is formed at the anode.

To sum up, Mr. Demir and Mrs. Ertan's assessment in this topic was comprehensive regarding to the purposes and the way of using them. Moreover, information received from assessment was used to make decisions for re-teaching and/or performing more exercises.

4.2.5.2. Fragmented Assessment Use in Radioactivity

4.2.5.2.1. How to Assess and Purpose of the Assessment

In radioactivity, Mr. Demir and Mrs. Ertan applied only two types of assessment methods, namely, informal questioning to elicit prior knowledge and unit test to grade (Table 18). An example of eliciting learners' prior knowledge was observed at the beginning of the radioactivity. Mr. Demir asked:

> **Mr. Demir:** What does isotope mean?
> **Stds:** They have the same number of protons but their mass numbers are different.
> **Mr. Demir:** What do I mean when I say U-238, U-235, and U-234?
> **Std-1:** Their mass numbers are different.
> **Std-2:** They have the same number of protons.
> **Mr. Demir:** They are the different isotopes of Uranium. What do we use them to discriminate from each other? Mass numbers **(Field observation, p.68)**.

In both participants' assessment use, formative assessment was missing in radioactivity. In contrast to assessment in electrochemistry, they did not assess learners' understanding through the topic, which also means that they did not take feedback to themselves for additional activities or re-teaching the points that learners have difficulties. Assessment was done at the beginning and at the end of the topic; therefore, it was fragmented assessment that does not go through the whole topic.

The types of questions asked was another difference observed. They asked only multiple choice items in the unit test. The example items were provided below:

Item-1: When aluminum-27 is bombarded with a neutron, a gamma ray is emitted and a single new isotope is produced. Which radioactive isotope is produced in the reaction?

a) Magnesium-27
b) Silicon-28
c) Silicon-27
d) Magnesium-28
e) Aluminum-28

Item-2: Which of the following types of radiation has the highest energy?

a) β^- particles
b) γ rays
c) visible light
d) α particles
e) All of these have the same energy

4.2.5.2.2. What to Assess

Similar to assessment applied in the first topic, they only aimed to assess the content presented. Although many discussions were held (e.g. nuclear energy, environment, and use of radioactivity in daily-life) in this topic, they were not included in the test. Likewise, NOS was implicitly mentioned but was not focused in the assessment.

To sum up, teachers' PCK and its use were different for teaching topics that have different nature (Table 20). The results showed that diverse topics necessitate divergent types of applications.

Table 20. Types of PCK for teaching electrochemistry and radioactivity

PCK components	Topics	
	Electrochemistry	**Radioactivity**
Instructional strategy	content-based and teacher-centered instruction	less teacher-centered Instruction enriched with implicit NOS and discussion on STSE
Learner	satisfactory knowledge of learner	deficient knowledge of learner
Curriculum	network of topics	limited network of topics
Assessment	coherent	fragmented
PCK type	**PCK-A**	**PCK-B**

In addition to nature of topics, some other factors may also explain the differences in PCK. For instance, although the study was started with the assumption that both teachers have robust SMK in both topics and they teach in a learner-centered way, some deviations were observed from the assumptions during data collection and analysis. The possible explanations of the whole picture obtained will be discussed with the help of the literature and the data collected in the discussion part.

4.3. Minor Differences between Participants' Teaching

In the first part of the result section, I tried to compare and contrast PCK in two topics. The focus of the study was analyzing PCK in different topics rather than comparing different teachers' PCK. Therefore, I tried to get categories more or less fit to teachers' teaching practice. Although both teachers' PCK components had the same label, there were not exactly identical. Some minor differences were detected. The labeling process was not like assigning "white" or "black" labels to the phenomena. Therefore, in this part of the results, I want to present the minor differences identified. However, doing a cross-case analysis was not aimed in the study. It is not scope of the study but still in order to give some idea of the differences between teachers' PCK, the differences were provided component by component below.

4.3.1. Orientations to Science Teaching

Regarding to purposes that participants had, I realized that their ideal and working purposes did not match. Therefore, both ideal and working purposes were provided in the previous part of the result section. In terms of ideal ones, Mr. Demir aimed to develop science-process skills and to let learners discover in his class. Mrs. Ertan intended to develop higher-order-thinking skills and scientific literacy. When the both participants' teachings were observed, these different central purposes turned into the same purposes, namely, to provide necessary knowledge to learners, to prepare learners for university entrance exam, and to relate chemistry to daily-life.

Second, in the working peripheral purposes, Mr. Demir stated that he aimed to develop consciousness in terms of environment and to provide knowledge about history of development of concepts. Mrs. Ertan, on the other hand, aimed to facilitate learners' interest in chemistry. When their practice was observed, again, I realized that they aimed to facilitate learners' interest in chemistry. Different than Mrs. Ertan, Mr. Demir also tried to develop consciousness in terms of environment through the discussions.

To sum up, their working purposes were quite similar although some differences were observed in their ideal purposes. They had enriched didactic orientation to science teaching.

4.3.2. Instructional Strategy

Although teachers used the same activities and teacher demonstrations, they applied different analogies to teach the same point. Moreover, they used the same analogy for teaching the different parts of the topic. For instance, Mrs. Ertan used waterfall analogy to tell the spontaneity of the cell reactions whereas Mr. Demir used it to tell another point. He stated that the height difference between the top and the bottom of the waterfall is analog to the potential difference between the electrodes. He also added that the amount water of the does not influence the height difference. In the cell, when the half-cell is multiplied, the half-cell potential does not change. Additionally, Mr. Demir's instructional repertoire was richer than Mrs. Ertan's repertoire. For instance, Mr. Demir used a representation to teach Standard Hydrogen electrode (SHE). He tried to tell the relative potentials determined by the use of a standard electrode and stressed:

> We select Hydrogen as a reference point and we determine the others' potentials relatively to Hydrogen electrodes potential. (**Field notes, week-5, p.39)**

He related the height difference among the lines in the representation (Figure 23) and how SHE is used in chemistry. He could give the idea that half-cell potentials are relative potentials determined by the use of SHE **(Field notes, week-5, p.39, and interview 1-5)**.

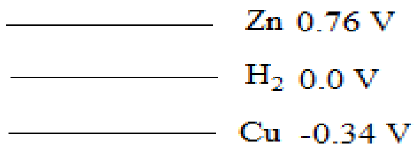


Figure 23. Representation of relative oxidation potential of Zn, H_2, and Cu.

However, Mrs. Ertan did not use anything to tell why standard electrode is necessary.

Another difference was observed in their use of questioning in radioactivity. Mrs. Ertan employed it extensively. She asked questions when she started to the topic and during teaching. Mrs. Ertan preferred to ask questions especially while he was teaching rather than using it at the beginning. Furthermore, Mr. Demir and his students discussed more about the nuclear energy and environment whereas Mrs. Ertan and her students discussed about nuclear explosions, WWII, and historical part of the topic. Moreover, Mrs. Ertan let one of the enthusiastic students to present his research about radioactivity, atomic bomb, and WWII. The presentation made the topic so interesting for learners that they discussed on some points such as why much more energy is released during fusion reaction. Finally, Mr. Demir was better in providing information about daily-use of cells and radioactivity. He stated that due to his experience in industry, he is so interested in daily-use of chemistry.

4.3.3. Curriculum Knowledge

Though both participants linked the topic to physics, Mr. Demir was slightly more successful relating the topic especially to physics. He provided the necessary information from physics when learners had difficulty in understanding and/or remembering a particular point. For instance, during the calculations in Faraday's Law in electrolytic cells, there were electrolytic cells connected in series. He also mentioned the circuits connected in parallel and series during the teacher demonstration in electrochemical cells **(Field notes, week-6, p.49)**.

4.3.4. Learners' Difficulties, Misconceptions, and Pre-requisite Knowledge

Mr. Demir had slightly richer collection of learners' difficulties, misconceptions, and pre-requisite knowledge than the Mrs. Ertan. For instance, he knew that learners had difficulty in understanding the electron flow from (-) to (+) electrode in electrolytic cell because learners had learned that it is from (+) to (-) in physics. Moreover, Mr. Demir's explanations to eliminate difficulties were better than the Mrs. Ertan's explanations. For instance, the explanation for the use of SHE and the representation that he used were really well. Another example was observed in radioactivity. Learners had difficulty to understand how elements can turn into other in nuclear reactions.

> **Std:** I cannot understand that how those are changed into new matter?
> **Mr. Demir:** OK. Let me ask something to you. When I say oxygen atom, how can I understand that it is oxygen?
> **Std:** From its chemical properties.

> **Mr. Demir:** Chemical properties... What is the basic point you focus on when you say chemical properties?
> **Std:** Atomic number.
> **Mr. Demir:** What is atomic number?
> **Std:** Number of protons.
> **Mr. Demir:** If the number of protons changes in the reaction, it does in nuclear reactions… (**Field notes, week-3,p.77)**

His guiding questions were so good that they directed learners how to think.

4.3.5. Assessment Knowledge

Mrs. Ertan used more diagnostic assessment especially in radioactivity than Mr. Demir did. She asked many questions at the beginning to get idea about what learners know about radioactivity, nuclear energy and use of it in life. Other than that, they used similar questions and strategies.

4.4. Examining the Nature of Interplay among PCK Components

In the last part of the results, the assertions about the nature of interplays among PCK components were provided. Then, specified points were explained with one example from the data collected. Due to the complexity of the interplays, only Mr. Demir's data from electrochemistry was examined. I decided not to include both participants' data due to the complex nature of the interplays. The data of Mr. Demir who had richer PCK than Mrs. Ertan was analyzed for the interplay among PCK components. In order to remember the details about how the data analyzed for the second research question, the reader can look at methodology sub-part 3.10.2. When the data were analyzed, it was interpreted that;

- some of the interactions are very simple whereas some of them are so complicated that more than two components of PCK and other knowledge domains (e.g. PK, SMK, etc.) interplay simultaneously,
- in addition to the interplay between PCK components, interplay may occur within the component; among the sub-components,

- orientation to science teaching, an overarching component in the PCK model, shaped instructional decisions,
- different types of interplay regarding to nature of them exist (e.g. instructive and formative interplays).
- missing interactions among the components were also detected (e.g. among curriculum and assessment knowledge of teacher)
- not only PCK components informed each other but also knowledge domains (e.g. SMK and PK) influenced PCK components.
- some of the interplays detected were mutual whereas some of them were one-sided. Moreover, direct and in-direct interplays were observed.
- the interplays have diverse parts, namely, diagnose, performance, and reflection.

Now, details of the points were provided.

4.4.1. Some of the Interactions are Simple whereas others are Complicated.

When all of the interplay instances belonging to Mr. Demir's teaching in electrochemistry were coded, I saw that there is a range of complexity of the interplays. For instance, there was an objective related to the Nernst Equation and performing some algorithmic exercises related to it in the 11th grade chemistry curriculum. So, due to that objective, Mr. Demir integrated some exercises with his lectures. In this example, his knowledge of curriculum informed the use of instructional strategies. The interplay was so simple that one PCK component informed the other one (Figure 24).

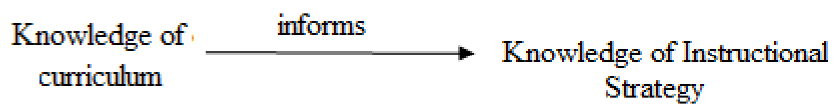


Figure 24. An example of simple interplay between PCK components

On the other hand, some of the interplays were so complicated that at least two components informed and/or influenced the others (Figure 25). For instance, Mr.

Demir stated that because the signs of anode and cathode are opposite in electrochemical cells and electrolytic cells, learners have difficulty in learning them. He also attributed the difficulty to prior learning in Physics course. Students had learnt that electron flow is from positive terminal to negative in Physics. However, in chemistry they learn that it is from anode, negative terminal, to cathode, positive terminal. Mr. Demir knew the confusion and the possible reasons of it. He taught electrochemical cells first and then started to teach the electrolytic cells. Due to the fact that he is aware of the confusion, he did not use signs of anode and cathode when teaching electrochemical cells. He postponed the use of them to electrolytic cells purposefully. When he started to teach electrolytic cells, he provided a comparison table that shows the signs of anode and cathode, and which reaction occurs in those terminals in electrochemical and electrolytic cells. Moreover, he was aware the curriculum objective regarding to the cells, namely;

> **Objective 2-1:** Learners should be able to discriminate electrode, half-cell, and electrochemical and electrolytic cell concepts.

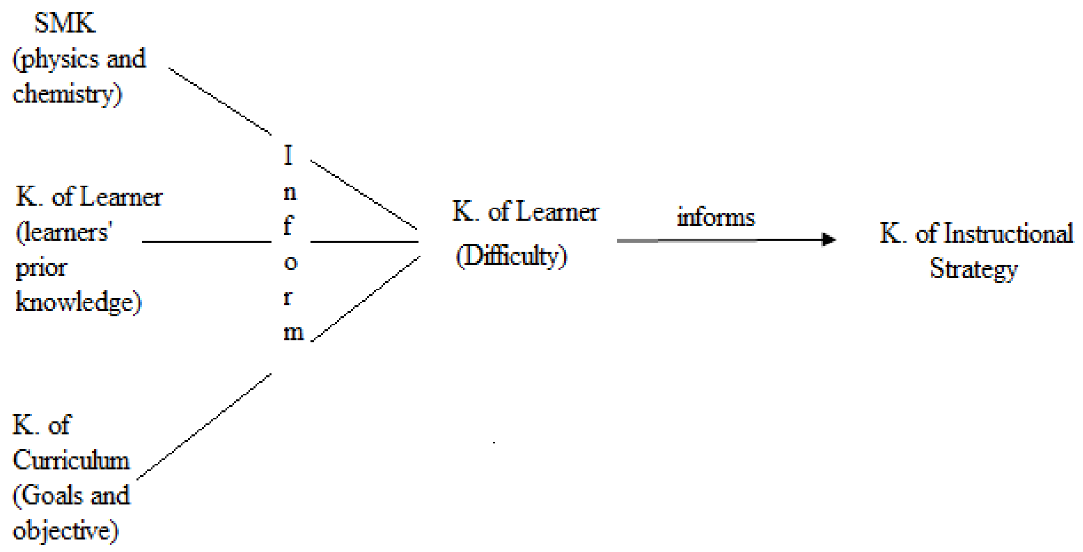


Figure 25. An example of complicated interplay of PCK components

4.4.2. In Addition to the Interplay between PCK Components, Interplay may Occur within the Component; among the Sub-components

An example of this interaction was observed when Mr. Demir drew a Zn-Cu cell including $ZnSO_4$ and $CuSO_4$ electrolytes in half cells. One of the learners asked the sources of the sulfate ions (SO_4^{2-}) in the half cells. Mr. Demir explained that they are spectator ions. He added that when $ZnSO_4$ is solved in water, it dissociates and forms Zn^{2+} and SO_4^{2-} ions. Then the student asked whether it is possible to use nitrate salt in one of them and sulfate salt in the other. Mr. Demir explained that they are generally the same; however, ions which do not react are preferred. In the interview after the observation, he stated that the student had problem in understanding spectator ions taught in last year. Therefore, he had difficulty in understanding the electrolytes in half cells. In this example, we saw that learner's prior knowledge sub-component of knowledge of learner informed him about another sub-component of learner knowledge, namely, learners' difficulty (Figure 26).

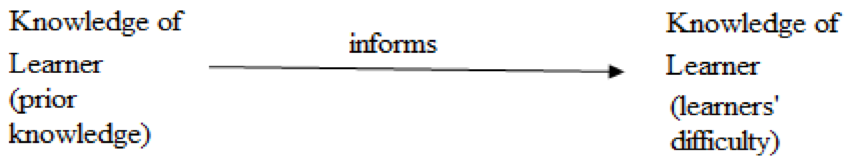


Figure 26. Interplay among the sub-components of PCK's component

In other words, the interplay does not have to be among different PCK components, rather, it can be among the sub-components of the same component.

4.4.3. Orientation to Science Teaching, an Overarching Component in the PCK Model, Shaped the Instructional Decisions

To clarify, Mr. Demir was aware of students' misconception that "anode is always on the left side of the cell". To address this misconception, he could have utilized different instructional strategies, for instance, he could have used a demonstration in which he forms two Zn-Cu cells. In the first one, anode which is Zn electrode is on the left and in the second one anode (Zn electrode) on the right. Then, he could have asked learners what they expect and take their reasons. In the next step he could have measured the potential difference in both cells with learners. After seeing that the potential difference does not depend on the position of the electrodes, they could have discussed it. However, he preferred to draw an electrochemical cell on the blackboard and told that it was not correct to think in that way. He stressed that, not the position, but the half cell potentials determine which electrode would be the anode or cathode. In this example, Mr. Demir's didactic orientation shaped the way how to address the misconception.

Similar manipulative influence of orientation to science teaching component on instructional decisions was observed in the interplay provided above. In the complicated PCK interplay example, Mr. Demir decided to stress the differences among electrochemical and electrolytic cells in terms of signs of electrodes (Figure-27)

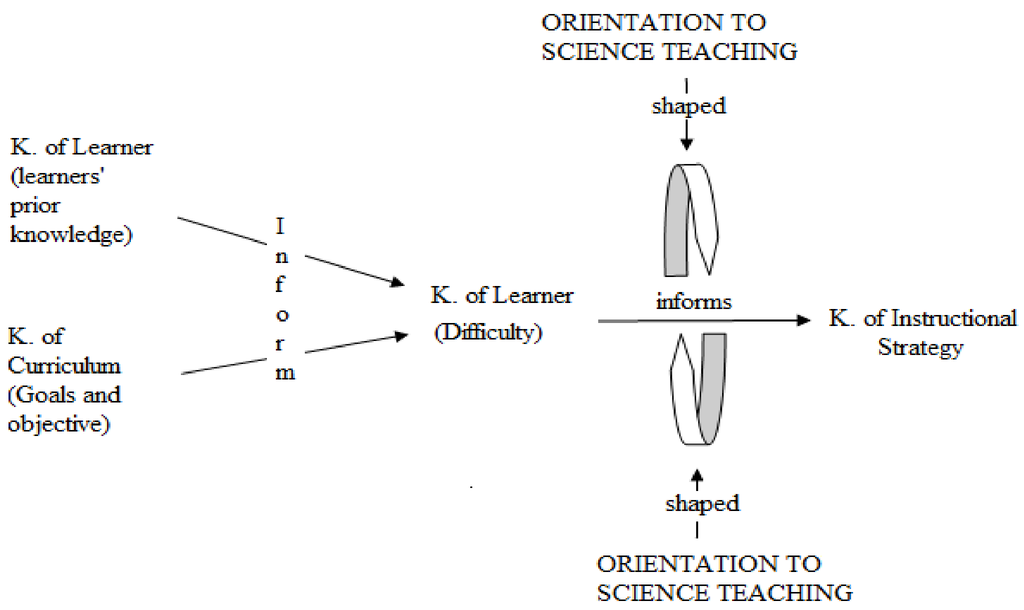


Figure 27. The shaping influence of orientation to science teaching component on instructional strategy use

4.4.4. Different Types of Interplay (e.g. Informative vs. Decisive Interplays) among Components Exist

In light of the previous assertion, it can be said that interplays are different in nature. In some of the examples, the nature of the interplay is informative whereas in others it is decisive. One of the examples provided above, knowledge of curriculum notified instructional strategy about the necessity of performing some exercises about Nernst Equation. This interplay is informative because one of the PCK components informs the other about addition of a new part to the teaching. However, the interplay among the instructional strategy and orientation to science teaching in the point 4.4.3. was decisive (Figure 27). In decisive type of interplays, orientation to science teaching component shapes teachers' decisions. In the example given above, the teacher preferred draw an electrochemical cell on the board and stated that it was not correct to think in that way. Then, he stressed that, not the physical placement but the half cell potentials determine which electrode would be the anode and/or cathode. Although there are many ways to handle with learners' misconception that is 'anode is always at the left side", the teacher's orientation to science teaching styled the way through which he addresses it. Therefore, the interplay was decisive rather than informative. In other words, in this interplay, it can be seen that orientation to science teaching component directs teachers decision of how to address misconceptions rather than letting teacher know that learners have the misconception.

