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Examination of Pre-Service Science Teachers' Model Based-Content Knowledge and Knowledge of Students' Understanding on Chemical Bonds

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Abstract

This study aims to examine pre-service science teachers' (PSTs') model-based (MB) content knowledge (CK) and knowledge of students' understanding (KSU) of chemical bonds. The participants of the study consist of 229 senior pre service science teachers. The study is a case study from qualitative research designs. The data of the study were collected by using the "Chemical Bonds Model Knowledge Test (CBMKT)". The obtained data were analyzed using the "Model Based-Content Knowledge Rubric (MB-CK Rubric)" and "Model Based-Knowledge of Students' Understanding Rubric (MB-KSU Rubric)". The findings showed that PSTs mostly have an understanding of wrong modeling and not being able to make any modeling in terms of MB-CK on chemical bonds. In addition, it has been determined that the majority of pre-service teachers have an invalid and weak level in terms of MB-KSU. These findings indicate that PSTs' professional knowledge of chemical bonds in their undergraduate education should be supported by model-based teaching.

Introduction

Models are visual learning tools to simplify the complex structures of the real world. Models are considered not only replicas of reality, but also tools for scientific reasoning (Nowak et al., 2013). Models are used to understand and explain scientific phenomena and to convey this understanding (Henze & Van Driel, 2011). Scientists try to visualize the macro-scale events going on and create models of this complex world. Building models to explain natural phenomena is a kind of scientific activity that involves visualizing abstract structures (National Research Council [NRC], 2012). From a theoretical perspective, the nature of models and modeling is part of the nature of science and is also a specific aspect of science epistemology essential to science education (Justi & Gilbert, 2002). Models are very useful in that they allow students to make predictions and explain scientific phenomena (Treagust et al., 2002). Research points that the importance of using models to help students learning on scientific content in their lessons (Passmore et al., 2014). In science education, students reason to learn how scientific knowledge is obtained (Hodson, 2014). Model-based reasoning is a powerful pedagogical tool for promoting meaningful learning for students (Werner et al., 2019). Greca and Moreira (2002) point out that students construct internal representations or models, based on their current knowledge and past experiences, to understand the world. Next Generation Science Standards (NGSS) (2013) considers the use of models as one of the main learning objectives for students to understand the nature of science in science and to improve their scientific literacy. Because models provide visual representations of students' understanding of science. Perhaps the field where model-based learning is most needed in the field of science is chemistry. Because most of the chemistry knowledge is complicated for students. Chemistry deals with fundamentally abstract subjects. Therefore, models play a vital role in learning knowledge in chemistry for students (Akaygun, 2016). Looking at the history of science, it is known that ideas about chemistry have developed and spread using models (e.g. atomic models) since the early days of chemistry science (Justi & Gilbert, 2002). In order to understand events at the macro scale in the field of chemistry, it is necessary to use models at the micro-scale (Oversby, 2000). This situation can be explained as follows: for example, salt can be seen to dissolve when sodium chloride is mixed with water, and if we test the conductivity of the solution with a submerged electrode, we will find that it becomes a much better conductor. In contrast, we cannot see what is happening at the microscopic scale. So we need a model to make visible the invisible event, that is, to explain or describe what it is and why the conductivity changes after the salt are dissolved (Bergqvist, 2017).

Chemical bonds are one of the most fundamental subjects in science education for students. Because the chemical bond is a basic principle that can be applied in all fields of chemistry (Bergqvist & Rundgren, 2017). For students, in order to understand the particulate structure of the atom, molecular structure, reaction mechanisms, solubility, molecular interactions, and some spectroscopic information, they should be able to learn correctly the situations in which chemical bonding can occur as a preliminary concept (Ortiz, 2019; Vrabec & Proksa, 2016). Due to its abstract and theoretical nature, chemical bonding is a challenging subject in chemistry education (Bergqvist, 2017; De Jong & Taber, 2014; Taber & Coll, 2002; Othman et al., 2008; Taber et al., 2012). Many science teachers, PSTs, and students perceive this subject as difficult, and students often develop many misconceptions about it (Bergqvist, 2017; Levy Nahum et al., 2010). In this respect, there is a need for effective pedagogical tools to teach the subject of chemical bonds to students correctly and to reduce their negative effects on learning. Models are at the forefront of these pedagogical tools (Gogolin & Krüger, 2017; Mendonça & Justi, 2011; Schwarz, 2009). Science education can't be implemented successfully without professional teachers. For this reason, it is an important issue that needs to be investigated whether science teachers and PSTs can guide their students correctly in modeling. The fact that science teachers have the true model knowledge in teaching the subject of chemical bonds and use them in their lessons is greatly affected by the information they acquire during the preparation period for teaching and the resources they use. PSTs mostly try to understand the complex theoretical knowledge of chemical bonds during the university period. PSTs need model-based learning to get a deep understanding of the theoretical knowledge they have acquired on chemical bonds (Oh & Oh, 2011).

Model-supported learning of PSTs contributes to both strengthening their content knowledge about chemical bonds and understanding how they can teach this subject more concretely to their students in future science lessons. From this point of view, it is very valuable to determine the model-based learning situations of PSTs about chemical bonds in the preparation period for the profession. Nicolaou and Constantinou (2014) stated that understanding the nature of models and modeling is an indicator of modeling competence. For PSTs to effectively teach the content of science subjects, they should have advanced professional knowledge about models in science and students' understanding of models (Gogolin & Krüger, 2017; Oh & Oh, 2011). Moreover, pre-service teachers should have the professional knowledge and competence to respond to different ways of understanding and learning about models of their students in the future (Kenyon et al., 2011). Past research shows that science teachers and PSTs' level of content knowledge on any subject in the field of science directly affects their students' knowledge of understanding wrong and incomplete learning in that subject (Naah, 2015; Käpylä et al., 2009). PSTs should know what pre-knowledge their students should have, what difficulties might prevent their learning, and which misconceptions they had about students learning chemical bonds by model-based in the future. PST should be able to acquire information about the students' lack of knowledge and mistakes about the model of chemical bonds during their professional preparation period. In the related literature, there are studies examining the professional knowledge structures of PSTs about chemical bonds, albeit in a limited number (Schultze & Nilsson, 2018; Kind, 2014). On the other hand, no research has been found that examines the model-based content knowledge (MB-CK) and knowledge of students' understanding (MB-KSU) of PSTs on chemical bonds. In this context, in the present study, we aimed to examine the MB-CK and MB-KSU on chemical bonds of PSTs studying in the 4th grade of four different universities in Turkey. For this purpose, answers to the following questions were sought in the study:

- RQ1. How are the PSTs’ MB-CKs regarding chemical bonds?
- RQ2. How are the PSTs' MB-KSUs regarding chemical bonds?

Theoretical Background and Literature Review

Models in Science Education

Models are simply defined as representations of objects, events, processes, ideas, or systems (Gilbert & Boulter, 2000). Models are defined as modifiable learning tools to test an idea and represent it in the best way (Werner et al., 2019). A model can represent scientific concepts, mechanisms, theories, structures, and functions, as well as invisible processes and properties (Schwarz et al., 2009). However, a model does not necessarily represent absolute reality and is not necessarily an exact replica of the real phenomenon (Lee, 2018). Models are categorized into physical and mental representations (Coll & Lajium, 2011). Mental models are the type of representation that has special characteristics, about what students produce during cognitive processes and to maintain the structure of what needs to be represented (Vosniadou & Brewer, 1994). In contrast, physical models are tangible representations of a scaled structure, both two-dimensional and three-dimensional (Upmeier zu Belzen, 2013). Models are effective educational tools that can be used in science education to help students learn scientific content or gain knowledge about the nature of science (Quillin & Thomas, 2015).

Models are an idealized representation or construction of reality in the sciences (Krell et al., 2014). Cheng and Lin (2015) found that there is a positive relationship between models and effective learning and better performance in science. Models, both traditionally in books and computer-prepared, are one of the most important pedagogical tools used in teaching and learning about complex chemical, physical events, and biological systems in science. Today, it is imperative that teachers and pre-service teachers understand the role of models in science teaching. Because models support students' in-depth understanding of many complex and abstract topics in science (Clement, 2000). Models in science courses enable tangible visualization of many scientific situations at various scales, which are especially difficult or impossible to see with the naked eye (Lee, 2018). In science, models are defined as mechanisms that represent observable aspects and properties of a phenomenon and explain how the phenomenon works (Nicolaou & Constantinou, 2014). As students develop more understanding of models and modeling in the sciences, they may understand that a model can be a simplified and abstract form of reality (Lee, 2018). It is very important to use the right models appropriate for the learning goal in science teaching. Students can learn effectively when there is no gap between the learning goal to be achieved and the models used (Werner et al., 2019).