4.4.5. The Interplays among Well-developed PCK Components are Used Notably. However, Some Missing Interplays among Rudimentary PCK Components are also Detected

Mr. Demir's knowledge of learner and curriculum components of PCK are more developed than knowledge of assessment and knowledge of instructional strategy. He was aware of learners' difficulties, confusions, and pre-requisite knowledge that learners need to learn the new topic. He could diagnose learners' misconceptions, difficulties, and confusion well. Similarly, he was very good in horizontal and vertical relations of topics in the chemistry and physics curriculum. He was aware of the goals and purposes stated in the curriculum. However, his repertoire of instructional strategy and assessment strategies were not rich enough to use different instructional and assessment strategies. When asked whether he employs diverse strategies to assess learners' understanding, he stated that he always used tests and quizzes including open-ended and multiple-choice questions.

Similar to assessment, his instructional strategy repertoire included didactic teaching, analogy, questioning, and lab activities. Inquiry, conceptual change, or other instructional strategies were not used in his teaching.

When interplays were examined, it was clear that in almost all of the detected interplays include either curriculum and/or learner knowledge. However, the interplay among assessment and other components were limited. Although he was knowledgeable about the curriculum, it did not inform his use of assessment strategies. He utilized traditional assessment techniques (e.g. test) to assess learners' understanding, however, performance-based and authentic assessment strategies were suggested to teachers to use in the curriculum. So, there was a weak relation among curriculum and how to assess sub-component of assessment knowledge. Moreover, he focused on assessing learners' understanding whereas assessment of science-process skills was also underlined in the curriculum. The only interplay among the curriculum and assessment knowledge was that his curriculum knowledge informed him to what to assess, in terms of objectives stated in the curriculum. He asked questions to assess whether or not they reached the objectives in the curriculum. In other words, there was a weak interplay among what to assess sub-component of assessment knowledge and curriculum knowledge. In Figure 28, the interplays among the components were shown with dotted line in order to demonstrate the weak relations among them.

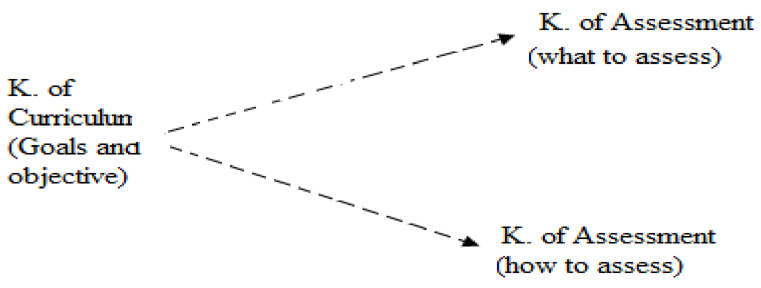


Figure 28. Weak relations among knowledge of curriculum and assessment

To sum up, some of the PCK components are more available for Mr. Demir than the others.

4.4.6. Not only PCK Components Informed each other, SMK, and PK also Influenced PCK Components

Mr. Demir used two animations to teach cells (instructional strategy). The first one included fewer details (just parts of cells) than the second one included details (electron flow, ion motion in the salt bridge, and sub-atomic representations of atoms, ions, and water molecule, etc.), he preferred to start with the simple one and then to continue with the complicated animation. When asked in the interview for explaining the reason for his choice, he stated that the first one was less complicated so it would be easier to understand at the beginning. Then he used the more complex animation. One of the basic principles of pedagogy, ‘learning should be simple to complex’, inform Mr. Demir’s teaching sequence. Therefore, it could be stated that his general pedagogical knowledge influenced his instructional strategies. Similarly, SMK had interplays with PCK components. For instance, Mr. Demir knew that in physics students learn that electricity current flows from (+) terminal to (-) one. But in chemistry, learners are taught that electron moves from anode (-) to cathode (+). Due to his robust SMK, he could diagnose the reason of the difficulty and provide extra explanation to learners.

4.4.7. The Interplays can be Assumed to Have Diverse Parts, Namely, Understand, Decision-making, Enactment, and Reflection

The first step is the understanding of the difficulty, misconception, and/or problem (Figure 29). Then, the decision for solving it is taken through the filter of orientation to science teaching. The enactment of the strategy decided is the third step. After the application of the strategy, the teacher reflected on the decision taken regarding to what extent it helps learners to understand and solve the problem detected. After reflection, if the teacher thinks that it is useful, he puts it into his repertoire and uses it next time.

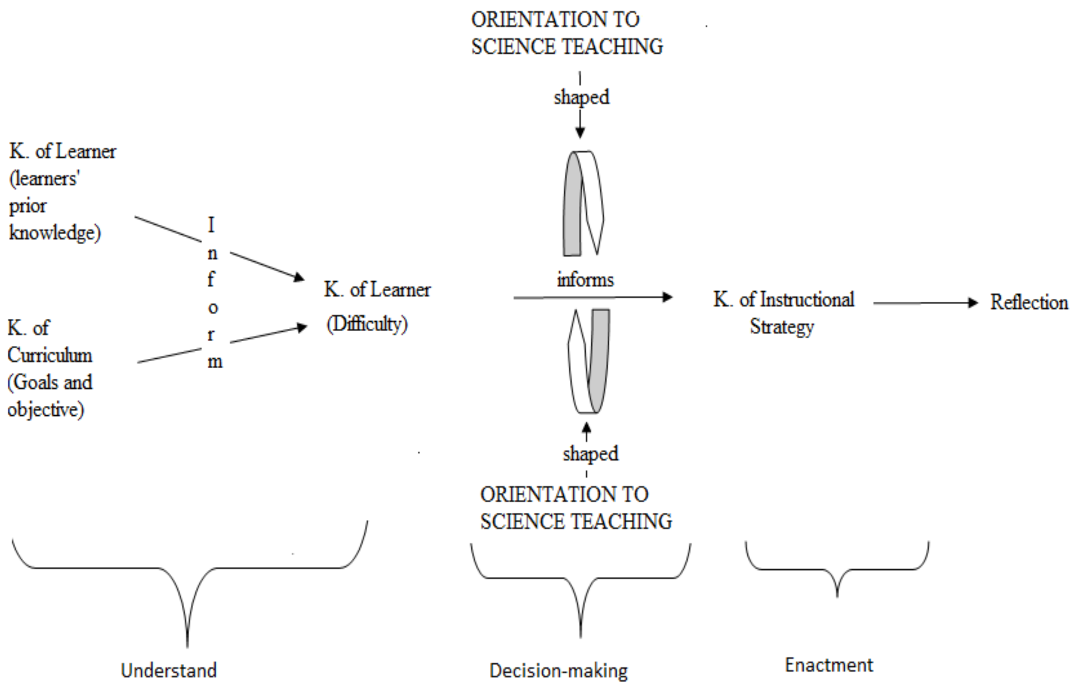


Figure 29. Steps included in the interplays among PCK components

When these parts of the interplays were examined, I saw that knowledge of learner, curriculum, PK, and SMK had essential roles in diagnosing. Orientation to science teaching component, on the other hand, mediated his choices about how to remedy it. Due to his didactic orientation, he usually responded the difficulties and/or misconceptions didactically. He preferred to provide scientific explanation, and to eliminate them through asking questions to learners, which makes them think on the point and creates dissatisfaction with their conception. Therefore, at the enactment step, knowledge of instructional strategy took the main role. In addition to instructional strategy, knowledge of assessment took part as well. As mentioned above, because learners had difficulties in determining anode, cathode, electron and ion flow in the electrochemical cells, Mr. Demir used an open-ended question asking learners to form a cell between two metals and determining all the details about the cell. In this example, the problem was diagnosed with help of knowledge of learner. Then his didactic orientation shaped his decision and he decided to enact the same traditional assessment which is test but with different types of questions. Rather than multiple-choice items, he included open-ended items. Finally, after the first try he reflected on it and realized that open-ended items were better than multiple-choice ones to see how much learners learn and at which points they have difficulties (Figure 30). Through this way, he accumulated the strategy which is one piece of his PCK.

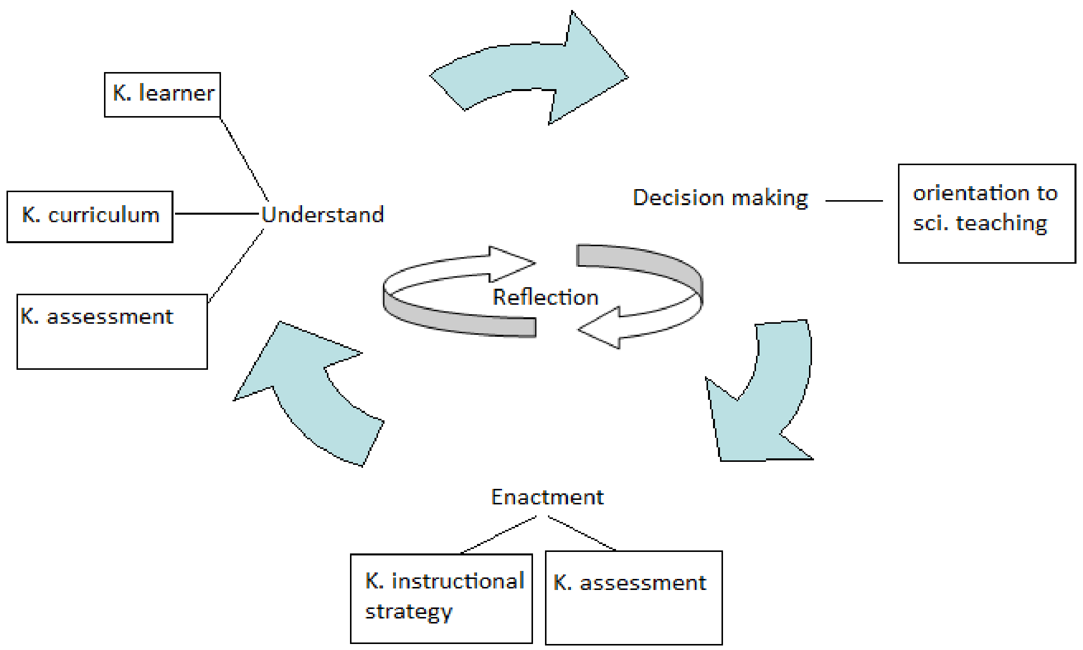


Figure 30. The PCK formation cycle

4.4.8. Some of the Interplays Detected were Mutual whereas some of them were One-sided

First, results showed that some of the interplays are mutual whereas some of them are one-sided. When all of the interplays were examined, it was realized that the interplay between learner-assessment and curriculum-learner were mutual. For instance, Mr. Demir's assessment informed him about the difficulties that learners had. When he did a quiz, he realized that learners confuse the signs of anode and cathode, and the reactions occur in anode and cathode in electrolytic and electro chemical cells. Likewise, his knowledge of learner noticed him how to use assessment strategies. For instance, due to the fact that learners had difficulties in determining anode, cathode, electron and ion flow in the electrochemical cells, Mr. Demir preferred to use an open-ended question to assess to what extent they learn the cell formation in the unit test. He usually chose multiple-choice questions in the exam, however, for the particular situation; he thought that he needs to see the all steps rather than seeing only the result. Similarly, the interplay between curriculum and learner knowledge was also reciprocal. Due to his robust curriculum knowledge, Mr. Demir was aware of the sequence of topics through grades. Moreover, he was knowledgeable about physics curriculum. Therefore, the knowledge about the structure of curriculum and when the topics are taught, he could inquiry the possible reasons of learners' difficulties. He realized that for many times, due to deficient pre-requisite knowledge, learners had difficulties in understanding the new topics. Knowledge of learner also informed knowledge of curriculum. For instance, in the curriculum, the electrochemistry starts with the Faraday's Law and calculations about it. Then, electrochemical cells follow it and finally, electrolytic cells are taught. Mr. Demir postponed teaching Faraday's Law and its calculations. He stated that it does not make sense to teach it before teaching electrolytic cells because they would eventually teach them. And also it would make learners confused. Therefore, first, teaching the cells and then preceding with the Faraday's Law and its calculations made more sense to them.

On the other hand, some of the interplays between PCK components were one-sided. For instance, interplay between a) instructional strategy and learner, b) curriculum and instructional strategy, and c) assessment and instructional strategy were one-sided. For example, Mr. Demir knew that learners had difficulty in learning the signs of anode and cathode in electrochemical and electrolytic cells (knowledge of learner). Therefore, he did not teach the signs of them in electrochemical cells and just focused the reactions occur. Later, at the beginning of the electrolytic cells, he mentioned the signs of electrodes by comparing and contrasting the signs in electrolytic and electrochemical cells (knowledge of instructional strategy). However, the reverse relation was not detected.

Second, regarding the nature of the interplays, it was realized that some of the influences were direct whereas others were indirect. To clarify, there was an objective related to the Nernst Equation and performing some algorithmic exercises related to it in the 11th grade chemistry curriculum. So, due to that objective, Mr. Demir integrated some exercises with his lectures. It is an example of direct influence among the PCK components. On the contrary, in one of the interplays we analyzed he realized that learners had difficulties in writing redox reactions regarding the cell in quiz papers. In other words, knowledge of assessment informed his knowledge of learners. So, he performed additional practices regarding how to write cell equations and re-taught it (knowledge of instructional strategy). It can be concluded that assessment of knowledge had an indirect influence on his instruction.

To sum up, when we put all these points together, the figure 31 given below was gathered. In the model, how the components of PCK interplay with each other was summarized. The solid lines between the components show that there is interplay between them whereas the dotted-lines show that no interplay was observed between them. Additionally, orientation to science teaching was placed at the center of the interplays and components due to its mediating role on the interplays. Finally, double arrows mean that there is a mutual relation between them whereas one-sided arrows mean that the interplay is one-sided.

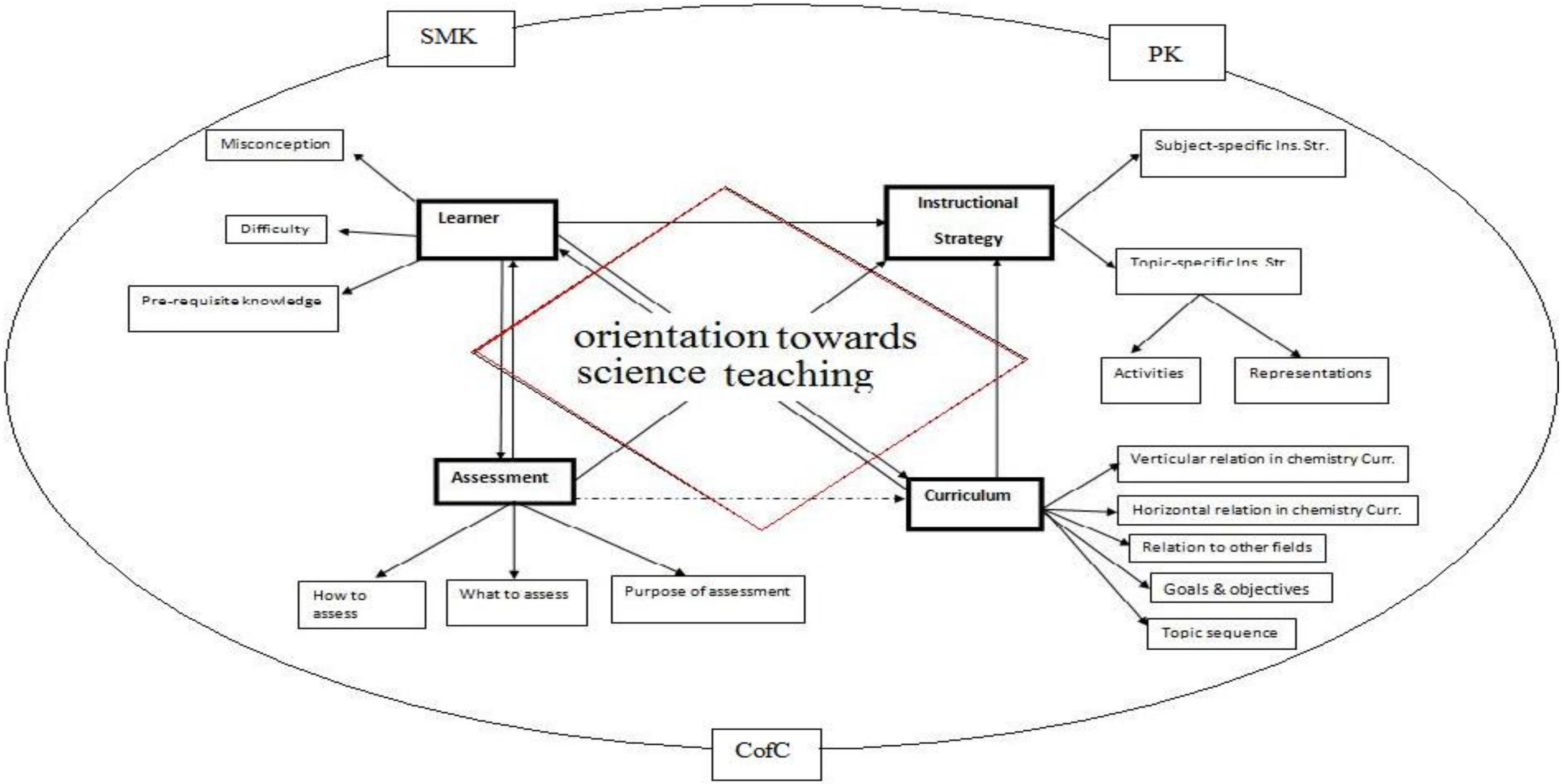


Figure 31. The model of interplay among PCK components

CHAPTER 5

CONCLUSION, DISCUSSION, & IMPLICATIONS

5.1. Conclusions

In this study, two experienced chemistry teachers' PCK was compared and contrasted in two topics, electrochemistry and radioactivity, in order to articulate topic-specific nature of PCK. To conclude, two teachers' PCK was specific to topic taught in terms of all components of PCK (e.g. knowledge of curriculum, assessment, etc.) although some negligible variations observed. To sum up, teachers' PCK for teaching electrochemistry (PCK A) and radioactivity (PCK B) have its own characteristics (Table 20). Electrochemistry and radioactivity have unlike nature regarding to types of reactions focused (chemical vs. nuclear reactions), pre-requisite knowledge necessary to learn the topics, and the relations to other topics in chemistry and physics. Moreover, electrochemistry has a composite structure including sub-parts. Regarding to differences in PCK, it was seen that PCK A, PCK for teaching electrochemistry, represented a teaching which is teacher centered and focused on the delivery of the content through the use of learner knowledge. In this type of PCK, teachers could relate electrochemistry to the other topics in chemistry and physics. Moreover, students' learning was assessed consistently through the topic. On the contrary, in PCK B, for teaching radioactivity, learners had more chance to talk, and the teachers focused on NOS and environmental issues in addition to content. The topic was connected to the other topics in chemistry and in physics but it was restricted and superficial. The assessment of learning was not done continuously rather at specific points it was assessed.

In addition to nature of topics, some other factors may also explain the differences in PCK. For instance, although the study was started with the assumption that both teachers have robust SMK in both topics some weaknesses were observed especially in radioactivity. Moreover, the support given for teaching the topics by the curriculum guide may have some responsibility in the differences observed. The possible explanations of the whole picture obtained will be discussed with the help of the literature and the data collected in the discussion part.

Second, regarding to the interplay among the PCK components, it was observed that the experienced teacher is able to use more than one PCK components to act in response to a specific situation. The interplays are sometimes so complicated that a teachers' response to a condition may include both PCK components (learner, assessment, and instructional strategy, etc.) and domains forming PCK (PK and SMK, etc.) simultaneously. When the interplays were examined, it was realized that they included different parts, for example, understanding, decision-making, enactment, and reflection. At these parts, different PCK components and knowledge domains take role to eliminate a misconception and/or to make the topic easier for students to learn. The analysis of the interplays also helped me to see that some of the PCK components may be more developed than others so they are more available for teachers. In other words, all PCK components may not grow with the same pace. In addition to well-built interplays, weak relations were also observed among some components, namely, knowledge of assessment and instructional strategy. Finally, orientation to science teaching is a component which is all-embracing the other components and the teachers' decisions for teaching and assessment. In other words, it directed the teacher in decision-making process for picking instructional and assessment strategies.

5.2. Discussions

In this part of the dissertation, the results of the study were compared and contrasted to the other studies in the PCK literature. The novel aspect of the research was that focusing on how PCK is specific to topic by comparing and contrasting chemistry teachers' PCK in two topics. In the literature, there are some studies that compared and contrasted teachers' PCK in area of specialization and out of it (Ingber, 2009; Sanders et al., 1993) and PCK for teaching a common topic for different fields, namely, teaching evolution topic by biology and geology teachers (Veal & Kubasko, 2003). In this part, the results were discussed. In order to be compact, first, the discussion of the results for topic-specific nature of PCK was provided component by component. Then, the discussion of the interplay among PCK components was presented.