The use of models in science aims to make sense of scientific phenomena and embody theoretical content and helps students gain insight into the activities of scientists (Harrison, 2001; Treagust et al., 2002). To help students for gaining a rich understanding of the products and processes of science, they need to learn and study scientific models and reflect on the nature of models. To achieve these goals, teachers need to have an adequate understanding of the nature of models and modeling in science (Henze et al., 2008). As students begin to develop and use models to make sense of subject content in science classes, they realize how modeling is inextricably linked with other scientific applications (Campbell & Fazio, 2020). As students engage in modeling practice, they also engage in other practices such as asking questions, planning and conducting research, collecting, analyzing, and interpreting data (Windschitl & Calabrese-Barton, 2016; Windschitl et al., 2008). The nature of models in science is defined at three levels (Grünkorn et al., 2014; Upmeier zu Belzen & Krüger, 2010): A model can be viewed as a replication (level I), an idealized representation (level II) and theoretical reconstruction (level III) of the original. Because models play an important role in the formation and justification of scientific knowledge, science can be viewed as a complex and dynamic network of models (Pluta et al., 2011). Teachers can only benefit from models and improve students' understanding when they realize the function of models (Nelson & Davis, 2012; Wang et al., 2014).

The Chemical Bonding and Models in Science Education

Chemical bonds are generally divided into four sub-themes: ionic bond, covalent bond, metallic bond, and intermolecular forces (Bergqvist, 2017). Chemical bonding is generally defined as forces between particles, for example: "forces that hold atoms together in stable geometric configuration" (Lagowski, 1997). The force holding two atoms together is called a chemical bond. Atoms form ionic compounds by electron exchange and covalent bonds by electron sharing. In both cases, a chemical bond is formed, and stability increases. While this bond is formed, atoms complete the number of valence shell electrons to eight or two electrons (octet/doublet rule) and become a structure similar to the stable electron configuration of the noble gases in the periodic table (Cokadar, 2006). Silberberg (2003) states that the forces between particles (for example, atoms) result from the electrostatic attraction between opposite charges, and this is called a chemical bond. Chemical bonding is a basic chemistry principle that can be applied to all areas of chemistry (Levy Nahum et al., 2013; Levy Nahum et al., 2010). Students need to understand chemical bonding to understand reaction mechanisms in chemistry, the physical properties of substances, solubility, molecular interactions, and some spectroscopic information (Ortiz, 2019). The properties of substances, their physical and chemical changes, and interactions between charged particles such as atoms or ions are determined by chemical bonding (Coll & Treagust, 2003).

Chemical bonds involve making sense of different models and explaining different properties of real observable phenomena at the macroscopic level (De Jong & Taber, 2014). Understanding the concept of chemical bonds is a fundamental assumption for learning other themes in chemistry such as chemical reactions, chemical equilibrium, thermodynamics, and molecular structure (Vrabec & Prokša, 2016). Due to its abstract and theoretical structure, chemical bonding is a challenging subject in chemistry education (Taber & Coll, 2002; De Jong & Taber, 2014). Therefore, students have problems understanding the subject of chemical bonds. Chemical bonding is a topic that students commonly find problematic and develop a wide variety of misconceptions (Özmen, 2004). It is known that chemical bonds have been developed and spread using visual models since the early days of the discipline. Chemical bonding is predominantly taught using models and is a complex subject (Taber & Coll, 2002). Students can't learn about chemical bonds without developing a mental model that includes the particulate nature of matter and the forces that hold these particles together (Akkuş et al., 2013; Tan & Treagust, 1999). So since we can't see how atoms or other particles are held together, students need to understand and use chemical bond models to understand chemistry (Bergqvist, 2017). A model of chemical bonding involves describing both particles and attractive and repulsive forces between particles (atoms, electrons, protons). The models provide an understanding of the relationships between these particles and forces in the formation of the chemical bond (Zohar & Levy, 2018).

Science Teachers' Knowledge for Teaching of Chemical Bonding

One of the most basic factors that determine the quality of education is the professional knowledge of teachers (Berry et al., 2015; Evens et al., 2018; Gess-Newsome et al., 2019). Teacher professional knowledge attracted attention with Shulman's (1986) PCK conceptualization. Since then, PCK has been tried to be explained by various models by many researchers (Gess-Newsome, 2015; Magnusson et al., 1999; Park & Oliver, 2008). In the related literature, science teachers' PCKs are mostly defined through knowledge components such as subject knowledge, curriculum knowledge, strategy, method and technique knowledge, knowledge of students' understanding, and evaluation knowledge (Magnusson et al., 1999; Park & Oliver, 2008). However, two of the science teachers' PCK sub-components came to the fore both in research and modeling studies. These sub-components are science teachers' knowledge of students' understanding and knowledge of the subject matter (Gess-Newsome, 2015; Magnusson et al., 1999; Park et al., 2018). In the field of science, teachers' knowledge of students' understanding includes the diversity of students' ideas about a particular science topic, prior knowledge about that subject, misconceptions, and learning difficulties (Magnusson et al., 1999). This knowledge structure also includes information about students' learning differences, learning styles, developmental levels, and needs (Park & Oliver, 2008). Subject knowledge in science includes information about the nature of scientific knowledge, knowledge of concepts, principles, and subjects in science, and information about relating subjects to other disciplines (Anderson & Clark, 2012). It is emphasized that teachers should be qualified and sophisticated in terms of both knowledge components for effective science teaching. Considering the complexity and abstractness of the subjects in science, teachers with weak content knowledge will be insufficient in acquiring their students' conceptual knowledge, explanations, examples, and the most appropriate questions that will capture the essence of science (Käpylä et al., 2009). Poor content knowledge leads to anxiety and low self-efficacy levels and leads to less effective teaching (Czerniak & Chiarelott, 1999). In addition, the fact that teachers do not know students' prior knowledge, learning difficulties, and misunderstandings about science is seen as an important issue that will make it difficult for students to learn science and reduce their motivation (Park & Oliver, 2008).

Learning most of the concepts in both middle and high school chemistry depends on understanding the basic ideas about chemical bonding (Levy Nahum et al., 2013). Moreover, chemical bonds are perceived as difficult by teachers as well as students (Bergqvist et al., 2016; Dhindsa & Treagust, 2014; Levy Nahum et al., 2010). Teachers find teaching chemical bonds challenging and difficult (Sibanda & Hobden, 2015). Chemical bonding is one of the most important topics in science classes and is mainly taught to students using textbooks and models offered by teachers (Bergqvist & Chang Rundgren, 2017). Teachers' model knowledge of chemical bonding refers to how much they transform the language of instruction into meaningful representations (Ortiz, 2019).

Science teachers should be aware that students may have many mental model structures that are inconsistent with scientific explanations for chemical bond models. Because the relevant literature emphasizes that students have developed many misconceptions about chemical bonding (Ortiz, 2019; Tsaparlis et al., 2020; Vrabec & Prokša, 2016). These misunderstandings about chemical bonds include failures to comprehend phenomena such as the type of chemical bond, electron transfer or sharing, octet rule, ion structure, compound structure, electrostatic force, and electron configuration (Bergqvist & Chang Rundgren, 2017). These wrong learnings also shape students' mental model knowledge. These student models, which are inconsistent with scientific explanations of chemical bonds, are largely shaped by science teachers' professional knowledge and textbooks (Levy Nahum et al., 2013). Textbooks can support alternative concepts of chemical bonds. Because books don't always show chemical bond models accurately (Bergqvist et al., 2013). Also, if science teachers did not have opportunities to expand their model-based professional knowledge about chemical bonds during their higher education and professional development, they will be inadequate in teaching students the subject. Because the quality of a science teacher's PCK depends on the integration and strength of each component of knowledge it contains (Park & Chen, 2012).

Research on Chemical Bonding Models in Science Education

Research on chemical bonds has an important place in the science education literature. The vast majority of these studies involve examining students' (Bergqvist et al., 2013; Coll & Treagust, 2003; Joki & Aksela, 2018; Özmen, 2004; Taber & Coll, 2002; Ünal et al., 2006; Zohar & Levy, 2019), science teachers and PSTs' (Kind, 2014; Schultze & Nilsson, 2018) conceptual knowledge of chemical bonds. In particular, there is a large research literature describing students' learning difficulties about chemical bonds. (Fadillah & Salirawati, 2018; Ortiz, 2019; Ünal et al., 2006; Taber et al., 2012). However, fewer studies are on the model knowledge of teachers and PSTs on chemical bonding. Among these studies, Sarawan and Yuenyong (2018) examined students' mental models of chemical bonds. Researchers have found that students have a misconception that metallic bonds occur by electron transfer as in ionic bonds.