5.2.1. Discussion of the Results for Topic-specific Nature of PCK

5.2.1.1. Orientation to Science Teaching

In this study, the participants held a didactic orientation to teaching science. However, labeling teachers' orientation to science teaching was not straight forward due to its multifaceted nature. Friedrichsen and Dana (2005) indentified that orientation to science teaching is so complex that it includes central and peripheral goals which are related to schooling, affective domain, and subject-matter. The participants in this study mostly were concentrated on schooling goals. In other words, teachers' central goals were preparing learners to UEE. The peripheral goals held by the participants were to facilitate learners' interest in chemistry, which was related to affective domain. However, due to the dominancy of the schooling goals, the others were ignored a little bit.

Many factors influence teachers' orientation to teaching science, for instance, exam-based teaching, teachers' beliefs, loaded program, teachers' concerns regarding to adequacy of their SMK were factors influencing their orientation (Friedrichsen et al., 2011; Friedrichsen & Dana, 2005; Nargund-Joshi, et al., 2011; Samuelowicz & Bain, 1992). Moreover, the contextual circumstances may force teachers to develop ideal and working orientations. Therefore, although teachers prefer to teach in a different way, they had to change teaching style in order to handle with the educational conditions in a specific context (Samuelowicz & Bain, 1992). In Turkey, in order to go college for taking higher education, high school students have to take UEE and get good scores. When the quota that all programs have and the number of people who want to pursue a higher education are compared, it is obvious that there is a large gap between the two. For instance, in 2010, the center for student election and 1.487.493 students took the exam (Ölçme, Seçme ve Yerleştirme Merkezi, [ÖSYM], 2010a). However, the quota existed for only 360.968 students (ÖSYM, 2010b) Therefore, students feel like as if they were in a long marathon. Due to the UEE system, high school education is based on performing multiple-choice exercises. Moreover, the quality judgments about teachers and schools are based on the scores taken from the UEE (Köse, 1999), which forces teachers to focus on the exam-based teaching. In this study, teachers recognize of the importance of providing experiments and activities in chemistry teaching, however, they are reluctant to spend much time with them in order to save more time for performing exercises. The similar point was stated by Nargund-Joshi et al., (2011) who studied Indian teachers' orientation to science teaching. The exam-based educational system in India also made teachers modify ideal goals of teaching so the variation was observed between what teachers' said about their teaching and their teaching practices. Likewise, in China, Zhang et al., (2003) identified the gap between what teachers think about teaching and how they teach. The reality of preparing learners to the exam forced teachers to play the game with its own rules. Although they were aware of the benefits of the inquiry teaching, they had to concentrate on didactic teaching for the exam.

Another probable reason of why teachers preferred to teach didactically may be the curriculum load (Samuelowicz & Bain, 1992), time necessary for preparing minds-on activities (Friedrichsen & Dana, 2005), and burden of teaching works (e.g. grading) (Nargund-Joshi, et al., 2011). The participants of the study complained about the loaded curriculum. During the card-sorting activity, they stated that they would like to apply more experiments and make learners more active during the activities; however, the time issue for covering all the content in the curriculum did not let them do that. Participants mentioned the point during the card-sorting interview.

Second, the discussion of results for knowledge of instructional strategy was done in the next part.

5.2.1.2. Knowledge of Instructional Strategy and its Use

In the use of instructional strategies and representations in electrochemistry and radioactivity, both correspondences and variations were identified in teaching of both topics. The similarities were the lack of use of subject-specific instructional strategies (e.g. learning cycle, conceptual change, etc.), the sequence of the instruction, and the delivering the content through didactic teaching. The distinctions were the level of teacher-centeredness of instruction, the aspects stressed during the instruction (e.g. content, NOS, etc.), the number of activities and demonstrations used, and time spent for performing algorithmic calculations.

In order to be able to discuss the results summarized, chemistry education and teacher education literature were reviewed to get possible explanations for the differences and similarities in instructional strategy use in two topics. PCK literature has indicated the importance of SMK for developing a robust PCK. Therefore, before starting to discuss the results of PCK components, it would be more appropriate to talk about participants' SMK here. SMK is essential for having a strong PCK (Abell, 2007; Magnusson et al., 1999; Shulman, 1986). Although I started the research with an assumption that teachers' SMK is equally strong in both topics, I realized that it was not indeed. Despite any instrument was not used to assess SMK, the observations of teachers' classes helped me to notice the differences. It was observed that teachers' SMK was different regarding to amount of SMK and organization of it. In electrochemistry, both teachers' SMK was deep whereas it was relatively superficial in radioactivity. In many parts of the observation, it was noticed that teachers could not answer many of the questions learners asked. Moreover, at one point, they had to talk to physics teachers and search from internet. Second, participants were able to structure electrochemistry topic in terms of sub-topics and the relations of sub-topics. However, it was not the case for radioactivity. The results of this study were consistent with the existing literature about the weak SMK that teachers have in radioactivity (Colchough et al., 2011; Liddicoat & Sebranek, 2005; Nakiboğlu & Tekin, 2006). In addition to observations, participants admitted the weakness of SMK in radioactivity during self-comparison interview. In the next part, the discussion for knowledge of instructional strategy was presented.

First, electrochemistry is one of the most difficult topics in chemistry for both learners and teachers (De Jong & Treagust, 2002; Nakiboğlu & Tekin, 2006). Moreover, to be able to learn electrochemistry well, learners need to have much pre-requisite knowledge both from chemistry and physics. The deficient understanding of the pre-requisite knowledge brings about troublesome in learning electrochemistry (Sirhan, 2007). In addition to pre-requisite knowledge from other topics in chemistry and from physics, it also has underpinnings within the topic (e.g. reactivity of metals and redox reactions) (De Jong & Treagust, 2002), which may be another possible feature of electrochemistry making learning it difficult, if not impossible. In light of the literature cited to make clearer the nature of electrochemistry topic, it may be stated that participants preferred to teach electrochemistry through more teacher-centered way because of the very composite nature of electrochemistry. Teachers may think that they had to teach the topic directly rather than sharing the responsibility with learners due to the fact that connections had to be done to the other topics (e.g. chemical reactions, solutions, etc.) and to physics (e.g. current, circuits, etc.). In other words, they may think that such a hard topic should be taught in such a way that teacher should orchestrate the instruction. Contrary to literature, they let learners talk less in class when they are knowledgeable about the topic, in electrochemistry. Although their SMK was strong, they did not discuss the points related to electrochemistry with learners. In radioactivity, they have weak SMK. When teachers could not answer learners’ questions, they admitted that they did not know and did research later. In Carlsen (1993) study, teachers did not let learners talk in the topics that teachers' SMK was weak. The contradiction may be explained by the points discussed below.

On the contrary, radioactivity is a very current topic on which scientist, media, society, and politicians discuss. Especially after Japan Tsunami in 2010, it is a hot-topic. Similar to discussions in news, teachers preferred discussions for the different aspects (e.g. energy, environment, etc.) of radioactivity topic in this study. Although it is a current topic, "instruction in nuclear chemistry is limited or lacking in the chemistry curriculum"(Nakiboğlu & Tekin, 2006, p.1712). It is not only limited in the curriculum but also put towards the end of it, which may lead teachers to ignore it or teach it superficially (Atwood & Sheline, 1989). Likewise, it is the last topic of the 11th grade program in Turkey. Radioactivity is mostly ignored by teachers because of the weak SMK that teachers have and its place in the textbook and/or curriculum (Atwood & Sheline, 1989). In this study, teachers did not ignore the topic. Teachers used discussions during teaching radioactivity although their teaching was generally didactic. They also made learners relatively more active in radioactivity than in electrochemistry and let them share ideas. It may be related to the nature of radioactivity topic that does not include algorithmic calculations, at least in high chemistry curriculum. However, electrochemistry includes both conceptual and algorithmic parts to learn (Niaz & Chacon, 2003), which was also indicated by the participants during the self-comparison interview. Therefore, that difference may lead teachers to teach in a different way in electrochemistry and radioactivity. Because they did not have to perform algorithmic calculations, they might spare time for discussions about nuclear energy, its effect, and its political aspects. It is not the case for electrochemistry which is one of the basic topics in chemistry curriculum in Turkey. Generally at least two questions are asked in the UEE each year from electrochemistry, which has also increased the importance of the topic for students to be able to go to college. Question from radioactivity is asked very rarely in the UEE. If there is a question from the topic, it is generally balancing a simple nuclear reaction. Therefore, teachers mostly pay less attention to radioactivity (Nakiboğlu & Tekin, 2006). Due to electrochemistry's importance regarding to UEE, teachers may think that it should be taught in a more teacher-centered way. Similarly, they may let learner talk for radioactivity topic due to the fact that it is not asked in UEE or even it is asked, it is easy to do questions.

Yet another possible explanation for more teacher-centered instruction for electrochemistry may be the number of the concepts taught in the topics. Participants stated that there are more concepts in electrochemistry than there are in radioactivity in the self-comparison interview. It may seem that when they have to focus on more concepts to teach, they may have a tendency to teach more-teacher centered to save time. Similarly, both of the participants stated that electrochemistry has numerous concepts (e.g. oxidation, reduction, anode, cathode, SHE, electrolytic cell, electrochemical cell, anode, cathode, ion and electron transfer, etc.). On the contrary, fewer concepts are supposed to be taught in radioactivity. Even if less time is spent to teach it, still it may be enough to activate learners in radioactivity.

Regarding to the number of activities used in the topics, those in electrochemistry exceed. It may be related to the large number of activities suggested in the practitioner journals (e.g. Volkmann & Abell, 2003), in the curriculum (NME, 2011), and on the internet. However, the amount of the support provided to the teachers for teaching radioactivity is not enough. Moreover, as a topic radioactivity has its own barriers regarding to use of experiments and activities (Liddicoat & Sebranek, 2005; Millar et al., 1990). Even having a Geiger counter is almost impossible for most of the high schools. In addition to equipments, another obstacle is the safety issues in radioactivity. Even if the counter and other radioactive sources exist, learners cannot perform the experiment due to safety regulations (Liddicoat & Sebranek, 2005; Millar et al., 1990). The same points were stated by the participants of the study. They stressed the limited activities suggested for teaching it in sources (e.g. activity books, internet, etc.) and lack of activity in the curriculum material in the self-comparison interview. Moreover, they said that when we think about Turkey context, there is no nuclear reactor to visit. However, many activities are safe and available for teaching electrochemistry.

In addition to activities and demonstrations, teachers also utilized representations (e.g. figures, animations, and analogies) in both topics. Although teachers drew on many analogies in electrochemistry, no analogy use was observed in teaching radioactivity. Similar to limited activities provided to teachers in radioactivity, it may be also related to the limited analogies presented in the sources. Regarding to the other types of representations, more or less all three levels of representations, namely, macroscopic, symbolic and sub-microscopic levels (Treagust, Chittleborough, & Mamiala, 2003) were applied when necessary. Understanding both particulate nature of matter and how the particles interact are crucial in learning chemistry (Harrison & Treagust, 2002; Millar et al., 1990; Sirhan, 2007). Sub-microscopic level of the fusion and fission representations were employed especially in the radioactivity to show what happens in particulate level. Similarly, sub-microscopic representations of cell reactions were integrated to the electrochemistry. Participants stated that they used them because visualization of the reactions helps learners to understand and remember the topic taught. Teachers implemented the all levels of the representation in both topics possibly because chemistry teaching requires integration of all levels of representations (Kozma, Chin, Russell, & Marx, 2000).

Although differences were observed in the participants' teaching the topics, the instructional sequence including lecturing, applying activities, and performing exercises was the same. The sequence started with the introduction of the topic and then continued with the lecturing during which all the necessary terminology and content knowledge were provided by teacher. Later, exercises were performed first by teacher and then the learners. Finally, an activity or demonstration was integrated to the class, which aimed to help learners visualize the reaction and to help them retain the information. Related to the point, DeBoer (1991) stated that this type of instructional sequence is the chronic illness of teachers' instruction for a long time. Likewise, Friedrichsen et al., (2007) observed the use of similar the instructional sequence in their study. It may be related to that this type of instruction may be only type that they have experienced. Grossman (1990) stated that observations of teaching as a student in the K-12 and undergraduate years are source of teachers' PCK. Therefore, inadequate subject-specific professional development and lack of experience how to teach in a different way with diverse sequence may explain why teachers generally teach with the same sequence.

The second similarity observed in their teaching the both topics was the lack of subject-specific strategies (e.g. learning cycle, conceptual change, etc.) in teaching the both topics. In the prominent study, Magnusson and her colleagues (1999) discussed the possible reason of teachers' reluctance to use subject-specific strategies. They stated that it may be related to teachers' beliefs. The instructional decisions that teachers had are filtered through the orientation to science teaching component including teachers' beliefs. Therefore, teachers preferred to use strategies which are fit to their orientation. It may also be related to the lack of knowledge about how to implement the strategies (Settlage, 2000) and the lack of experience teaching in that way (Flick, 1996). The participants did not take any chemistry-specific or science-specific professional development. Moreover, they may not have a chance to observe how these strategies can be brought into play. Ingber (2009) and De Jong et al., (1995) revealed that the lack of subject-specific strategy may be explained by *teacher-specific* teaching rather than topic-specific one. Teachers had a tendency to implement the similar types of activities with the same purpose and the sequence without considering the topic taught. In this study, the participants had their own style to deliver the content; however, it has some variations in two topics. The sequence of the instruction, mentioned above, and the purpose and the way of the activities and demonstrations employed were the same for both topics. On the contrary, the aspects (content, NOS, energy and environmental issues, etc.) integrated to the teaching, and the amount of learners' participation were different in two topics.

Finally, although NOS understanding of teachers' was not assessed or examined in the study, in terms of very implicit NOS addition to radioactivity, it seems that participants' NOS understanding is quite limited. They mentioned that science is subject to change; however, they did not stress the point explicitly as suggested by the literature (Abd-El-Khalick & Lederman, 2000; Lederman, 2007). It may be related to the lack of training on how to integrate NOS and teach it (Abd-El-Khalick, Bell, & Lederman, 1998). Additionally, it may be also related to the lack of NOS stress in the curriculum (Lederman, 1992). It is assumed that if it was in the curriculum as a goal to attain, it is reasonable to believe that teachers would integrate to their teaching. It is reasonable to assume it because teachers stated that they started to teach how and where radioactivity is used in life due to the fact that it is put into the curriculum recently. Therefore, if it was in the curriculum, it is more likely that teachers would teach and assess it.

5.2.1.3. Curriculum Knowledge and its Use

Third, the differences and similarities in the curriculum knowledge and use of it were discussed here. Participants' curriculum knowledge and its use were better in electrochemistry regarding to the links to the other topics and disciplines, and the altering the curriculum and sequence. The formation of network among the topics in chemistry and in physics is most probably associated to nature of the electrochemistry. As mentioned above, electrochemistry is tough to learn because it necessitates much pre-requisite knowledge both from chemistry (e.g. chemical reactions, periodic table, chemical equilibrium, oxidation number- charge, etc.) and from physics (e.g. circuits, electron flow, etc) The lack of the pre-requisite knowledge results in problems in learning electrochemistry (Sirhan, 2007, p. 8) In addition to that, electrochemistry includes many underpinning concepts (e.g. redox reactions, reactivity, etc.), which makes previous ones (e.g. reactivity of metals) pre-requisite for learning the later ones (electrochemical cells). Therefore, for effective electrochemistry teaching, teachers should be aware of the chemistry curriculum regarding to sequence of the topics, and horizontal and vertical relations. On the contrary, radioactivity is quite different from other chemistry topics where focus is on the electron, electron cloud, and bonds formed by transition of electrons or sharing electrons. Radioactivity is related to the reactions occurring in the nucleus. It requires some pre-requisite knowledge, for instance, atom, isotope, atomic and mass number, etc. (Nakiboğlu & Tekin, 2006). However, radioactivity does not necessitate network of topics as much as electrochemistry does. It may explain why teachers' curriculum knowledge had a network in electrochemistry but had limited network in radioactivity.

Second, in terms of being able to change the sequence of the sub-topics, it may be connected to both curriculum saliency and robust SMK that teachers had. Teachers questioned the sequence of the sub-parts in the electrochemistry and changed the sequence of them. Rollnick et al., (2008) described curriculum saliency that "refers to the teacher's understanding of the place of a topic in the curriculum and the purpose(s) for teaching it" (p. 1367). Therefore, owing to curriculum saliency teachers diagnosed a problem in sequence of the sub-topics in the curriculum that may result in a problem in teaching electrochemistry and altered it. In addition to saliency, it is highly probable that teachers' strong SMK in electrochemistry may help them to realize the problem. As admitted by the teachers in self-comparison interview, they feel quite comfortable in teaching electrochemistry due to robust SMK. This point was contrary to the literature because teachers generally thought that teaching electrochemistry is hard (De Jong & Treagust, 2002). When compared to radioactivity, they experienced more stressful time in radioactivity due to deficient SMK. Rollnick et al., (2008) stated that teachers' superficial understanding of the topic might make the relation difficult for teachers.

Finally, regarding to curriculum knowledge, the support provided in the curriculum is an important aspect to discuss here. It is also related to other types of knowledge (e.g. knowledge of instructional strategy). In the curriculum, two laboratory activities were suggested to teachers (NME, 2011). One of them was used by the participants (reactivity of metals activity). The other one was a laboratory activity during which Zn- MnO_2 is opened. However, no activity was provided for teaching radioactivity. Participant teachers also complained about the lack of suggestion of teaching activity in radioactivity during the self-comparison interview. The similar critic was made by

Colchough et al., (2011) for curriculum guidebook in England. The researchers stated that activities for teaching radioactivity and the points on which learners have difficulty and/or misconception should be integrated to the curriculum guides in order to help teachers teach such an advance topic. Radioactivity is not overlooked only by high school curricula as indicated by Nakiboğlu and Tekin (2006) and Colchough et al., (2011), but also by undergraduate chemistry programs (Zevos, 2002) and by the chemistry textbooks (Liddicoat & Sebranek, 2005).

5.2.1.4. Knowledge of Learner and its Use

In this study, teachers were highly knowledgeable about learners' difficulties and misconceptions in electrochemistry. Moreover, they were aware of the pre-requisite knowledge necessary to learn electrochemistry. However, in radioactivity, teachers were partially aware of difficulties and misconceptions that learners may have, and the pre-requisite knowledge necessary to learn the topic well. Regarding to the topics' history through which they have been studied, radioactivity is a new a field of science and has been started to be studied at the very beginning of twentieth century (Malley, 2012). On the contrary, electrochemistry is one of the oldest topics that were studied from mid 1700s. Therefore, radioactivity has many unknown pieces than electrochemistry has, which may partially explain the limited education study on learners' misconceptions and difficulties in radioactivity, and why it is ignored in curriculum and textbooks.

With this in mind, corresponding to the literature (Millar et al., 1990; Liddicoat & Sebranek, 2005; Nakiboğlu & Tekin, 2006), teachers in this study had limited knowledge at which points learners have difficulties and/or misconception in radioactivity. It may be related to the limited research on students' misconceptions and difficulties in radioactivity. In electrochemistry, however, teachers' knowledge of learner was much better than it was in radioactivity, which is also parallel to the idea that the more studies are conducted, the more awareness teachers may have about the specific difficulties and misconceptions that learners have. When looked at the literature, it can be seen that there are many studies about learners' difficulties and/or misconceptions in electrochemistry, and how to teach electrochemistry (e.g. Garnett & Treagust, 1992a, 1992b; Niaz, 2002; Niaz & Chaco´n, 2003; Sanger & Greenbowe, 1997a, 1997b; Schmidt et al., 2007).

In addition to research, teacher education programs and colleges ignore radioactivity regarding to SMK and PCK (Atwood & Sheline, 1989). Research revealed that when teachers have strong PCK in a topic, they are more likely focus on learners' difficulties and misconceptions, and learners' need (Sanders et al., 1993). In this study, participants stated that their SMK in electrochemistry was more robust than their SMK in radioactivity. Congruent with the literature, teachers were more knowledgeable about learners' both difficulties and misconceptions in electrochemistry whereas they are not aware of them in radioactivity. Moreover, at many times they missed possible misconceptions that learners had. The well-structured SMK may help teachers realize at which points learners may have difficulties.