Also, Wang et al. (2014) investigated the model knowledge and practices of Chinese teachers. The results showed that teachers' knowledge of some known chemistry models is limited and they adopt a general pattern while applying the models in their teaching. However, there is limited research on the PCK of science teachers, which is the main theme of our research. Bergqvist (2017) explored ways for teachers' knowledge of how to teach chemical bonds and improve students' understanding. To explore ways to improve teachers' PCK, the researcher conducted a study in which three science teachers explored and reflected on their teaching practices together. The researcher revealed that chemical bond representations in textbooks and used by teachers can cause learning difficulties in students. The researcher pointed out that teachers are often unaware of how these representations will affect students' understanding, which means that their pedagogical content knowledge (PCK) needs to be developed. With this research, teachers improved their representations of chemical bonds and became more aware of students' understandings. They were able to make their teaching practices, content, and strategy choices more effective.

Bergqvist et al. (2016) focused on science teachers' PCKs on chemical bonds. The results of the study showed that the teachers did not know the model that would enable the students to grasp the subject of chemical bonds effectively, they had problems understanding the learning difficulties of the students, and they mostly used inadequate teaching strategies to advance the student's understanding of the subject. In addition, this study revealed that teachers are often unaware of how the models they use affect students' understanding. The results showed that teachers' knowledge of student understanding of PCK components and their knowledge of teaching representations and strategies need to be improved. Bergqvist and Chang Rundgren (2017) examined the effect of textbooks on science teachers' knowledge of chemical bond representations related to students' comprehension difficulties. The results showed that many of the representations that teachers selected from textbooks on chemical bonding models helped students develop alternative concepts about chemical bonding and posed difficulties in understanding this topic. The study points out that student learning weaknesses can be eliminated by improving teachers' PCKs with chemical bonds and scientific models in general.

Joki and Aksela (2018) determined that teachers' pedagogical content knowledge (PCK) on chemical bonding should be developed both in pre-service teacher education and during in-service training. Levy Nahum et al. (2013) found that some of the difficulties experienced by students in understanding chemical bonds stemmed from the way the subject was taught. Schultze and Nilsson (2018) investigated how an experienced science teacher could improve PCK by collaborating with two 12th-grade students as an assistant teacher on chemical bonds. The results showed that such an application improved the teacher's understanding of student learning difficulties in chemical bonding. In another study, Sibanda (2018) found that many of the teachers were unable to demonstrate subject-specific professional knowledge on how to improve the teaching and learning of chemical bonds in schools.

Method

Research Design

This study is a case study to examine the level of senior PSTs' MB-CK and MB-KSU on the subject of chemical bonds. The most important feature of case studies is that they provide the opportunity to examine one or more cases in depth (Patton, 2002; Yin, 2003). Here, we focused on PSTs' own models of chemical bonds and their mental images of student models. Based on the results of the study, we make a due diligence on the effectiveness of the professional preparation process of PSTs. The timeline of this study is shown in Figure 1.