Regarding to knowledge of learner, research stated that teaching experience is the most important source of it (van Driel et al., 2002); however, the experienced teachers in this study could not develop solid knowledge of learner in radioactivity topic. It may be related to teachers' limited SMK in radioactivity. It seems that if SMK is robust in a topic, it may assist their understanding of pre-requisite knowledge, and possible difficulties and misconceptions. As Shulman (1986), Grossmann (1990), and Magnusson et al., (1999) stated, PCK is formed through the transformation of SMK into the understandable form for learners. Therefore, teaching experience may be a valuable source for developing knowledge of learners' difficulties and misconceptions; however, the influence of experience is most probably mediated by SMK. To conclude, teaching experience does not guarantee that experienced teachers have rich PCK (Friedrichsen et al., 2009). Furthermore, as Henze et al., (2008) asserted that the development of PCK components may vary from topic to topic. The variation in the topic may be related to the quality of SMK that teachers have in a particular topic. Correspondingly, teachers in this study had rich knowledge of learner in electrochemistry but deficient knowledge of learner in radioactivity.

5.2.1.5. Knowledge of Assessment and its Use

Regarding to assessment knowledge, teachers implemented assessment strategies from the beginning to the end coherently in electrochemistry whereas they preferred to use fragmented assessment in radioactivity. The picture got here may be related to the composite nature of electrochemistry that includes underpinning parts (e.g. redox reactions, cells, etc.) (De Jong & Treagust, 2002). Therefore, in order to move forward, teachers may need to be sure that previous parts are understood well by learners. In addition to that, to be able to learn electrochemistry, learners need to have some other pre-requisite knowledge as mentioned previously. The lack of them results in troubles in learning electrochemistry topic (Sirhan, 2007). It may be responsible why teachers used a coherent assessment in electrochemistry. The composite nature of electrochemistry may lead teachers assess permanently learners' prior knowledge (e.g. oxidation number, charge, and chemical reactions, etc.) at the beginning. During teaching, they informally examined to what extend students understand the sub-topic. At the end of the one sub-part, they preferred to have a quiz before starting to the new one and used the assessment results for helping learners to fix deficient parts. On the contrary, radioactivity has a distinct feature from electrochemistry which is that there are no clear-cut sub-parts. Therefore, teachers may not consider permanent assessment necessary for teaching radioactivity, which may result in fragmented assessment in radioactivity.

The reason of why teachers' assessment was fragmented in radioactivity but coherent in electrochemistry may be related to the amount of knowledge of learner that they have in the topics. Henze et al., (2008) stated that the more teachers know about learners' difficulties and misconceptions, the better they assess students' understanding. When we looked at the knowledge of learner, teachers have deficient knowledge of learner in radioactivity when compared to electrochemistry. It is reasonable to think that if teachers are more aware of the specific points that make learning the topic hard or that make learners confuse, it is more likely that teachers focus on them during both teaching and assessing.

Another point that is necessary to discuss is lack of assessment of NOS and other aspects such as environment and energy issues discussed in radioactivity. Although teachers mentioned only 'science is subject to change' aspect of NOS very implicitly, and nuclear energy and environmental issues, they did not assess learners' understanding of them. Similar result was obtained in Hanuscin, Lee, & Akerson (2011). "What is noticeably absent from teachers' practice is the use of formal and/or summative assessment strategies to determine NOS learning outcomes of individual students" (p.162). One possible reason may be lack of knowledge of how to assess them. Hanuscin et al. (2011) stated that knowledge of assessment for NOS is hard to develop even if professional development is provided to teachers. Another reason may be the inadequate emphasis of integration and assessment of NOS (Abd-El-Khalick et al., 1998; Hanuscin et al., 2011), and environmental problems in the curriculum. When the 11th grade chemistry curriculum in Turkey was examined, the lack of goals related to developing NOS understanding was seen for electrochemistry and radioactivity. Moreover, lack of NOS assessment may be related to the importance that teachers give to NOS understanding and/or environmental issues. Hanuscin et al., (2011) stated that "[t]his was not because they did not view NOS as important for students to understand, but rather they had insufficient knowledge of assessment specific to this topic." Although I agree with the inadequate knowledge of how to assess NOS understanding part, also teachers' view about the importance of NOS may explain the existing situation here. Contrary to the US education system, in Turkey, there is an exam-based system which requires students to perform as many exercises as possible. Moreover, the questions asked in the UEE are focused on the content taught rather than NOS or other socio-scientific issues, which may lead teachers to close their eyes to integrating those aspects into their teaching and to assessment of them. Even if teacher may view that NOS should be taught, the system may force them to ignore. Similar situation has been observed in other countries which have an exam-based education system, for instance, in China (Zhang et al., 2003) and in India (Nargund-Joshi et al., 2011). “It is impossible for educators to discount the national college entrance exam“ (Zhang et al., 2003, p. 494), therefore, they prefer to discount other aspects that are not included in the UEE system. The context regarding to country and school in which teachers teach has a big influence on their teaching (Loughran et al., 2004)

Yet another issue about the assessment knowledge is that although the use of assessment (e.g. coherent vs. fragmented) was diverse for the topics studied, the methods of the assessment strategies (e.g. informal questioning, tests, homework,) employed were quite similar for both topics. They are expected to be different due to the major differences between the topics and the due to the description of PCK that is specific to topic (Magnusson et al., 1999). Experienced teachers are supposed to have a strong PCK due to extensive experience in teaching (Grossman, 1990; van Driel et al., 2002). However, having teaching experience without any explicit support through professional development does not promise for strong PCK regarding to all components. Literature revealed that especially the development of knowledge of assessment may take more time than the development of other components (Hanuscin et al., 2011; Henze et al., 2008).

Finally, the assessment strategies used in both topics were tradional ones (e.g. quiz, test, homework). Due to the social, political and energy issues related to radioactivity, and many use of radioactivity in daily life (e.g. X-ray in medicine, food irradiation, external radiation therapy, radiocarbon dating in archeology, and nuclear power plants), authentic assessment strategies would be highly appropriate to assess learners’ understanding in radioactivity (Abell & Volkmann, 2006). For instance, teachers may have asked learners to prepare a poster about the use of radioactivity or prepare a presentation about the advantages and disadvantages of nuclear energy in order to assess their understanding. Similarly, they may have used them in electrochemistry. However, teachers have a tendency to implement assessment strategies with which their understanding was assessed when they were student (Kamen, 1996). Therefore, because teachers had an experience in how to use them, they may just use the traditional assessment strategies to assess to what extent students learned. Moreover, the lack of science- or chemistry-specific professional development on authentic assessment strategies and how to use them may also trigger the focusing on the use of traditional ones. In addition to that, teachers' didactic orientation to science teaching may influence the use of assessment strategy. "What the teachers choose to assess and how they choose to assess were mediated by their orientation" (Lannin et al., 2008; p. 6). Participants in this study had didactic orientation so they may have chosen to focus on assessing knowledge through traditional assessment techniques. Parallel to the literature, participants also mentioned that they felt more limited in assessing radioactivity than assessing electrochemistry.

To sum up, in theory, PCK is specific to topic regarding to instructional and assessment strategies used, knowledge of learner that includes difficulties, misconceptions and pre-requisite knowledge to learn the topic, and knowledge of curriculum containing relations to previous topics and other disciplines. The results of this study revealed that teachers' instructional and assessment strategies were specific to the topic regarding to some aspects (e.g. types of the strategies used). In assessment part, it was specific to topic regarding to the way of doing assessment, namely, coherent and fragmented. However, regarding to the methods of assessment, teachers employed traditional assessment techniques (e.g. informal assessment and test) in both topics so there was no difference between the topics. Due to the differences in the nature of the topics aforementioned, specific assessment techniques can be used in assessing learners' understanding of different topics. In the curriculum and learner knowledge, the quality of the knowledge (network of topics vs. limited network, and satisfied vs. deficient knowledge of learner) made it specific to the topic. In the literature, the topic-specificity has not been described clearly yet. Does it mean specificity to topic regarding to the types of strategies used or the quality of PCK for teaching the topic, the purpose of the use, or all of them? It is needed to be specified. In light of the results, topic-specificity includes different aspects, namely, types, purpose, and quality for different PCK components. If the topic-specific nature of PCK means that teachers should be able to use effective and specific strategies with specific purposes, it would be the ideal definition. Similar to Lederman and Gess-Newsome (1992), it can be explained with ideal gas law analogy. There is no ideal gas in the nature but chemists assume it. Under some conditions that are high temperature and low pressure, gases approach to be ideal gas. Likewise, in practice, teachers may not be able to develop topic-specific PCK regarding to all aspects with or without long term professional development (Hanuscin et al., 2011; Henze et al., 2008). For instance, in this study, teachers' knowledge of curriculum in electrochemistry was specific to the topic in terms of quality, type, and purposes. However, it is not the case for curriculum knowledge in radioactivity. Therefore, 'PCK is specific to topic' is an ideal situation that teachers are supposed to reach. They may attain to that point at some PCK components earlier than others (Friedrichsen et al., 2007; Hanuscin et al., 2011; Henze et al., 2008). Additionally, they may have topic-specific PCK for some topics but not in others. Similar to real gases that approach to be an ideal gas under specific conditions, the condition is also necessary, namely, long-term professional development (De Jong, Veal, & van Driel, 2002; Henze et al., 2008) for teachers to reach the ideal point that is developing topic-specific PCK regarding to all components.

5.2.2. Discussion of the Interplay among PCK Components

In this study, the interplay among PCK components was also elaborated. Although PCK has been studied more than 25 years, the interaction of the PCK components has not been clearly explained in the literature (Abell, 2008; Henze et al., 2008; Lee & Luft 2008; Park & Oliver, 2008). The results o f the study revealed that experienced teachers are able to use PCK components concurrently (Lankford, 2010; Lee & Luft, 2008) to solve the difficulties that learners have, to make the topic more understandable to learners, and to make links to the other topics and to other disciplines. Interplays among the components are so complex that it makes the identification of the components in interplays extremely hard. As Abell (2008) revealed, PCK is not one component rather its amalgamated structure makes it essential for effective teaching.

First, when the interplays were examined, it was obvious that orientation to science teaching is over-arching component that moderate the decisions made by teachers (Friedrichsen & Dana; 2005; Friedrichsen et al., 2011). Teachers' orientation to science teaching directed the way how teachers respond learners' misconceptions. The didactic orientation of participants, made teachers warn learners about the misconceptions that learners had in previous years or made teachers give the scientific explanation. Similarly, the didactic orientation most probably influenced teachers' way of assessment and use of it.

Second, different than the results received in the previous studies, it was noticed that the sub-components of the PCK components may inform each other as well. To the best of my knowledge, this point has not been revealed by the previous studies yet. It is important to show that how complicated PCK is. As literature shows, it is hard to outline the interplays and to illustrate them. When the interplays among sub-components are focused, it would make the examination of interplays much harder. Third, although teachers bring into play different components of PCK to respond to an instructional event in chorus, the accessibility of the components were not the same. In the study, it was obvious that knowledge of curriculum and learner were the most available components to the participants. However, knowledge of instructional strategy and assessment were less vacant ones. Research showed that experience does not make all PCK components expand; therefore teachers need support through professional development (De Jong et al., 2002; van Driel et al., 1998). In other words, it is not necessary to wait for inventing the wheel by all teachers through experience; on the contrary, it may take much less time to invent it with the help of training. Especially, it seems that support for knowledge of instructional strategies and assessment are crucial to build up robust PCK.

Forth, the interplays are both mutual and one-sided. The ease of access of the PCK components may be responsible of the why some of the components influence each other mutually whereas others do one-sided. Similar results were obtained in Henze et al, (2008). Henze and his colleagues stated that through the support of professional development for three years, the interplay among the PCK components increased. In our study, the interplay among knowledge of learner and instructional strategy, curriculum and instructional strategy, and assessment and instructional strategy were one-sided. Moreover, no interplay between knowledge of curriculum and assessment was noticed. It seems that if teachers' PCK development is assisted by professional support through the time, it is more likely that teachers are able to draw on more PCK components simultaneously. The missing interplay and the one-sided ones also make us think that teachers may necessitate more support in those components than the others. Additionally, it is also clear that the development of one component does not mean that others develop as well. "[L]ack of coherence among the components would be problematic with in an individual's developing PCK and increased knowledge of a single component may not be sufficient to stimulate change in practice" (Park & Oliver, 2008, p. 264). As Abell (2008) indicated, PCK is not one or two components rather it is more than their addition. Therefore, all PCK components should be paid attention in professional development activities.

Finally, when the teacher's PCK components interplay in order to respond a difficulty that learners have and/or to take an instructional decision, the use of PCK contains different divisions, namely, understand, decision-making, enactment, and reflection. Park and Oliver (2008) mentioned to divisions that are understanding and enactment. Moreover, they stated that self-efficacy that teachers have is a link between teachers' understanding and their enactment. However, the results of this study revealed that some parts of the interplay are missing in Park and Oliver's (2008) assertion. I assert that between the understanding and enactment, there is a decision-making step in which teacher's orientation to science teaching takes role. The assertion is also congruent with the research stating that orientation to science teaching is the over-arching component that influences other components

(Friedrichsen & Dana, 2005; Magnusson et al., 1999). "If the teachers believe that students learn best through careful listening (didactic and rigor orientation), then the teacher will likely choose lectures as the most appropriate strategy" (Friedrichsen et al., 2007, p. 5). When teachers need to think for an instructional decision, their choices are filtered through their orientation. In addition to decision-making step, there is also reflection step in which teachers reflect on the decision that they made. Park and Oliver (2008) stated that teachers reflect on the decision during the decision moment that is reflection-in-action and after the decision that is reflection-on-action. They focused on the reflection regarding to PCK development. However, I assert that in addition to PCK development, it is also part of the decisions that include interplays of PCK components. In other words, it is important regarding to how teachers draw on PCK. Furthermore, regarding the parts of interplay, when teachers' instructional strategy repertoire is imperfect, the enactment step may be weak. In our example, although the teacher could diagnose the specific learner difficulties and misconceptions, they could not implement effective strategies to remedy them. To sum up, the completion of the interplay depends on the quality of the PCK components. The deficient part would bring about disconnection between the components and/or unproductive treatment for the difficulty that learners experience. In conclusion, there are many interactions among PCK components and sub-components. Therefore, it is difficult both to examine and to illustrate the interplays. When there is a deficient and/or limited component, the interplays are also deficient and/or incomplete.

5.3. Implications

In light of the results revealed and the points discussed, the study has many implications for pre-and in-service teacher education, curriculum developers and textbook writers, and teacher education research.

First, teaching experience is an important source of teachers' PCK (Grossman, 1990; van Driel et al., 2002). However, it does not promise well-developed and integrated

PCK (Friedrichsen et al., 2009). Therefore, teachers should be provided professional development activities in which they received professional help for enriching instructional and assessment strategies, for elaborating learners' difficulties and misconceptions, and how to respond to them. Furthermore, the support should be specific to discipline and the topic that is taught (Nakiboğlu & Tekin, 2006). The participants of this study complained about the lack of chemistry and/or topic specific training, especially in radioactivity. They had some professional development that was general to all teachers. For instance, they participated in an activity for assessment. However, as can be seen from the results it did not help much, especially in the types of assessment strategies used. Moreover, although they could handle the lack of support in electrochemistry, their inadequacy was quite obvious in assessment of radioactivity possibly because of limited SMK triggered it in radioactivity. Therefore, teachers should be given chance to reflect on the specific topics regarding to how to teach, assess, and use knowledge of learner and curriculum to make teaching more effective. Moreover, support should be provided for also NOS teaching and assessment (Hanuscin et al., 2011). To sum up, long-term professional development seems to be the key for opening the lacked door of chest hiding well-developed and integrated PCK inside (De Jong et al., 2002; Gilbert, De Jong, Justi, Treagust, & van Driel, 2002; Hanuscin et al., 2011; Nakiboğlu & Tekin, 2006; van Driel et al., 1998).

Second, for pre-service teacher education, this study has also good implications. Pre-service teacher education is important because future teachers training in the programs. Therefore, the more support that they receive, the better teacher they will be. Research showed that similar to in-service teachers, pre-service teachers have weak SMK in radioactivity (Colclough et al., 2011), which is most probably related to the ignorance of the topic in college education (Zevos, 2002). Therefore, radioactivity topic should be integrated to the chemistry courses (e.g. general chemistry course) to help pre-service teachers develop strong SMK (Colchough, Lock, & Soares, 2011). In addition to SMK, pre-service teachers should be assisted regarding to PCK for teaching the topic (Nakiboğlu & Tekin, 2006). For instance, in method course, instructors should be aware of the pre-service teachers' limitation in radioactivity. Activities for teaching radioactivity, learners' misconceptions and difficulties, how to eliminate them, and how to assess learners' understanding should be part of science teaching method course. In addition to radioactivity, there may be other topics ignored. In addition to science teaching method course, radioactivity can be incorporated into other pedagogical or content courses. For instance, the results of this study informed us about the weaknesses in radioactivity regarding to both SMK and PCK. Then, we decided to cover radioactivity in Laboratory Experiments in Science Education offered to pre-service chemistry teachers. Although the course includes experiments, we could integrate three activities due to the radioactivity's own barriers regarding to safety issues and the expense of materials (Liddicoat & Sebranek, 2005; Millar et al., 1990). One of them is domino activity for helping learners differentiate fission reactions occurring in nuclear reactor and atomic bomb. The second one was found in the Journal of Chemical Education. It was entitled "*The Tasmanian empire: A radioactive dating activity*" by Bindel (1988). The last one was taken from American Physical Society's webpage (2011). It is about the half-life and aims to determine the half-life of an M&M sample. To sum up, the results of the study informed us, pre-service teacher educators, about the deficient point and then we took a step to fix it. These activities can also be applied in professional development activities for in-service teachers. Thus, we accomplished the goal that was stopping the convention of teaching which is as 're-invention of the wheel' by every teacher (Bucat, 2004; van Driel et al., 1998). With the help of the participants' practice in this study, we learned domino activity that can be used in teaching radioactivity. Their wisdom of practice let us learn it. Furthermore, calling attention to teachers' limited repertoire in radioactivity and then providing some other activities for both pre- and in-service teacher education are hoped to be a remedy for the 'professional amnesia' of the teaching profession (Bucat, 2004). Moreover, teachers' knowledge of curriculum in electrochemistry that was 'network of topics' is supposed to be a good model for both pre- and in-service teachers regarding to how to link the topics, how previous ones are used in teaching the latter one, and how knowledge of curriculum is used for detecting the difficulties that learners have.

Additionally, the analogies and representations that participants used in this study were also successful regarding to making abstract electrochemistry concepts (e.g. SHE, spontaneity of cell reactions, and how electron is given and received simultaneously) concrete. They would be valuable for other teachers teaching electrochemistry.

For pre-service teacher education, elective courses focusing on nuclear energy, nuclear waste, and environmental issues can be offered for a semester (Zevos, 2002). For readings and assignments, Zevos's article describing the details of the course can be examined. Radioactivity should not be ignored, on the contrary it should be paid more attention due to the fulfillment of energy needed in this century (Zevos, 2002) and due to the growing increase in the application of radioactivity in daily life (e.g. X-ray in medicine, food irradiation, external radiation therapy, radiocarbon dating in archeology, and nuclear power plants, etc.)

Third, some implications are obvious for curriculum developers. In the curriculum materials, teachers should be supported regarding to learners' difficulties and/or misconceptions, the pre-requisite knowledge necessary for learning the topic. In Turkey, the curriculum materials presented the points mentioned in electrochemistry, however, the support in radioactivity was so weak that there was no activity suggestion. More support should be provided teachers for teaching the topics in which teachers have problems and suffer from inadequate SMK (e.g. radioactivity). Moreover, useful activities for teaching and assessment should be also made available to teachers. This implication should also be paid attention by textbook writers. In the teacher copies of textbooks, the aspects that teachers need to be aware should be supplied. Just in case of lack of professional development, the suggestions would be crucial for teachers.