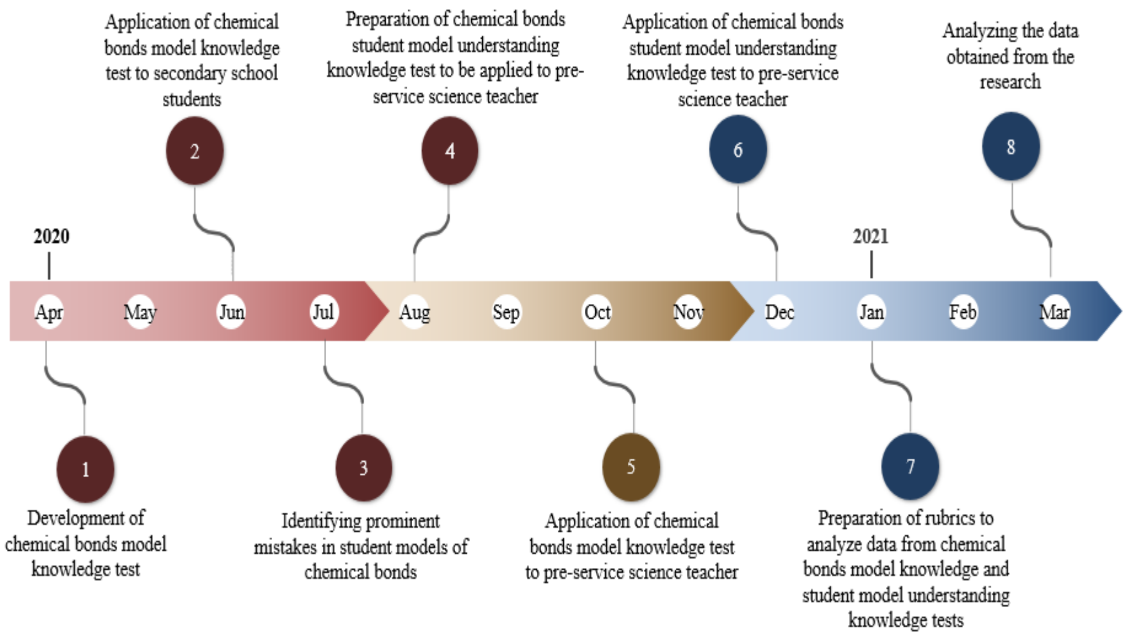


Figure 1. Timeline of the Study

Participants

The distribution of PSTs participating in the study by universities and gender is given in Figure 2.

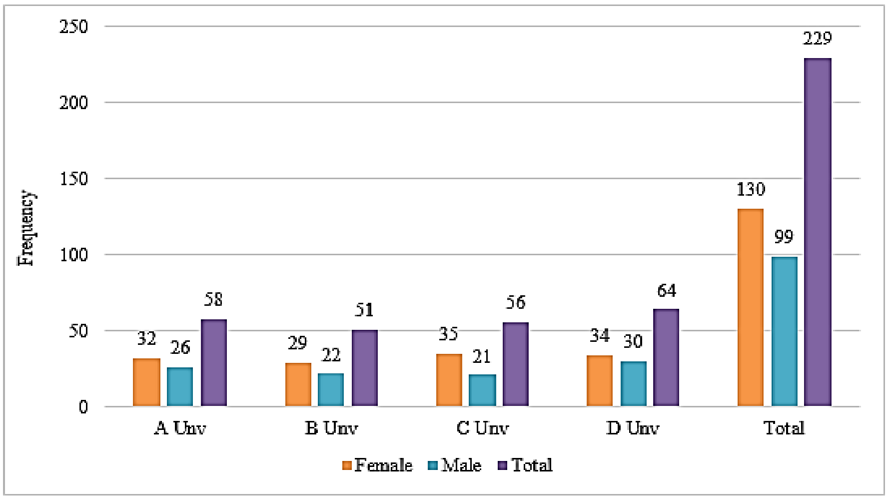


Figure 2. Distribution of PSTs Participating in the Study by Universities and Gender

229 (130 female, 99 male) PSTs studying in the 4th grade of science teaching at four universities in Turkey participated in the study. All four of these universities have many years of experience in science teacher education. When the student placement status of the science teaching program of the universities in which the study was conducted was examined in the context of the "Undergraduate Placement Exam" scores in Turkey, it was seen that A and C were in the middle ranks and B and D were in the lower ranks among the science teaching programs.

Prior to 2016 in Turkey, there was no rank requirement for students to enter science teacher education and other teacher education programs at universities. Prospective students could be placed in these programs by making a choice based on the score they got from the Undergraduate Placement Exam. As of 2016, the Higher Education Council in Turkey has stipulated that students must be able to enter the first 240 thousand in the Undergraduate Placement Exam in order to choose their teaching program. An average of 2.5 million students take the undergraduate placement exam in Turkey every year. In this context, the success ranking of the pre-service teachers participating in this study is more positive than in the past. For admission to the program, prospective teachers must be successful in advanced courses in biology, chemistry, physics and mathematics in high school. The science teacher education program in Turkey includes a period of eight semesters. During this 60-week training period, pre-service teachers take courses with professional knowledge (840 hours), field education (1230 hours) and general culture (420 hours). Pre-service teachers take a total of 8 hours of teaching practice (internship) in the 7th and 8th semesters for 30 weeks, 6 hours of which is practical at a state secondary school, 2 hours of which is theoretical at the university. The pre-service teachers who participated in this study took almost all of the stated professional formation and field education courses. In this context, only the "teaching practice-2" course and the "nature and teaching of science" course that they should take in the 8th semester are missing.