Finally, regarding to implications for research, it was clearly experienced and understood that PCK is specific to context (e.g. both school and country level) in which teachers work, specific to learners to whom teachers teach, to the topic, and to the teachers who teach (Abell, 2008; Lankford, 2010; Nargund-Joshi, et al., 2011; Park & Oliver, 2008). Therefore, PCK is not a construct with a unique nature that is valid for all countries, schools, and teachers. Therefore, PCK research does not focus of a question that has only one accurate answer (Park & Oliver, 2008). On the contrary, there may be many correct answers to the question. The accuracy of the answer is determined by the context, the topic, teacher, and the learners. Therefore, the attempt to universally accepted PCK model may be a little bit futile because it is contrary to the nature of the construct. However, it does not mean that PCK and its nature should not be studied. In contrast, PCK and nature of it should be elaborated in research that takes into account the previous research's findings. For instance, in this study, I tried to examine topic-specific nature of PCK through focusing on chemistry teachers' PCK in different topics. Similarly, if PCK is specific to learners that teachers study with (Park & Oliver, 2008), then, it should be examined with a teacher who teaches to different groups of learners (e.g. high and low achievers, etc.). Or, PCK is context-depended (Nargund-Joshi et al., 2011), then how the context (e.g. teaching and urban and rural schools) influences teachers' PCK should be focused on. The results of these types of studies may supply more beneficial information about nature of PCK, and interplay among the components. Rather than trying to put PCK into a solid shape, it is more necessary to dig up the unexplored characteristics. Abell (2008) stated that researchers studying on PCK should focus on the unanswered questions about PCK and its nature.

REFERENCES

Abd-El-Khalick, F., Bell, R.L., & Lederman, N.G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*,417-436.

Abd-El-Khalick, F. & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching, 37,* 1057-1095.

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell, & N. G. Lederman (Eds), *Handbook of Research on Science Education.* (pp.1105-1151). New Jersey: Lawrence Erlbaum Associates.

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

Abell, S. K. & Volkmann, M. J. (2006). *Seamless assessment in science: A guidebook for elementary and middle school teachers.* Portsmouth, NH: Heinemann.

American Physical Society (2011). Retrieved on 26, December, 2011 from http://www.physicscentral.com/experiment/physicsquest/upload/pq07-bonus.pdf

Alsop, S. J., Hanson, J., & Watts, D. M. (1998) Pupils' perceptions of radiation and radioactivity: the wary meet the unsavoury. *School Science Review, 72,* 75-80.

Atwood, C.H. & Sheline, R.K. (1989). Nuclear chemistry: Include it in your curriculum. *Journal of Chemical Education, (66)5,* 389-393.

Avraamidou, L., & Zembal-Saul, C. (2005). Giving priority to evidence in science teaching: A first-year elementary teacher's specialized practices and knowledge. *Journal of Research in Science Teaching, 42(9),* 965-986.

Avraamidou, L. & Zembal-Saul, C. (2010). In search of well-started beginning science teachers: Insights from two first-year elementary teachers. *Journal of Research in Science Teaching, 47(6),* 661-686.

Aydın, S., Boz, N., & Boz, Y. (2010). Factors that are influential in pre-service chemistry teachers' choices of instructional strategies in the context of methods of separation of mixtures: A case study. *The Asia-Pacific Education Researcher, 19(2),* 251-270.

Aydın S. & Boz, Y. (2012). Review of Studies Related to Pedagogical Content Knowledge in the Context of Science Teacher Education: Turkish Case. *Educational Sciences: Theory & Practice, 12(1),* 479-505.

Aydın, S. & Çakıroğlu, J. (2010). Teachers' views related to the new science and technology curriculum: Ankara case. *Elementary Education Online, 9 (1),* 301-315.

Aydın, S., Demirdöğen, B., Tarkın, A., & Uzuntiryaki, E. (2009). Effectiveness of a course on pre-service chemistry teachers' Pedagogical content knowledge and subject matter knowledge. In M.F. Taşar & G. Çakmakçı (Eds.), *Contemporary science education research: pre-service and in-service teachers Education* (pp. 59-69). Ankara, Turkey: Pegem Akademi.

Ball, D. L., Hill, H. C., & Bass, H. (2005). Knowing mathematics for teaching: Who knows mathematics well enough to teach third grade, and how can we decide? *American Educator, 29(3),*14-46.

Baxter, J. A., & Lederman, N. G. (1999). Assessment and content measurement of pedagogical content knowledge. *In J. Gess-Newsome & Lederman, N. G. (Eds.), Examining pedagogical content knowledge: The construct and its implications for science education* (pp.147-162). Hingham, MA, USA: Kluwer Academic Publishers.

Berg, T. & Brouwer, W. (1991). Teacher awareness of student alternate conceptions about rotational motion and gravity. *Journal of Research in Science Teaching, 28 (1), 3*-18.

Bindel, T.H. (1988). The Tasmanian Empire: A Radioactive Dating Activity. *Journal of Chemical Education, 65(1),* 47-48.

Berliner, D. C. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research, 35,* 463-482.

Berry, A., Loughran, J., & van Driel, J. H.(2008). Revisiting the roots of pedagogical content knowledge. *International Journal of Science Education, 30(10),*1271-1279.

Bogdan R. C. & Biklen, S. K. (1998). *Qualitative research for education: An introduction to theory and methods* (3rd ed.). Allyn and Bacon, Boston.

Bolt, L. & Swartz, N. (1997). Contextual Curriculum: Getting More Meaning From Education. *New Directions for Community Colleges, 97,* 81-88.

Boz, N. & Boz, Y. (2008). A qualitative case study of prospective chemistry teachers' knowledge about instructional strategies: Introducing Particulate Theory. *Journal of Science Teacher Education, 19,* 135–156.

Bucat, R. (2004). Pedagogical Content knowledge as a way of forward: Applied research in chemistry education. *Chemistry Education: Research and Practice, 5,* 215-228.

Bybee, R. (1997). *Achieving Scientific Literacy: From Purposes to Practices*. Portsmouth, NH: Heinemann Educational Books.

Cambazoğlu, S., Demirelli, H., ve Kavak, N. (2010). Fen bilgisi öğretmen adaylarının maddenin tanecikli yapısı ünitesine ait konu alan bilgileri ile pedagojik alan bilgileri arasındaki ilişkinin incelenmesi, *İlköğretim Online, 9(1),* 275-291.

Carlsen, W. S. (1993). Teacher knowledge and discourse control: Quantitative evidence from novice biology teachers' classrooms. *Journal of Research in Science Teaching, 30,* 471-481.

Carlsen, W. (1999). Domains of teacher knowledge, In J. Gess-Newsome & N. G. Lederman (Eds.). *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 133-144). Boston: Kluwer.

Clermont, C.P., Borko, H., & Krajcik, J.S. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of Research in Science Teaching, 31,* 419–441.

Clermont, C.P., Krajcik, J.S., & Borko, H. (1993). The influence of an intensive in-service workshop on pedagogical content knowledge growth among novice chemical demonstrators. *Journal of Research in Science Teaching, 30,* 21–43.

Cochran, K. F., DeRuiter, J. A., & King, R. A. (1993). Pedagogical Content Knowing: An integrative model for teacher preparation, *Journal of Teacher Education, 44,* 263-272.

Cochran, K. F., King, R. A., & DeRuiter, J. A. (1991). *Pedagogical Content Knowledge: A Tentative Model for Teacher Preparation*. East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service No. ED340683).

Colchough, N. D. (2007). *Trainee teachers and ionizing radiation: understandings, attitudes and risk assessments a descriptive study in one institution.* Unpublished doctoral dissertation, The University of Birmingham, Birmingham, UK.

Colclough, N. D., Lock, R., & Soares, A. (2011). Pre-service Teachers' Subject Knowledge of and Attitudes about Radioactivity and Ionising Radiation. *International Journal of Science Education, 33(3),* 423-446.

Committee on Science and Mathematics Teacher Preparation (2001). Educating teachers of science, mathematics, and technology. New practices for new millennium. Washington, DC: National Academy Press.

Corbin, J., & Strauss, A. (2008). *Basics of qualitative Research: Techniques and procedures for developing grounded theory* (3rd ed.). Thousand Oaks, CA: Sage.

Çekbaş, Y. (2008). Fen *bilgisi öğretmen adaylarının temel fizik alan bilgilerinin değerlendirilmesi.* Yayımlanmamış yüksek lisans tezi, Pamukkale Üniversitesi, Denizli, Türkiye.

Çoruhlu, T. Ş. & Çepni, S. (2010). Reflection of an in-service education course program: Pedagogical content knowledge about alternative measurement and assessment techniques and attitude development. *Elementary Education Online, 9(3),* 1106-1121.

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice.* New York, NY: Teachers College Press.

De Jong, O., Acampo, J., & Verdonk, A. (1995). Problems in teaching the topic of redox reactions. *Journal of Research in Science Teaching, 32(10),* 1097-1110.

De Jong, O., Veal, W., & Van Driel, J. H. (2002). Exploring chemistry teachers' knowledge base. In: J. Gilbert, O. de Jong, R. Justi, D. Treagust & J. van Driel (Eds.). *Chemical Education: Towards Research-based Practice* (pp.369-390). Dordrecht: Kluwer Academic Publishers.

De Jong, O., van Driel, J., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42,* 947-964.

De Jong, O., & Treagust, D. (2002). The teaching and learning of electrochemistry. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust & J. H. van Driel (Eds.), *Chemical Education: Towards research-based practice* (pp. 317-337). Dordrecht: Kluwer Academic Publishers.

Drechsler, M. & van Driel, J. H. (2008), Experienced teachers' pedagogical content knowledge of teaching acid–base chemistry. *Research in Science Education, 38,* 611-631.

Fernandez-Balboa, J., & Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching and Teacher Education, 11(3),* 293-306.

Flick, L. B. (1996). Understanding a generative learning model of instruction: A case study of elementary teacher planning. *Journal of Science Teacher Education, 7(2),* 95-122.

Fraenkel, J.R., & Wallen, N.E. (2006). *How to design and evaluate research in education.* New York: McGraw-Hill.

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

Friedrichsen, P.M., Lankford, D., Brown, P., Pareja, E., Volkmann, M., & Abell, S. K. (2007). *The PCK of future science teachers in an alternative certification program*, Paper presented at the National Association for Research in Science Teaching Annual Conference, New Orleans, LA, April 15-18, 2007.

Friedrichsen, P. M., (2008). A conversation with Sandra Abell: Science teacher learning. *Eurasia Journal of Mathematics, Science and Technology Education, 4(1),* 71-79.

Friedrichsen, P. M., & Dana, T. M. (2003). Using a card-sorting task to elicit and clarify science-teaching orientations. *Journal of Science Teacher Education, 14(4),* 291−309.

Friedrichsen, P. M., & Dana, T. M. (2005). Substantive-level theory of highly regarded secondary biology teachers' science teaching orientations. *Journal of Research in Science Teaching, 42(2),* 218–244.

Friedrichsen, P., Van Driel, J., & Abell, S. (2011) Taking a closer look at science teaching orientations. *Science Education, 95,* 358-376.

Garnett, P. J. & Treagust, D. F. (1992a). Conceptual difficulties experienced by senior high school students of electrochemistry: electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29,* 1079-99.

Garnett, P. J. & Treagust, D. F. (1992b). Conceptual difficulties experienced by senior high school students of electrochemistry: electric circuits and oxidation-reduction equations. *Journal of Research in Science Teaching, 29,* 121-42.

Geddis, A.N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education, 77,* 575–591.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation nature, sources and development of pedagogical content knowledge for science teaching, In J. Gess-Newsome & N. G. Lederman (Eds.). *Examining pedagogical content knowledge: The construct and its implications for science education* (pp.3-17). Boston: Kluwer.

Gilbert, J.K., De Jong, O., Justi, R., Treagust, D.F., & Van Driel, J.H. (2002). Research and development for the future of chemical education. In J.K. Gilbert, O. de Jong, R. Justi, D.F. Treagust, & J.H. Van Driel (Eds.), *Chemical education: Toward research-based practice* (pp. 391-408). Dordrecht, The Netherlands: Kluwer Academic Press.

Greenwood, A. M. (2003). Factors influencing the development of career-change teachers' science teaching orientation. *Journal of Science Teacher Education, 14(3),* 217-234.

Grossman, P.(1990). *The Making of a Teacher.* New York: Teachers College Press.

Hanuscin, D., L., Lee, M. H., & Akerson, V. L. (2011). Elementary teachers' pedagogical content knowledge for teaching the nature of science. *Science Education, 95(1),* 145-167.

Harrison A.G. & Treagust D.F. (2002). The particulate nature of matter: challenges in understanding the submicroscopic world, *In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust and J. H. Van Driel (Eds.), Chemical education: towards research-based practice* (pp. 213-234), Dordrecht: Kluwer Academic Publishers.

Hashweh, M.Z. (2005). Teacher pedagogical constructions: A reconfiguration of pedagogical content knowledge. *Teachers and Teaching: theory and practice, 11*, 273-292.

Henze, I., van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe'. *International Journal of Science Education, 30(10),*1321-1342.

Ingber, J. (2009). *A comparison of teachers' pedagogical content knowledge while planning in and out of their science expertise*. Unpublished doctoral dissertation, Columbia University, NY, USA.

Işıksal, M. (2006). *A study on pre-service elementary mathematics teachers' subject matter knowledge and pedagogical content knowledge regarding the multiplication and division of fractions.* Unpublished Doctoral Dissertation, Middle East Technical University, Ankara.

Kagan, D. M. (1990). Ways of evaluating teacher cognition: Inferences concerning the Goldilocks Principle. *Review of Educational Research, 60*(3), 419–469.

Kagan, D. M. (1992). Professional growth among preservice and beginning teachers. *Review of Educational Research, 62*, 129-169.

Kamen, M. (1996). A teacher's implementation of authentic assessment in an elementary science classroom. *Journal of Research in Science Teaching, 33,* 859-877.

Kaya, O. N. (2009). The nature of relationships among the components of pedagogical content knowledge of pre-service science teachers: 'Ozone layer depletion' as an example. *International Journal of Science Education, 31 (7),* 961–988.

Käpylä, M., Heikkinen, J., & Asunta, T. (2009). Influence of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education, 31(10),* 1395-1415.

Kılınç, A. ve Salman S. (2009). Biyoloji eğitiminde 1998-2007 yılları arasında uygulanan programın alan ve öğretmenlik bilgisi yönünden incelenmesi. *Gazi Eğitim Fakültesi Dergisi, 29(1),* 93-108.

King, B., and Newman, F.M. (2000). Will teacher learning advance school goals? *Phi Delta Kappan, 81(8),* 576-580.

Korthagen, F. & Kessels, J. (1999). Linking theory and practice: Changing the pedagogy of teacher education. *Educational Researcher, 28(4),* 4-17.

Kozma, R., Chin, E., Russell, J., & Marx, N. (2000). The roles of representations and tools in the chemistry laboratory and their implications for chemistry learning. *The Journal of the Learning Sciences, 9(2),* 105-143.

Köse, M. R. (1999). Üniversiteye giriş ve liselerimiz [Entrance to the university and high schools], *Hacettepe University the Journal of Education, 15,* 51-60.

Lankford, D. (2010). *Examining the pedagogical content knowledge and practice of experienced secondary biology teachers for teaching diffusion and osmosis.* Unpublished doctoral dissertation, University of Missouri, MO, USA.

Lannin, J. K., Abell,, S. K., Arbough, F., Chval, K., Friedrichsen, P. , & Volkmann, M. (2008). *Researching Teacher Knowledge: Further Delineating the PCK Construct for Science and Mathematics Education,* Paper presented at the annual meeting of the American Educational Research Association, March 24-28, New York, NY.

Lederman, N.G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29,*331-359.

Lederman, N. G. (2007). Nature of Science: Past, present, and future. In S.K. Abell, & N. G. Lederman (Eds), *Handbook of Research on Science Education* (pp. 831-880). New Jersey: Lawrence Erlbaum Associates.

Lederman, N.G. & Gess-Newsome, J. (1992). Do subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge constitute the ideal gas law of science teaching? *Journal of Science Teacher Education, 3(1),* 16-20.

Lee, E., Brown, M. N., Luft, J. A., & Roehrig, G. H. (2007) Assessing beginning secondary science teachers' PCK: Pilot year results. *School Science and Mathematics, 107 (2),* 52-60.

Lee, E., & Luft, J.A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30(10),* 1343-1363.

Liddicoat, S., & Sebranek, J. (2005). Using an authentic radioisotope to teach half life. *The Science Teacher, 72(9),* p.36-41.

Lincoln, Y. S. & Guba, E.G. (1986) 'But is It Rigorous? Trustworthiness and Authenticity in Naturalistic Evaluation', In *David D. Williams (ed.) Naturalistic Evaluation*, pp. 73–84. San Francisco: Jossey-Bass.

Loughran, J. J. (2007). Science teacher as learner. In S. K. Abell, & N. G. Lederman (Eds), *Handbook of Research on Science Education*. (pp.1043-1065). New Jersey: Lawrence Erlbaum Associates.

Loughran, J., Gunstone, R., Berry, A., Milroy, P., & Mulhall, P. (2000). *Documenting science teachers' pedagogical content knowledge through PaP-eRs,* Paper presented at the annual meeting of the American Educational Research Association, April 24-27, New Orleans, LA.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education, 31*(2), 289-307.

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

Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and Developing Science Teachers' Pedagogical Content Knowledge.* Rotterdam: Sense Publishers.

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring pedagogical content knowledge in science teacher education. *International Journal of Science Education 30(10),* 1301-1320.

Lumpe, A. T. (2007). Application of effective schools and teacher quality research to science teacher education. *Journal of Science Teacher Education, 18,* 345–348.

Magnusson, S., Borko, H., & Krajcik, J. (1994). *Teaching complex subject matter in science: Insights from an analysis of pedagogical content knowledge.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, March 26-29, Anaheim, CA.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Boston: Kluwer.

Malley, M. C. (2011). *Radioactivity: A history of a mysterious science*. Oxford University Press, New York, USA.

Marks, R. (1990) Pedagogical content knowledge: From a mathematical case to a modified conception. *Journal of Teacher Education, 41(3),* 3-11.

Marshall, C., & Rossman, G. B. (2006). *Designing Qualitative Research* (4th ed.). Thousand Oaks, CA: Sage.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. London: Sage.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco: Jossey-Bass.

Mıhladız, G. & Timur B. (2011). Pre-service science teachers views of in-service science teachers' Pedagogical content knowledge. *Eurasian Journal of Physics and Chemistry Education, January, (Special Issue),* 89-100.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd Ed.). Thousand Oaks: Sage Publications.

Millar, R. , Eijkelhof, H., & Klaassen, K. (1990). Teaching about radioactivity and ionising radiation: An alternative approach. *Physics Education , 25(6),* 338-342.

Miller, M. L. (2001). *Enriching pedagogical content knowledge of prospective chemistry teachers: How can the science methods course help?* Unpublished doctoral dissertation, Purdue University, Indiana, USA.

Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 21–50). Dordrecht, The Netherlands: Kluwer.

Mulhall, J., & Wallace, J. (2005). Growing the tree of teacher knowledge: Ten years of learning to teach elementary science. *Journal of Research in Science Teaching, 42(7),* 767–790.

Nakiboğlu, C. ve Karakoç, Ö. (2005). Öğretmenin sahip olması gereken dördüncü bilgi: Alan öğretimi. *Kuram ve Uygulamada Eğitim Bilimleri, 5(1),* 181-206.

Nakiboğlu, C., Karakoç, Ö., & De Jong, O. (2010). Examining pre-service chemistry teachers' pedagogical Content knowledge and influences of Teacher course and practice school. *Journal of Science Education, 11(2),* 76-79.

Nakiboğlu, C., Tekin, B. B. (2006). Identifying students' misconceptions about nuclear chemistry. A study of Turkish high school students. *Journal of Chemical Education, 83(11),* 1712-1718.

Nargund-Joshi, V., Park-Rogers, M. A., & Akerson, V. (2011). Exploring Indian secondary teachers' orientation and practice for teaching science in an era of reform. *Journal of Research in Science Teaching, 48(6),* 624-647.

National Ministry of Education (2006). *Elementary 6th, 7th, and 8th Grades Science and Technology Curriculum*. Ankara: National Ministry of Education Publications.

National Ministry of Education (2007). Secondary 9th Grade Chemistry Curriculum. Ankara: National Ministry of Education Publications.

National Ministry of Education (2011). Secondary 11th Grade Chemistry Curriculum. Ankara: National Ministry of Education Publications.

National Research Council (1996). National science education standards. Washington, DC: National Academy Press.

Nespor, J. (1987). The role of beliefs in the practice of teaching. Journal *of Curriculum Studies, 19,* 317–328.

Newton, D. P., & Newton, L.D. (2001). Subject content knowledge and teacher talk in the primary science classroom. *European Journal of Teacher Education, 24(3),* 369-379.

Niaz, M. (2002). Facilitating conceptual change in students' understanding of electrochemistry. *International Journal of Science Education, 24(4),* 425–439.

Niaz, N. & Chaco´n, E. (2003). Conceptual change teaching strategy to facilitate high school students' understanding of electrochemistry. *Journal of Science Education and Technology, 12(2),* 129-134.

Nilsson, P. (2008). Teaching for understanding: The complex nature of pedagogical content knowledge in pre-service education. *International Journal of Science Education, 30,* 1281-1299.

OECD (2007). PISA 2006: Science Competencies for Tomorrow's World Executive Summary.

OECD (2009). PISA 2009: Assessment Framework Key competencies in reading, mathematics and science. Retrieved April 26, 2010, from http://www. Oecd.org

Oskay, Ö. Ö., Erdem, E., & Yılmaz, A. (2009). Pre-service chemistry teachers' beliefs about teaching and their pedagogical content knowledge. *Hacettepe University Journal of Education, 36,* 203-212.

ÖSYM (2010a, April). ÖSYM basın toplantısı. Retrieved on February 25, 2012 from http://osym.gov.tr/belge/1-11898/2010-osys-ygs-basin-bulteni.html

ÖSYM (2010b). ÖSYS yerleşen kontenjan. Retrieved on February 25, 2012 from http://osym.gov.tr/dosya/1-56323/h/2010osysyerlesenkontenjan.pdf

Özdemir, Z. (2006). *Fen bilgisi öğretmen adaylarının bazı biyoloji konularındaki alan bilgilerinin değerlendirilmesi*. Yayımlanmamış yüksek lisans tezi, Gazi Üniversitesi, Ankara.

Özden, M. (2008). Konu alan bilgisinin pedagojik alan bilgisi üzerine etkisi: Maddenin fiziksel hâllerinin öğretilmesi durumu. *Kuram ve Uygulamada Eğitim Bilimleri, 8(2),* 611-645.

Padilla, K., Ponce-de-León, A. M., Rembado, F. M., & Garritz, A. (2008). Undergraduate professors' pedagogical content knowledge: The case of 'amount of substance'. *International Journal of Science Education, 30(10),* 1389- 1404.

Pajares, M. F. (1992). Teachers' beliefs and educational research: cleaning up a messy construct. *Review of Educational Research, 62(3),* 307-333.

Park, S., Jang, J., Chen, Y., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for Reformed science teaching? Evidence from and empirical study. *Research in Science Education, 41,* 245-260.

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

Patton, M. Q. (2002). *Qualitative evaluation and research methods* (3rd ed.). Thousand Oaks, CA: Sage.

Prather E. (2005) Students' beliefs about the role of atoms in radioactive decay and half-life. *Journal of Geoscience Education, 53,* 345-354.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning. *Educational Researcher, 29 (1),* 4-15.

Roberts, D. A. (1988). What counts as science education? In P. Fensham (Ed.), Development and Dilemmas in Science Education (pp.27-54). London: The Falmer Press.

Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education, 30 (10),* 1365–1387.

Samuelowicz, K., & Bain, J. D. (1992). Conceptions of teaching held by academic teachers. *Higher Education, 24 (93),* 93-111.

Sanders, W., L. (2000). Value-added assessment from student achievement data: Opportunities and hurdles. *Journal of Personnel Evaluation in Education, 14(4),* 329-339.

Sanders , L. R., Borko, H., Lockard, J. D. (1993). Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching, 30(7),* 723-736.

Sanger, M. J. & Greenbowe, T. J. (1997a). Common student misconceptions in electrochemistry: Galvanic, electrolytic, and concentration cells. *Journal of Research in Science Teaching, 34,* 377-398.

Sanger, M. J., and Greenbowe, T. J. (1997b). Common student misconception in electrochemistry: Current flow in electrolyte solutions and the salt bridge. *Journal of Research in Science Teaching, 30,* 111-126.

Selection and Placement of Students in Higher Education Institutions (2010). The Selection and Placement of Students in Higher Education Institutions system, Retrieved April 20, 2010, from http://osys.osym.gov.tr

Settlage, J. (2000). Understanding to learning cycle: Influences on abilities to embrace the approach by preservice elementary school teachers. *Science Education, 84,* 43-50.

Seviş, Ş. (2008). *The effects of a mathematics teaching methods course on pre-service elementary mathematics teachers' content knowledge for teaching mathematics.* Unpublished master thesis, Middle East technical University, Ankara, TURKEY.

Schmidt, H., Marohn, A., & Harrison, A. G. (2007). Factors that prevent learning in electrochemistry. *Journal of Research in Science Teaching, 44(2),* 258-283.

Shannon, J. C. (2006). *How is PCK embodied in the instructional decisions teachers' make while teaching chemical equilibrium?* Unpublished doctoral dissertation, University of Washington, USA.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching, *Educational Researcher, 15,* 4-14.

Shulman, L. S. (1987). Knowledge and training: Foundations of the new reform. *Hardward Educational Review, 57,* 1-22.

Sirhan, G. (2007). Learning difficulties in chemistry: An Overview. *Journal of Turkish Science Education, 4(2),* 2-20.

Smith, D.C. (1999). Changing our teaching: The role of pedagogical content knowledge in elementary science. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp.163-197). Boston: Kluwer.

Southerland, S. A., Sinatra, G. M., & Matthews, M. (2001). Belief, knowledge, and science education. *Educational Psychology Review, 13,* 325-351.

Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education, 4(2),* 99-110.

Tekin, S. (2006). *Özel Öğretim Yöntemleri Derslerinin öğrencilerin pedagojik içerik bilgilerine katkılarının irdelenmesi*. Poster 7. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi'nde sunulmuştur, 7-8-9 Eylül 2006, (s.1559-1563), Ankara.

Tobin, K., & McRobbie, C. (1999). Pedagogical content knowledge and co-participation in science classrooms, In J. Gess-Newsome & N. G. Lederman (Eds.). *Examining pedagogical content knowledge* (pp. 215–234). Dordrecht, The Netherlands: Kluwer.

Treagust, D. F., Chittleborough, G. D., & Mamiala, T. L. (2003). The role of sub-microscopic and symbolic representations in chemical explanations. *International Journal of Science Education, 25(11),* 1353-1369.

Uşak, M. (2005). *Fen bilgisi öğretmen adaylarının çiçekli bitkiler konusundaki pedagojik alan bilgileri.* Yayımlanmamış yüksek lisans tezi, Gazi Üniversitesi, Ankara.

Uşak, M. (2009). Preservice science and technology teachers' pedagogical content knowledge on cell topics. *Educational Sciences: Theory & Practice, 9(4),* 2033-2046.

Uşak, M., Özden, M. & Eilks, I. (2011). A case study of beginning science teachers' subject matter (SMK) and pedagogical content knowledge (PCK) of teaching chemical reaction in Turkey. *European Journal of Teacher Education, 34(4),* 407-429.

van Dijk, E. M., & Kattmann, U. (2007). A research model for the study of science teachers' PCK and improving teacher education. *Teaching and Teacher Education 23,* 885–897.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38(2),* 137-158.

Van Driel, J. H., de Jong, O., & Verloop, N. (2002). The development of preservice chemistry teachers' pedagogical content knowledge. *Science Education, 86,* 572-590.

Van Driel, J.H., Veal, W.R., & Janssen, F.J.J.M., (2001). Essay review: Pedagogical content knowledge: An integrative component within the knowledge base for teaching. *Teaching and Teacher Education, 17,* 979-986.

Van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35,* 673-695.

Veal, W. R., & Kubasko, D. S. (2003). Domain specific pedagogical content knowledge of evolution held by biology and geology teachers. *Journal of Curriculum and Supervision 18(4), 334-352.*

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. *Electronic Journal of Science Education, 3,* Retrieved March 10, 2010, from http://unr.edu/homepage/crowther/ejse/vealmak.html

Volkmann, M. J., Abell, S. K., & Zgagacz, M. (2005). The challenges of teaching physics to preservice elementary teachers: Orientations of the professor, teaching assistant, and students. *Science Education, 89(5),* 847-869.

Volkmann, J. M. & Abell, K. S. (2003). Rethinking laboratories: Transforming cookbook labs into inquiry. *The Science Teacher, 9,* 38-41.

Yalçın, A., & Kılınç, Z. (2005). Öğrencilerin yanlış kavramaları ve ders kitaplarının yanlış kavramalara etkisi örnek konu: Radyoaktivite. *Gazi Eğitim Fakültesi Dergisi, 25(3),* 125-141.

Yıldırım, A. & Şimşek, H. (2006). *Sosyal Bilimlerde Nitel Araştırma Yöntemleri,* Seçkin Yayıncılık Ankara.

Yılmaz-Tüzün, Ö. (2008). Pre-service elementary teachers' beliefs about science teaching. *Journal of Science Teacher Education. 19,* 183-204.

Wilson, S., Shulman, L., & Richard, A. (1987). "150 Different ways" of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teachers' thinking.* (pp.104-124). London: Cassell.

Zembal-Saul, C., Krajcik, J., & Blumenfeld, P. (2002).Elementary student teachers' science content representations. *Journal of Research in Science Teaching, 39,* 443-463.

Zevos, N. (2002) Radioactivity, Radiation, and the Chemistry of Nuclear Waste. *Journal of Chemical Education, 79*, 692-696.

Zhang, B., Krajcik, J., Sutherland, L. M., Wang, L., Wu, J., & Qiang, Y. (2003). Opportunities and challenges of China's inquiry-based education reform in middle and high school: Perspectives of science teachers and teacher educators. *International Journal of Science and Mathematics Education, 1,* 477–503.

APPENDIX A

THE SCHEMATIC DIAGRAM OF THE DATA COLLECTION PROCESS OF THE STUDY

At the very beginning of the research: Card-sorting Activity

Topic-1: Electrochemistry

At the beginning of the topic: CoRe application with interview

During teaching the topic: Observations by using observation schedule

Weekly interviews at the end of the **each week** with participants

Topic-2: Radioactivity

At the beginning of the topic: CoRe application with interview

During teaching the topic: Observations by using observation schedule

Weekly interviews at the end of the **each week** with participants

At the end of the study: Self-comparison interview: Semi-structured interviews about differences in PCK use in electrochemistry and

Figure 32. Data collection process

APPENDIX B

GENERAL PURPOSES OF CHEMISTRY COURSE AND LABELING THE GOALS BASED ON ROBERT'S CURRICULUM EMPHASIS

1. The new curriculum developed has purposes related to developing understanding of the basic concepts of matter and interaction between matters (correct explanation), understanding of the historical development of these concepts (structure of science or history of science), and their effects on individuals and their social, economical, and technological effects (science-technology-society, STS). Moreover, developing conscious in terms of their relation to environment is aimed (Environmental ethics).

2. Another purpose is developing skills related to building up models and reaching concepts by using data and information about a particular topic (scientific skill development). Moreover, students should develop skills of using chemical terminology for explaining those models or concepts (vocabulary OR self as explainer). Additionally, they should learn how transition is possible from simple skills such as observation, experimentation, and data collection to problem solving skills and adapting higher order communication skills (scientific skill development).

3. Finally, students should develop desire for examining matter and interaction between matters. Furthermore, the program will help them to have respect to themselves, their environment, society and others' opinion (affective). Yet another purpose is helping students to develop skills of comparing and contrasting different ideas in chemistry critically (scientific skill development).

APPENDIX C

SCENARIOS FOR CARD-SORTING ACTIVITY (IN ENGLISH)

1. A good way to effectively teach students about fusion and fission is by lecturing and using the blackboard to draw sample reactions and tell the students the differences between fusion and fission reactions (Didactic).
2. One way to effectively teach students about electrolytic cells is to use lab activities in which will provide the students the best opportunity to learn the topic (Activity driven).
3. The best way to teach students about oxidation and reduction potentials is for students to plan an investigation that allows them to sequence the reactivity of metals (Discovery).
4. A good way to teach students about oxidation and reduction reactions is to ask questions and/or to use a demonstration that will check on the students' prior knowledge of the topic and then try to eliminate their misconceptions with scientific conception (Conceptual Change).
5. One way to effectively teach students about Faraday's Law is to solve different and difficult questions (problems) (Academic-rigor).
6. One way to effectively teach students about the factors influencing the oxidation of iron is to allow students to design their own experiments using variables they decide upon (Guided inquiry).
7. The best way to teach relative radioactivity of elements is to use data including number of protons and neutrons of radioactive and nonradioactive elements. Then you ask students to formulate hypothesis, interpret data, analyze the data, and communicate their results with others in the class (Scientific skill development).

8. One way to effectively teach students about radioactivity is for the teacher to start with by giving students a historical account of the topic (Curriculum goal: History of development of concepts).

9. One way to effectively teach about environmental awareness is for students to do research on the effects of the use of nuclear reactors and then have the students present their findings to the class (Curriculum goal: Developing environmental consciousness)

10. One way to effectively teach about radioactivity is for students to participate in a group game that makes them use concepts about radioactivity in a meaningful way (Curriculum goal: Terminology).

11. You as a teacher think that the best thing to do for students is to prepare them for college. Therefore, you teach the topics and then try to solve as many algorithmic problems as possible (Reality of Turkish education system).

12. One way to effectively teach about the effects of research in electrochemistry has on the development of technology is for students to interview experts in those fields. These could include a variety of people, such as engineers and scientists (Curriculum goal, STS).

13. One way to effectively teach your students about being an environmentally conscious and responsible citizen is to have students conduct research on nuclear reactors and the solutions found to protect the environment from the growing nuclear waste problem (Curriculum goal: Environmental ethics).

14. One way to effectively teach your students about pursuing a career in chemistry is to provide students with positive examples of how chemists have changed our lives, and will continually bring benefits to our society (Affective Domain).

APPENDIX D

CARD-SORTING ACTIVITY INTERVIEW QUESTIONS (IN ENGILISH)

Part A. Determining the teachers' goals for teaching science at high schools and how they had those goals.

1. What do you think are the reasons for studying science/chemistry at high school?
2. How do you have these goals for teaching science/ chemistry? Which sources did inform you or help you to have them? Where did you get them from?

Part B. Sorting cards and talking about reasons why they sort them in a particular way.

Researcher requests teacher to sort cards into three categories that are cards represent how they would teach, cards do not represent how they would teach and unsure. During sorting part, the researcher will also focus on the teacher's reaction to scenarios and she will take notes about their mimics. After the teacher sorts cards, the researcher will ask questions about the reasons why s/he sorted cards in a particular way.

Questions will be after card sorting

1. You thought that this scenario is parallel to your teaching. In what ways does it help you achieve your goals? I mean how do these meet your goals for teaching chemistry? (for scenarios that represent how they would teach)

2. Can you give details about similarities between scenarios that reflect your teaching and your actual teaching? (for scenarios that represent how they would teach)

3. In addition to strategies used in the card do you use other strategies for ….. topic? What are they? How these additional strategies help you attain your goals? (for scenarios that represent how they would teach)

4. For the first group of scenarios, what are the common properties that they have?

5. For the second group of cards that do not reflect your teaching, why do not they reflect your teaching?

6. For second group of scenarios, what are the common properties that they have? (for scenarios that do not represent how they would teach)

7. With which kinds of changes do you use them? (for scenarios that do not represent how they would teach)

8. Why are not you sure about the last group of scenarios?

9. Is there anything that you want to add?

APPENDIX E

INTERVIEW QUESTIONS (IN ENGILISH)

Interview during Filling The CoRe

Topic Domain 1: The topics that students should learn

Lead-off Question: What do you intend the students to learn about …….?

1. What do you expect students to understand about these concepts and be able to do?
2. *What do you see as the most important ideas for students to grasp? How did you come to identify these ideas?*
3. What are the standards related to …… topic in the high school chemistry curriculum?

Topic Domain 2: The importance of knowing the topic

Lead-off Question: Why is it important for students to know ……?

1. What are the advantages to learn … for students?
2. How will students eventually use this knowledge and skills? *What if they don't pursue a career in science? Will they still find this knowledge/skills useful? How?*

Topic Domain 3: Difficulties/limitations connected with teaching this idea

Lead-off Question: What are the difficulties related to teaching … topic?

1. Why do you think is it difficult to teach it? What are the factors making teaching it difficult?
2. How do you come to know that it is difficult to teach?

Topic Domain 4: Students' Thinking

Lead-off Question: Now, I want to talk about the students' thinking about …. topic. Can you tell me about which difficulties do students have while learning …. topic?

1. **1.** Which misconceptions may students have related to the big ideas you will teach?
2. **2.** What kind of prerequisite knowledge and skills do you think students need in order to learn…. topic successfully?
3. **3.** How do learners' difficulties and misconceptions in ….topic influence your teaching? I mean how do you use the learners' difficulties and misconceptions during planning the lesson?

Topic Domain 5: Other factors that influence your teaching of this idea.

Lead-off question: What are the other factors that influence your teaching of these ideas?

1. **1.** How do these factors affect your teaching?
2. **2.** How much freedom/autonomy do you have in terms of teaching this topic?

Topic Domain 6: Teaching procedures

Lead-off Question: What are the teaching strategies (analogies, demonstrations, simulations, graph, daily-life example, etc.) that you will use to help students develop an understanding of these concepts? (Or; what specific activities might be useful for helping students develop an understanding of these concepts?)

1. **1.** What are the particular reasons for using them? Why do you prefer to use them?
2. **2.** How did you learn to use this teaching strategy? Did you develop this strategy yourself or learn it from another person?
3. **3.** If you realize that students have a misconception about the topic during teaching it, what do you do?
4. **4.** How do you come to realize that they will work?
5. **5.** How do you know your teaching is effective?

Topic Domain 7: Assessment of students' understanding

Lead-off Question: How do you assess whether students understand those topics or not?

1. **1.** Which assessment techniques do you use to assess their understanding in ….. topic?

2. What are the particular reasons for using them to assess students' understanding?
3. How do you use the assessment results? What do the results tell you?
4. How did you learn students' misconceptions and difficulties in …. topic? What are your sources?

QUESTIONS FOR INTERVIEW-1 (WEEKLY INTERVIEWS)

Topic domain 1: Purpose of the lesson taught

Lead-off Question: What were your (purposes and) goals for this week/the lesson? How did you decide on these purposes?

1. How did you plan the lessons that you taught this week? Which points do you focus on while planning?
2. How did you learn to plan in that way? What were your sources?

Topic domain 2: Teachers' idea about the lesson

Lead-off Question: How do you think the lesson went?

1. I have selected some parts of the instruction I found particularly interesting. I want to ask you some questions about them.

a. What were you thinking when this was occurring? Tell me more about what was happening when you __________ .

b. **[K of Learners]** What do you think the student was thinking when s/he was doing …? Why do you think the student was having difficulty at that point?

c. What knowledge about students did you use when doing …… (instructional decisions)? In what ways, did students influence your teaching decisions today? What have you learned about students from teaching this topic in previous years?

d. **[K of Instructional Strategies]** Tell me about that (example/analogy/activity/lab)? Why did you decide to use that? How did this teaching strategy help you achieve your overall goals? Are there strategies you’ve used in past years, but decided not to use this year? Why or why not?

e. Where did you learn to teach it that way?

f. I noticed that you used a picture (graph, equation, analogy…) during teaching. Why did you use that picture (graph, equation, analogy…). How do you think this (picture, graph, equation, analogy) helps students learn about (this topic)?

g. **[K of Curriculum]** Did the activities achieve the purpose you intended? Why do you think that? How did your curriculum materials support or hinder you in implementing your plan? Do you follow a textbook? If so, what do you like about the chapter? What changes did you have to make? Is there a curriculum guide for this unit? Did you develop it? How does it work for you?

h. **[K of Assessment]** What do you think students got out of the lesson? How do you know? Tell me about how you found out about student learning. Why did you decide to do that? Where did that idea come from? How do you think it worked? What do you learn from looking at student work?

Topic domain 3: Changes in Teachers’ Plan

Lead-off Question: In what ways was the lesson I observed different than your plans? Why did these differences occur?

1. In CORE you stated that you would use ……… instructional strategy. However, you used ……..Why did you change your plan?
2. Which factors contributed to this change?
3. How did they contribute to this change?
4. Was there any time during the instruction when you changed your plan other than that I asked? Tell me about that. Why did you make these changes? Which factors did influence you?
5. Based on what happened this week/today, what do you plan to do for the next week? Will you change anything from your original plans? If yes why?

INTERVIEW- 2: SELF-COMPARISON OF PCK IN DIFFERENT TOPICS

Lead-off Question: Can you compare your teaching in …. and … topics? What are the similarities in teaching both topics?

1. What are the differences in teaching both topics?
2. Is any of them easier to teach than the other? If yes, why do you think so? How is it easier than the other?
3. What do you think about your knowledge of curriculum, goals, and curriculum materials for .. and … topics?
4. Which activities, graphs and analogies do you use for teaching… and…… topics?
5. What do you think about your knowledge of students' difficulties and misconceptions in .. and …topics? How do students' difficulties and misconceptions inform your teaching? Can you compare them?
6. How do you assess students' understanding in … and … topics?
7. What specialized teaching knowledge to you have for teaching …. that is different for the knowledge you have for teaching ….?

APPENDIX F

OBSERVATION PROTOCOL

The observer(s) will have selected 3-5 interesting instances to discuss. What constitutes an interesting instance?

Knowledge of Learners

- Student making a profound comment and the teacher does or doesn't recognize it or misinterprets what the student says or does.
- Student makes a comment that demonstrates confusion, and the teacher does or doesn't recognize or misinterprets why the student is confused?
- Teacher explicitly recognizes potential student difficulties.

Knowledge of Instructional Strategies

- The teacher makes an instructional decision that alters the flow of the classroom by asking a question or directing students to perform a particular task.
- The teacher uses an example or analogy or representation to clarify an idea.

Knowledge of Curriculum

- A particular task is chosen that may or may not elicit the student thinking that was intended.
- The teacher modifies the plan "on the fly" based on what occurs in the classroom.

- Teacher refers to math/science content in other parts of the course/curriculum (vertical or horizontal curriculum alignment).

Knowledge of Assessment

- Teacher implements assessment to ascertain student prior knowledge.
- The teacher recognizes that the students are having difficulty with a particular idea.
- The teacher uses a low-level assessment strategy such as providing an “exit slip” that requires students to define rather than explain or synthesize.
- The teacher acts on data collected during student assessment.

APPENDIX G

THE INSTRUMENTS USED IN THE STUDY (IN TURKISH)

KART GRUPLAMA AKTİVİTESİ

1. Öğrencilere fisyon ve füzyon tepkimelerini öğretmenin etkili bir yolu düz anlatım yöntemiyle tahtaya örnek tepkimeler yazıp ikisi arasındaki farkları anlatmaktır (Didactic)
2. Laboratuar aktivitelerini kullanmak elektroliz konusunu öğretmek için etkili bir yoldur (Activity driven)
3. İndirgenme-yükseltgenme potansiyellerini öğretmenin en iyi yolu, öğrencilere metallerin aktifliklerini sıralayabilecekleri bir etkinlik planlatmaktır (Discovery)
4. İndirgenme-yükseltgenme reaksiyonlarını öğretmenin iyi bir yolu öğrencilerin konu ile ilgili ön bilgilerini ortaya çıkaracak sorular sorarak ve/veya gösteri deneyi kullanarak yanlış kavramaları belirlemek ve sonrasında sahip oldukları yanlış kavramaları gidermeye çalışmaktır (Concetual change)
5. Faraday Kanunu öğretmenin etkili bir yolu konu ile ilgili farklı ve zor sorular çözmektir (Academic-rigor)
6. Demirin paslanmasında rol oynayan etkenleri öğretmenin etkili bir yolu öğrencilerin değişkenlerine kendilerinin karar verdikleri bir deney tasarlamalarına izin vermektir (Guided inquiry)
7. Elementlerin bağıl radyoaktifliklerini öğretmenin etkili bir yolu radyoaktif ve radyoaktif olmayan elementlerin proton ve nötron sayılarını içeren verileri kullanmaktır. Daha sonra öğrencilerden neden bazı elementler doğal radyoaktiftir ile ilgili hipotez kurmalarını, verileri yorumlamalarını, analiz

etmelerini ve sonuçlarını sınıftaki diğer öğrencilerle paylaşmalarını istemektir (Scientific skill development)

8. Radyoaktivite konusunun tarihsel gelişimi hakkında bilgi vererek konuya başlamak konuyu anlatmanın etkili bir yoludur (Curriculum goal: History of development of concepts)
9. Öğrencilerden nükleer reaktörlerin çevreye etkisi hakkında araştırma yapıp araştırmanın sonuçlarını sınıfta paylaşmalarını istemek onlara çevreyi koruma bilincini kazandırmak için etkili bir yollardan biridir (Curriculum goal: Developing environmental consciousness).
10. Öğrencilere içinde radyoaktivite kavramlarının anlamlı bir şekilde kullanıldığı grup oyunları oynatmak radyoaktivite konusunu öğretmenin etkili yollarından biridir (Curriculum goal: Terminology).
11. Bir öğretmen olarak öğrencileriniz için yapabileceğiniz en iyi şeyin onları üniversiteye hazırlamak olduğunu düşünürsünüz. Bu yüzden, konuyu öğretip sonrasında mümkün olduğu kadar fazla soru çözmeye çalışırsınız (Reality of Turkish education system)
12. Elektrokimya alanında yapılan araştırmaların teknolojideki gelişmelere etkisini öğretmenin etkili yollarından biri öğrencilerden konu ile ilgili uzmanlar kişilerle (mühendisler ve bilim insanları, vb.) görüşme/mülakat yapmalarını istemektir (Curriculum goal: STS)
13. Öğrencileri çevreye duyarlı ve sorumluluk sahibi bir vatandaş olarak yetiştirmenin etkili bir yolu öğrencilerden nükleer reaktörler ve gittikçe büyüyen bir problem olan nükleer atıklara nasıl çözüm bulunacağı üzerine araştırma yapmalarını istemektir (Curriculum goal: Environmental ethics)
14. Öğrencilerin kimya ile ilgili bir alanda eğitimlerine devam etmelerini sağlamanın etkili yollarından biri bu alanda çalışan bilim insanlarının hayatımızı nasıl değiştirdiğine dair olumlu örnekler vermek ve gelecekte de topluma nasıl olumlu katkılar sağlayacağını belirtmektir (Affective domain)

Note: Due to the fact that Turkish literature lacks the translation of types of orientations, they were given in English in order not to cause any problem.

Kart Gruplama Aktivitesi: Görüşme Soruları

Bölüm A. Öğretmenlerin "Liselerde neden fen/kimya öğretiyoruz? sorusuna ilişkin görüşlerinin ve bu görüşlere nasıl sahip olduklarının belirlenmesi.

1. Sizce liselerde fen/kimya öğretilmesinin sebepleri/amaçları nelerdir? Bu konudaki görüşünüz nedir?
2. Bahsettiğiniz bu amaçları/hedefleri nasıl belirlediniz? Bu amaçları/hedefleri belirlemenize neler yardımcı oldu?

BÖLÜM B. Kartları gruplama ve kartları neden belli bir şekilde grupladıkları hakkında konuşma:

Araştırmacı öğretmenden kartları üç gruba ayırmasını rica eder. İlk kart grubu öğretmenin yaptığı öğretimi/öğretim yöntemini yansıtan, ikici grup öğretmenin öğretimini yansıtmayan ve son grup ise öğretmenin yaptığı öğretimi yansıtıp yansıtmadığı konusunda emin olmadığı kartları içerir. Araştırmacı, kartların gruplanması anında öğretmenin kartlara verdiği tepkilere de dikkat eder ve mimiklerle ilgili notlar alır. Bu işlem bittikten sonra, araştırmacı öğretmene yaptığı gruplamanın nedenlerini sorar.

Kart gruplama aktivitesinden sonra sorulacak sorular:

1. ….Kartının yaptığınız öğretim ile paralel olduğunu düşünüyorsunuz. Bu karttaki senaryo (daha önce bahsettiğiniz) amaçlara ulaşmanıza nasıl yardımcı oluyor? Başka bir deyişle, bu senaryolar kimya öğretimi için olan amaçlarınızla/hedeflerinizle nasıl bağdaşmaktadır? (Öğretmenin öğretimi ile paralel olan kartlar için)

2. Kendi yaptığınız öğretim ile öğretiminizi yansıtan senaryolar arasındaki benzerlikler nelerdir?
3. Kartlardaki senaryolarda bulunan öğretim yöntemlerine ek olarak ……. Ünitesinde kullandığınız başka yöntemler var mı? Var ise nelerdir? Ek olarak bahsettiğiniz yöntemler amaçlarınıza ulaşmanıza nasıl yardımcı olmaktadır?
4. Birinci gruptaki senaryoların ortak özellikleri nelerdir?
5. İkinci grupta bulunan senaryolar yaptığınız öğretimi neden <u>yansıtmamaktadır</u>?
6. İkinci gruptaki kartların ortak özellikleri nelerdir? (Öğretiminizi yansıtmayan kartlar için)
7. İkinci grup kartlarda bulunan senaryoları ne tür değişiklikler yaparak kullanırsınız?
8. Son grupta bulunan kartlardan niçin emin olamadınız?
9. Eklemek istediğiniz başka bir şey var mı?

İÇERİK GÖSTERİMİ MATERYALİNİ DOLDURURKEN SORULACAK MÜLAKAT SORULARI

<u>Konu Alanı 1. Öğrencilerin Öğrenmesi Gereken Konular</u>

<u>Ana Soru: …… ünitesinde öğrencilerin neleri (hangi temel noktaları) öğrenmesini istiyorsunuz?</u>

1. Müfredatta … konusunda bulunan kavramların sıralanışı nasıl?
2. Öğrencilerin hangi kavramları öğrenmesini ve bu bilgilerle neleri yapabilmesini bekliyorsunuz?
3. Sizce öğrencilerin öğrenmesi gereken en önemli kavramlar/noktalar nelerdir? Bu noktaları/ kavramları nasıl belirlediniz?

4. Bu konu ile ilgili lise kimya müfredatında bulunan kazanımlar nelerdir? (Müfredatta bu konu ile ilgili öğrencilerin hangi kavram/becerileri geliştirmeleri bekleniyor?

Konu Alanı 2: Konuyu Bilmenin Önemi

Ana Soru: Öğrencilerin …. konusunu bilmesi neden önemlidir?

1. …..yı öğrenmeleri öğrencilere ne gibi avantajlar sağlar?
2. Öğrenciler öğrendikleri bu bilgi ve becerileri nasıl kullanacaklar? Eğer öğrenciler fen alanında bir meslek seçmezlerse, bu bilgi ve beceriler onlara nasıl faydalı olacak? Olmayacaksa nedenini açıklar mısınız?

Konu Alanı: 3 Konuyu öğretmek ile İlgili Zorluk ve Sınırlılıklar

Ana Soru: …. Konusunu öğretirken yaşadığınız zorluklar nelerdir?

1. Sizce bu konuyu öğretmek neden zordur? Bu konuyu öğretmeyi zorlaştıran etkenler nelerdir?
2. Bu konuyu öğretmenin zorluklarını nasıl öğrendiniz? (Bu konuyu öğretmenin zor olduğuna nasıl kanaat getirdiniz?)

Konu Alanı: 4 Öğrencilerin Düşünceleri

Ana Soru: Bu aşamada öğrencilerin ….konusundaki düşünceleri/kavramaları hakkında konuşmak istiyorum. Öğrenciler … konusunu öğrenirken hangi noktalarda zorlanıyorlar?

1. Öğrencilerin yukarıda bahsettiğiniz ana kavramlarla ilgili olarak sahip oldukları yanlış kavramalar neler olabilir?
2. Öğrenciler …. konusunu öğrenebilmeleri için hangi ön bilgilere ve becerilere sahip olmalıdırlar?
3. Öğrencilerin …konusundaki kavram yanılgıları ve yaşadıkları zorluklar sizin öğretiminizi etkiliyor mu? Nasıl? Evet ise, ders planınızı yaparken öğrencilerin zorlandıkları noktaları ve yanlış kavramalarını nasıl kullanıyorsunuz?

Konu Alanı 5: Öğretmenin ...yı öğretmesini etkileyen diğer faktörler

Ana Soru: Yukarıda bahsettiğiniz kavramların öğretimini etkileyen diğer etkenler nelerdir?

1. Bu faktörler yaptığınız öğretimi nasıl etkilemektedir?
2. Bu konuyu öğretirken kendinizi ne kadar özgür/bağımsız/seçme hakkına sahip hissediyorsunuz?

Konu Alanı: 6 Öğretim Prosedürleri

Ana Soru: Öğrencilerin bahsettiğiniz kavramları anlamasına yardımcı olmak için hangi öğretim stratejilerini (analoji, gösteri deneyi, benzetim/simülasyon, grafik, günlük hayat örnekleri vs.) kullanacaksınız? (Ya da hangi aktiviteler öğrencilerin o kavramları anlamalarında yardımcı olabilir?)

1. O stratejileri kullanmayı tercih etmenizin nedenleri nelerdir?
2. Bu stratejileri kullanmayı nasıl öğrendiniz? Bu stratejileri kendiniz mi geliştirdiniz yoksa başka kaynaklardan mı (kişi, kaynak, vb) öğrendiniz?
3. Konuyu öğretirken öğrencilerin konu ile ilgili yanlış kavramalara sahip olduklarının farkına varsanız ne yaparsanız?
4. Yapmayı planladığınız bu aktivite/strateji vs.' nin etkili olduğunu/olacağını nasıl öğrendiniz/anladınız/nereden biliyorsunuz?
5. Yaptığınız öğretimin etkili olup olmadığını nasıl anlarsınız?

Konu Alanı: 7 Öğrencilerinin Anladıklarının Ölçülmesi:

Ana Soru: Öğrencilerin konuyu anlayıp anlamadıklarını nasıl ölçersiniz?

1. Öğrencilerin ….. konusunda ne öğrendiklerini hangi ölçme tekniklerini kullanarak ölçersiniz?
2. Niçin bu ölçme tekniklerini kullanmayı tercih ediyorsunuz?
3. Değerlendirme sonuçlarını nasıl kullanıyorsunuz? Bu sonuçlar size neler anlatıyor?
4. Öğrencilerin ….. konusundaki yanlış kavramalarını ve zorlandıkları noktaları nasıl öğrendiniz? Kaynaklarınız nelerdir? (Sadece kitap vb. kaynakları kastedilmediği vurgulanacak)

HAFTALIK GÖRÜŞMELER İÇİN MÜLAKAT SORULARI

Konu Alanı: 1 Dersin Amacı

<u>Ana Soru:</u> <u></u>Bu haftaki dersler için amacınız/amaçlarınız neydi? Bu amacı/amaçları nasıl belirlediniz?

1. Bu hafta yaptığınız öğretimi nasıl planladınız? Plan yaparken hangi noktalara odaklandınız/ağırlık verdiniz?
2. Bu şekilde plan yapmayı nasıl öğrendiniz? Kaynaklarınız nelerdir? (Sadece kitap vb. kaynakları kastedilmediği vurgulanacak)

<u>*Konu Alanı 2: Öğretmenin Ders Hakkındaki Görüşleri*</u>

<u>Ana Soru :</u> Sizce ders nasıl gitti?

1. Gözlemlediğim öğretiminiz ile ilgili birkaç ilginç kısım seçtim. O kısımlar ile ilgili birkaç soru sormak istiyorum.

a. …. Olurken ne düşünüyordunuz? …. yaparken neler olduğunu anlatabilir misiniz?

b. Öğrenci … yaparken sizce ne düşünüyor olabilir? Sizce öğrenci o konuda/anda/noktada neden zorlanmış olabilir?

c. …. Yaparken öğrenciler hakkında edindiğiniz hangi bilgi size yardımcı oldu? Öğrenciler bugün öğretim ile ilgili verdiğiniz kararları nasıl etkiledi? Daha önceki yıllarda bu konu ile ilgili yaptığınız ders anlatımlarından öğrencilerin size kazandırdı bir şeyler oldu mu? (Bu konuyu önceki yıllarda öğretmiş olmanız size öğrencilerle ilgili ne gibi bilgiler kazandırdı?)

d. Bana biraz …. örneğinden/analojisinden/aktivitesinden/laboratuardan bahsedebilir misiniz? Neden onu/onları kullanmayı tercih ettiniz? Bu strateji sizin kimya öğretimi ile ilgili olan amaçlarınızı gerçekleştirmenize nasıl yardımcı olmaktadır? Daha önceki yıllarda kullanıp da artık kullanmadığımız stratejiler var mı? Neden artık onları kullanmıyorsunuz?

e. <u>Bu şekilde öğretim yapmayı nasıl öğrendiniz?</u>

f. <u>Öğretim yaparken şu fotoğrafı/grafiği/eşitliği/analojiyi kullandığınızı gözlemdim. O fotoğrafı/grafiği/eşitliği/analojiyi kullanma nedeniniz nedir? O fotoğraf/grafik/eşitlik/analoji öğrencilerin konuyu öğrenmelerine nasıl yardımcı olabilir?</u>

g. Kullandığınız aktiviteler kimya öğretimi ile ilgili olan amaçlarınızın gerçekleşmesini sağladı mı? Nasıl? Müfredatta sunulan materyaller sizin öğretiminizi nasıl destekledi ya da engelledi? Herhangi bir ders kitabı takip ediyor musunuz? Eğer takip ediyorsanız, … ünitesi ile ilgili kitabın beğendiğiniz noktaları nelerdir? Kitap üzerinde..konusunda hangi değişikleri yapmak durumunda kalıyorsunuz? Bu konu ile ilgili müfredatın size sunduğu bir öğretmen kitabı var mı? Varsa eğer size nasıl yardımcı oluyor?

h. Sizce öğrenciler bugünkü derste neler öğrendiler? Bunu nasıl anladınız? (Yani öğrencilerin bugün öğrendiklerini belirlemek için ne yaptınız?)Neden o yöntemi kullanıyorsunuz? Bu fikrin kaynağı nedir? Sizce kullandığınız … öğrencilerin neyi öğrenip öğrenmediği konusunda size iyi bilgi veriyor mu? Öğrencilerin ödevlerine/çalışmalarına baktığınızda öğrencilerin neyi öğrenip öğrenmediği konusunda neler fark ediyorsunuz?

Konu Alanı: 3 Öğretmenin ders planında yaptığı değişiklikler

Ana Soru: Gözlem yaptığım ders hangi açılardan yaptığınız ders planından farklıydı? Neden o noktalarda değişiklikler yaptınız?

1. Ünite başında yaptığımız görüşmede ….. yöntemini kullanacağınızı belirtmiştiniz. Ancak derste gözlediğim kadarıyla … yı kullandınız. Niçin planınızı değiştirdiniz? Hangi faktörler bu değişikliklerin yapılmasına yardımcı oldu?

2. Bahsettiğiniz faktörler değişikliklerin yapılmasına nasıl etki etti?

3. Az önce konuştuklarımız dışında ders planınızda herhangi bir değişiklik yaptınız mı? Evet ise bundan biraz bahsedebilir misiniz? O değişiklikleri neden yaptınız? Hangi etkenler o değişikliği yapmanıza etki etmiş olabilir?
4. Bu haftaki derslerinize dayanarak, gelecek hafta neler yapmayı planlıyorsunuz? Planınızda herhangi bir değişiklik yapmayı düşünüyor musunuz? Evet, ise neden değişiklik yapacağınız hakkında konuşmak istiyorum.

GÖRÜŞME 2: ÖĞRETMENLERIN FARKLI KONULARDAKI PAB'LARINI ÖZDEĞERLENDIRMELERI MÜLAKAT SORULARI (ÇALIŞMA SONUNDA)

<u>Ana soru: … konusu ve … konusundaki öğretiminizi karşılaştırabilir misiniz?</u>

1. Bu iki konunun öğretimindeki farklılıklar nelerdir? Bu farklılıklar nereden kaynaklanıyor?
2. Sizce bu konulardan birinin öğretimi diğerininkinden daha kolay mı? Evet ise, .. nın öğretimi hangi açılardan diğerinin öğretiminden daha kolaydır?
3. Sizce .. ve .. konusu ile ilgili olarak, bu ünitelerin müfredatları, amaçları, ve de müfredat malzemeleri ile sahip olduğunuz bilgi hakkında ne düşünüyorsunuz?
4. … ve .. konusu için hangi aktivite, grafik ve analojileri kullandınız?
5. .. ve .. konusu öğrencilerin zorlandıkları noktalar ve de yanlış kavramaları hakkındaki bilginiz hakkında ne düşünüyorsunuz? Bu bilgiler öğretiminizi ne şekilde etkiledi?
6. … ve … konusu öğrencilerin ne anladıklarını nasıl değerlendiriyorsunuz? Değerlendirme açısından farklılıklar oldu mu? Biraz açıklayabilir misiniz?
7. .. konusunu işlerken kullandığınız hangi bilgiler .. konusunu işlerken kullandığınız bilgilerden farklıdır?

GÖZLEM PROTOKOLÜ

Gözlemci 3-5 ilginç noktayı seçerek onları öğretmen ile birlikte konuşacaktır. Neler ilginç örnek olabilir:

Öğrenci Bilgisi:

- Öğrenci önemli bir yorumda bulunuyor ancak öğretmen öğrencinin söylediklerini fark ediyor, fark etmiyor, ya da öğrencinin söylediklerini yanlış yorumluyor.

- Öğrencinin söyledikleri onun bazı şeyleri birbirine karıştırdığını gösteriyor ama öğretmen öğrencinin neden karmaşa yaşadığını fark edemiyor ya da yanlış yorumluyor.
- Öğretmen öğrencilerin zorlandıkları noktaları fark ediyor.

Öğretim Metotları Bilgisi:

- Öğretmen soru sorarak ya da öğrencilere bir ödev/aktivite/ etkinlik/ görev vererek dersin gidişatını değiştiren bir karar alıyor.
- Öğretmen bir kavramı açıklamak için bir örnek ya da analoji kullanıyor.

Müfredat Bilgisi:

- Öğrencilerin ne düşündüğünü ortaya çıkarabilecek ya da çıkaramayacak bir aktivite seçimi.
- Öğretmen ders sırasında sınıfta olanlara dayanarak mevcut planında değişiklikler yapar.
- Öğretmen konuyu matematik/fen derslerinin/müfredatının farklı kısımlarıyla ilişkilendirir.

Ölçme Bilgisi:

- Öğretmen öğrencilerin ön bilgilerini açığa çıkarmak için ölçme yapar.
- Öğretmen öğrencilerin belli bir noktada zorlandıklarını fark eder.
- Öğretmen düşük seviye ölçme stratejileri (örneğin öğrencilerin sadece tanımlama yapmalarını gerektiren) kullanmaktadır.
- Öğretmen öğrencilerden topladığı verileri kullanmaktadır.

APPENDIX H

CoRe (CONTENT REPRESENTATIONS)

Grade level for which this CORE is prepared ……………………..	IMPORTANT SCIENCE IDEAS/CONCEPTS			
	BIG IDEA A	BIG IDEA B	BIG IDEA C	BIG IDEA D
What you intend the students to learn about this idea				
Why it is important for students to know this				
What else you know about this idea (that you do not intend students to know yet)				
Difficulties/limitations connected with teaching this idea.				
Knowledge about students' thinking which influences your teaching of this idea.				
Other factors that influence your teaching of this idea.				
Teaching procedures (and particular reasons for using these to engage with this idea).				
Specific ways of ascertaining students' understanding or confusion around this idea (including likely range of responses).				

Figure 33. CoRe instrument

APPENDIX I

PERMISSION FOR USE OF CoRe

MONASH University

Research Assistant Sevgi AYDIN
Middle East Technical University,
College of Education,
Secondary Science and Mathematical Education Department,
Office: 209,
Phone: 0090 312 210 40 86
06800
Ankara/ TURKEY

6th April, 2011

Dear Sevgi AYDIN,

I am pleased to hear from you and look forward to hearing about the success of your intended doctoral research.

I am very happy to approve your use of the CoRe methodology for your dissertation "The comparison of experienced chemistry teachers' pedagogical content knowledge in Electrochemistry and radioactivity units".

I trust all goes well for you.

Yours sincerely,

Professor J. John Loughran
Foundation Chair, Curriculum & Pedagogy
Dean, Faculty of Education.

APPENDIX J

EVIDENCE FOR CREDIBILITY OF RESEARCHER

Science Education Center
Patricia J. Friedrichsen

321E Townsend Hall
Columbia, MO 65211-2400
VOICE (573) 882-6828
FAX (573) 884-2917

University of Missouri-Columbia

June 16, 2010

To Whom It May Concern:

I am writing this letter to document Sevgi Aydin's participation in my doctoral seminar course, *LTC 8900 Science Teacher Learning*, which I taught in the spring semester of 2010. During this time, Sevgi was a visiting scholar at the University of Missouri, so she did not officially enroll in the course as a student. However, Sevgi was a full participant in the course, attending all of the weekly class meetings. In preparation for class, she completed all the reading assignments and came prepared to critically analyze the readings. During class, Sevgi was a strong contributor to class discussions. She also completed all the course assignments and her work was of exceptional quality. Sevgi's participation in the course contributed to my learning and the learning of all class members. If Sevgi had received a grade for course, she would have earned an "A" as she was one of the two top students in the course. I enjoyed working with Sevgi and look forward to reading her work in the future.

Sincerely yours,

Patricia J. Friedrichsen

Patricia J. Friedrichsen, Ph.D.
Associate Professor

APPENDIX K

IRB PERMISSION

T.C.
ANKARA VALİLİĞİ
Milli Eğitim Müdürlüğü

BÖLÜM : İstatistik Bölümü
SAYI : B.08.4.MEM.0.06.22.00-60599/29815 12/04/2011
KONU : Araştırma İzni
Sevgi AYDIN

ORTA DOĞU TEKNİK ÜNİVERSİTESİNE
(Eğitim Fakültesi)

İlgi : a) MEB Bağlı Okul ve Kurumlarda Yapılacak Araştırma ve Araştırma Desteğine Yönelik İzin ve Uygulama Yönergesi.
b) Üniversiteniz Eğitim Fakültesinin 23/03/2011 tarih ve 3765 sayılı yazısı.

Üniversiteniz Eğitim Fakültesi doktora öğrencisi Sevgi AYDIN' ın **"Deneyimli kimya öğretmenlerinin pedagojik alan bilgisinin elektrokimya ve radyoaktivite ünitelerinde karşılaştırılması"** konulu tezi ile ilgili çalışma yapma isteği Müdürlüğümüzce uygun görülmüş ve araştırmanın yapılacağı İlçe Milli Eğitim Müdürlüğüne bilgi verilmiştir.

Mühürlü anketler (12 sayfadan oluşan) ekte gönderilmiş olup, uygulama yapılacak sayıda çoğaltılması ve çalışmanın bitiminde iki örneğinin (CD/disket) Müdürlüğümüz İstatistik Bölümüne gönderilmesini rica ederim.

Gülçin UYSAL
Müdür a.
Müdür Yardımcısı

EKLER :
Anket (12 sayfa)

İl Milli Eğitim Müdürlüğü-Beşevler
İstatistik Bölümü
Bilgi İçin:Nermin ÇELENK

Tel : 223 75 22
Fax: 223 75 22
istatistik06@meb.gov.tr

IRB Permission Taken from Middle East Technical University

1956

Orta Doğu Teknik Üniversitesi
Middle East Technical University
Fen Bilimleri Enstitüsü
Graduate School of
Natural and Applied Sciences
06531 Ankara, Türkiye
Phone: +90 (312) 2102292
Fax: +90 (312) 2107959
www.fbe.metu.edu.tr

Sayı: B.30.2.ODT.0.AH.00.00/126/36

4 Mart 2011

Gönderilen: Doç. Dr. Yezdan Boz
Ortaöğretim Fen ve Matematik Alanları Eğitimi Bölümü

Gönderen : Prof. Dr. Canan Özgen *Canan Özgen*
IAK Başkan Yardımcısı

İlgi : Etik Onayı

"Deneyimli Kimya Öğretmenlerinin Pedagojik Alan Bilgisinin Elektrokimya ve Radyoaktivite Ünitelerinde Karşılaştırılması" isimli araştırmanız "İnsan Araştırmaları Komitesi" tarafından uygun görülerek gerekli onay verilmiştir.

Bilgilerinize saygılarımla sunarım.

Etik Komite Onayı

Uygundur

04/03/2011

Canan Özgen

Prof.Dr. Canan ÖZGEN
Uygulamalı Etik Araştırma Merkezi
(UEAM) Başkanı
ODTÜ 06531 ANKARA

IRB Permission Taken from Middle East Technical University (continued)

O.D.T.Ü
FEN BİLİMLERİ ENSTİTÜSÜ
YÖNETİM KURULU KARARI

Tarih: 10.03.2011
Sayı: FBE: 2011/3

GÖREVLENDİRME VE İZİN

Ortaöğretim Fen ve Matematik Alanları Eğitimi EABD doktora programı öğrencisi Sevgi Aydın'ın 1 Mart-17 Haziran 2011 tarihleri arasında "*Deneyimli kimya öğretmenlerinin pedagojik alan bilgisinin elektrokimya ve radyoaktivite ünitelerinde karşılaştırılması*" başlıklı araştırmasına ilişkin hazırlanan anketi ekli etik kurul başvuru formunda belirtilen okullarda uygulama yapmak için görevlendirilme başvurusu incelenmiş; ilgili danışman görüşüne dayanarak adı geçen öğrencinin isteği doğrultusunda görevlendirilmesine oybirliği ile karar verilmiştir.

Prof. Dr. Canan Özgen *FBE Müdürü*	Prof. Dr. Gürsevil Turan *FBE Müd. Yard.*	Doç. Dr. Nil Uzun *FBE Müd. Yard.*
Prof. Dr. Vedat Toprak *Üye* KATILAMADI	Prof.Dr. Haluk Sucuoğlu *Üye*. KATILAMADI	Doç. Dr. Ayşe Berkman *Üye*

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: AYDIN, Sevgi
Nationality: Turkish (TC)
Marital Status: Single
Phone: +90 312 210 40 86
Fax: +90 312 210 79 71

email: sevgi.aydin45@hotmail.com

EDUCATION

Degree	**Institution**	**Year of Graduation**
MS Gazi University,	Secondary Science and Mathematics Education,	2005
BS Gazi University,	Secondary Science and Mathematics Education,	2005
High School	Türkbirliği Süper Lisesi, Salihli, Manisa,	2000

FOREIGN LANGUAGES

English

PUBLICATIONS

A. Papers published in Journals:

Aydin, S., Demirdogen, B., & Tarkin, A. (2012). Are they efficacious? Exploring pre-service teachers' teaching efficacy beliefs during practicum. *The Asia-Pacific Education Researcher, 21(1),* 203-213. *(Indexed in SSCI)*

Aydin S. & Boz, Y. (2012). Review of Studies Related to Pedagogical Content Knowledge in the Context of Science Teacher Education: Turkish Case. *Educational Sciences: Theory & Practice, 12(1),* 479-505 (Indexed in SSCI).

Aydin, S. & Hanuscin, D. L. (2011). Secret in the Margins: Rutherford's Gold Foil Experiment. *The Science Teacher, 78(7),* 56-60.

Aydin, S., Boz, N., & Boz, Y. (2010). Factors that are Influential in Pre-service Chemistry Teachers' Choices of Instructional Strategies in the Context of Methods of Separation of Mixtures: A Case Study. *The Asia-Pacific Education Researcher, 19(2),* 251-270. (Indexed in SSCI)

Aydin, S. & Boz, Y. (2010) Pre-Service Elementary Science Teachers' Science Teaching Efficacy Beliefs and Their Sources. *Elementary Education Online, 9(2),* 694–704.

Aydin, S., & Cakiroglu, J. (2010). Teachers' views related to the new science and technology curriculum: Ankara case. *Elementary Education Online, 9(1),* 301-315.

Aydin, S., Aydemir, N., Boz, Y., Cetin A., & Bektas, O. (2009). The contribution of constructivist instruction accompanied by concept mapping in enhancing pre-service chemistry teachers' conceptual understanding of chemistry in the laboratory course. *Journal of Science Education and Technology, 18,* 518-534. (Indexed in SSCI)

B. Papers Presented in International Conferences:

Aydin, S., & Boz, Y. (2012). *Further Examination of Interplay between Pedagogical Content Knowledge Components.* Paper was presented at the meeting of NARST Annual International Conference, 25-28 March, Indianapolis, IN, USA.

Boz, Y. & Aydin, S. (2012). *Comparison of Experienced Chemistry Teachers' Pedagogical Content Knowledge in Electrochemistry and Radioactivity.* Paper was presented at the meeting of NARST Annual International Conference, 25-28 March, Indianapolis, IN, USA.

Aydin, S., & Hanuscin, D. L. (2011). *Graduate assistants' journey toward learning to teach.* Paper presented at the meeting of World Conference on New Trends in Science Education, 19-23 September, Kuşadası, Turkey.

Aydin, S., Friedrichsen, P., Hanuscin, D. L., & Abell, S. K. (2011). *A closer look at topic-specific nature of pedagogical content knowledge in secondary chemistry.* Paper presented at the meeting of World Conference on New Trends in Science Education, 19-23 September, Kuşadası, Turkey.

Aydin, S., Akin, F. N., & Tarkin, A. (2011). *Needs assessment for teaching assistants: What do they need to develop teaching skills?* Paper presented at the meeting of World Conference on New Trends in Science Education, 19-23 September, Kuşadası, Turkey.

Tarkin, A., Demirdöğen, B., & Aydin, S. (2010). *Pre-service Teachers' Teaching Self-Efficacy Beliefs.* Paper presented in the 9th National Science and Mathematics Education Conference, 23-25 September, Izmir, TURKEY.

Aydin, S., Demirdöğen, B., Tarkin, A., & Uzuntiryaki, E. (2009). *Effectiveness of a Course on Preservice Chemistry Teachers' Pedagogical Content Knowledge and Subject Matter Knowledge*. Paper presented at ESERA, 31 August- September 4, Istanbul, Turkey. (Fulltext was published in proceedings of ESERA 2009, p. 59-69).

Aydin, S. & Boz, Y. (2009). *Six Pre-service Teachers' Experience on Factors Influencing Choice of Instructional Strategies*. Paper presented at ECER, 25-30 September, Vienna/ Austria.

Aydin, S. & Boz, Y. (2008). *Senior Pre-service Chemistry Teachers' Misconceptions about Gases and their Knowledge of Learners' Misconceptions.* Paper presented at ICES, 23-25 June, Famagusta, Cyprus.

Aydın, S., Boz, Y., Cetin-Dindar, A., Yazici, N., & Bektas, O. (2008). *Pre-service Chemistry Teachers' Sub-microscopic Knowledge about Solution.* Paper presented at ECRICE, 6-9 June, Istanbul, Turkey.

Aydin, S. & Boz, Y. (2008). *Are Senior Pre-service Chemistry Teachers Aware of the Students' Misconceptions Related with Particulate Nature of Matter (PNM) in the Context of Gases?* Paper presented at ECRICE, 6-9 June, Istanbul, Turkey.

Aydın, S., Yazici-Aydemir, N., Cetin-Dindar, A., Boz, Y., Bektas, O. (2008). *How Do Pre-service Chemistry Teachers Link Chemistry to Daily Life?* Paper presented at ECRICE, 6-9 June, Istanbul, Turkey.

Aydemir, N., Aydin, S., Bektas, O., Cetin-Dindar, A., Boz, Y. (2008). *Development of Pre-service Chemistry Teachers' Understanding of Electrochemistry*. Paper presented at ECRICE, 6-9 June, Istanbul, Turkey.

Aydın, S., Yazici-Aydemir, N., Cetin-Dindar, A., & Bektas, O. (2008). *The Effect of Conceptual Change Approach on Pre-Service Chemistry Teachers' Misconceptions about Chemical Equilibrium*. Paper presented at ECER, 8-12 September, Gothenburg, Sweden.

Aydemir, N., Cetin-Dindar, A., Aydin, S., Boz, Y., & Bektas, O. (2008). *Development of pre-service chemistry teachers' understanding of particulate nature of matter*. Paper presented at IOSTE, 21-26 September, Kusadasi, Turkey.

Cetin-Dindar, A., Aydemir, N., Bektas, O., Boz, Y., & Aydin, S. (2008). *Pre-service chemistry teachers' misconceptions on evaporation, boiling, and vapour pressure*. Paper presented at IOSTE, 21-26 September, Kusadasi, Turkey.

Aydin, S. & Boz, Y. (2008). *Pre-Service Science Teachers' Teaching Self-Efficacy Beliefs.* Paper presented at Further Education in Balkan Countries, 23-26 October, Konya, Turkey.

C. Posters Presented in Conferences:

Aydin, S. (2012). *Review of Research on Inquiry-Based Laboratory Activities in Science Education in the Last Decade*. Poster was presented at the meeting of NARST Annual International Conference, 25-28 March, Indianapolis, IN, USA.

Aydin, S., Sinha, S., Izci, K., & Volkmann, M. (2011). *Turkish, Indian, and United States chemistry textbooks use of inscriptions to represent chemical reactions.* Poster presented at the biannual meeting of the European Science Education Research Association (ESERA), 5-9 September, Lyon, France.

Aydin, S., Demirdogen, B., Muslu, N., & Hanuscin, D. (2011). *Professional articles as a source for pedagogical content knowledge for teaching nature of science.* Poster presented at the biannual meeting of the European Science Education Research Association (ESERA), 5-9 September, Lyon, France.

Akin, F. N., Tarkın, A., & Aydin, S. (2011). *Which types of knowledge that chemistry educators should have?* Poster presented in the 2nd Chemistry Education Conference, July, 5-8, Erzurum, TURKEY.

Aydın, S., Tarkın, A., & Boz, Y. (2010). *The Instructional Strategies that Pre-service Teachers Feel Inadequate to Implement in their Teaching and the Reason of the Inadequacy*. Poster presented in the 9th National Science and Mathematics Education Conference, 23-25 September, Izmir, TURKEY.

Aydın, S., Tarkın, A., & Demirdöğen, B. (2010). *Pre-service teachers' View about the Teaching Experience Course Enriched with Microteaching*. Poster presented in the 9th National Science and Mathematics Education Conference, 23-25 September, Izmir, TURKEY.

Cakiroglu, J. & Aydın, S. (2009). *Examination of Science Process Skills in New Elementary Science and Technology Curriculum.* Poster was presented at NARST, 17-21 April, Garden Grove, California, USA.

Tarkin, A., Aydin, S., Uzuntiryaki, E., & Boz, Y. (2009). *An examination on pre-service and in-service teachers' sense of efficacy beliefs*. Poster was presented at ESERA, 31 August- September 4, Istanbul, TURKEY (Fulltext was published in proceedings of ESERA 2009, p.71-75).

Aydin, A. & Boz, Y. (2008). *Diagnosis of Senior Pre-service Chemistry Teachers' Misconceptions on Particulate Nature of Matter in the Context of Gases and Their Awareness of Learners' Misconceptions*. Paper presented at IOSTE, 21-26 September, Kusadasi, TURKEY.

Cetin-Dindar, A., Bektas, O., Aydin, S., Boz, Y., & Aydemir, N. (2008). *Preservice chemistry teachers' drawings of atom models in their mind.* Poster presented at National Science and Mathematics Education Conference, 27-29 August, Bolu, TURKEY

D. Awards:

- NARST Scholarship Winner in 2012.
- ESERA Scholarship Winner in 2011.
- ECER Scholarship Winner in 2009.

E. Professional Membership:

- National Association for Research in Science Teaching (NARST),
- Postgraduate Research Association within EERA.
- National Science Teacher Association (NSTA).
- NSTA Missouri Student Chapter.

F. Other Experiences:

- Reviewer for Chemistry Education: Research and Practice (CERP) Journal in October, 2011.
- Reviewer for NARST 2011.
- Chair in IOSTE 2009, Kusadasi, IZMIR-TURKEY.
- Grant Writing Experience:

  Grant Writing Group (Fall 2010) *Improving Teacher Quality Grants* –

  PI: Dr. Deborah Hanuscin, Co-PI: Dr. Delinda van Garderen

  Participated in weekly meetings leading up to the submission of a $472,000 grant for K6 science teacher professional development. Activities included reviewing and interpreting the RFP; attending sponsor technical assistance meetings; assisting in conceptualizing the PD; providing input on program design, evaluation, and budget; and conferring with the Office of Sponsored Programs.

G. Hobbies:

Playing tennis, visiting historical places, watching soccer game, and movies