Study Context

In the science curriculum (Ministry of Education [MOE], 2018) updated in Turkey in 2018, secondary school students take the subject of chemical bonds as a basis for the first time at the 7th grade level, and then they learn ionic and covalent bonds in more detail in the 8th grade. Students learn the topics/concepts of atoms (nucleus, layer, proton, neutron, and electron) and molecules under the title of "Particulate Structure of Matter (6 lesson hours)" at the 7th-grade level. In these courses, it is aimed that the students know the structure of the atom consisting of protons, neutrons, and electrons. Also, at the 7th-grade level, they learn the subject/concepts of elements, symbols of elements, compounds, and compound formulas under the title of "Pure Substances (6 lesson hours)". In these courses, students will be able to classify elements, compounds, and mixtures based on pure and impure matter and give examples; expressing that the same or different atoms will come together to form a molecule and create various molecular models; It is aimed to express the names, symbols and some usage areas of the first 18 elements and common elements in the periodic system and to express the formulas, names and some usage areas of common compounds. At the 8th grade level, students learn the subject and concepts of group, period, and classification of the periodic system under the title of "Periodic System (4 lesson hours)". In these courses, it is aimed that students will be able to explain how groups and periods are formed in the periodic system and to classify elements as metal, semimetal, nonmetal, and noble gas on the periodic table. Again at the 8th grade level, they learn the subjects and concepts of the formation of chemical reactions under the title of "Chemical Reactions (3 lesson hours)". In these courses, it is aimed that students know that compounds are formed as a result of the chemical reaction.

Besides this, PSTs take the subject of chemical bonds during their university education in Türkiye within the scope of chemistry 1 (2 hours of theory, 2 hours of practice) at the 1st grade level. In this course, PSTs will learn about the atom and its electron structure (atomic nucleus, atomic theories, electron structure); periodic table (classification of elements, periodic properties); metals (alkali metals, alkaline earth metals, head group elements; nonmetals: noble gases, halogens); chemical compounds (compound types, formulation, and naming of compounds, mole concept); acids and bases (arhenius acid-base definition, brönsted-lowry acid-base definition, lewis acid-base definition, strong-weak acid-bases definition) and chemical bonds (basic concepts, chemical bond, ionic bonding, covalent bonding, bond energy, molecule geometry) (Higher Education Institution, 2018).

Data Collection and Instruments

The data of the study were collected in a period covering November-December 2020. Data were collected using the "Chemical Bond Model Knowledge Test (CBMKT)" (see Appendix 1). The test was designed by focusing on the basic concepts of chemical bonds and the two targeted teacher professional knowledge components (content knowledge and knowledge of student understanding). CBMKT was developed by the researchers of this study. The CK and KSU, which are among the dimensions of teacher professional knowledge discussed within the scope of this research, attracted attention with Shulman's (1986) conceptualization of PCK and the researchers who followed it. Previous studies support that these two knowledge components are the most important dynamics of teacher professional knowledge (Magnusson et al., 1999; Park & Oliver 2008; Park & Chen 2012). Science teachers and PSTs' CKs and KSUs on a specific subject in science have been the subject of many studies (Barendsen & Henze, 2019; Coetzee et al., 2020; Kaya et al., 2022; Chan & Yung, 2018; Mesci et al., 2020; Moodley & Gaigher, 2019). In recent years, besides traditional data collection techniques, innovative tools called "paper pencil tests" have started to be used in examining professional knowledge sub-dimensions such as CK and KSU of science teachers and PSTs (Becerra et al., 2022; Jüttner & Neuhaus, 2012; Jüttner et al., 2013; Park et al., 2018; Schmelzing et al., 2013). Within the scope of this research, we considered "paper-pencil test" samples for the preparation and development of CBMKT. Each question in this test consists of two parts. The first part aims to determine the MB-CK of PSTs on chemical bonds.

The second part aims to determine the MB-KSU, which is one of the professional knowledge sub-dimensions of PSTs. When the relevant literature is examined, no "paper pencil test" example was found that evaluates the model-based professional knowledge (model-based pedagogy) of science teachers or PSTs on a science subject. Therefore, while preparing CBMKT, we acted according to the "model-based paper-pencil test" logic. In order to evaluate PSTs' MB-CKs on chemical bonding, we first created a model-based question pool. These questions include the chemical bond that will form between ions (eg A^{+3} B^{-2}, Ionic bond), the chemical bond in the formation of a compound (CO_2, covalent bond), the chemical bond that will form between its elements ($_{12}X$ - $_{9}Y$ and $_{12}Mg$ - $_{17}Cl$, ionic bond) and chemical bond (OF_2, covalent bond) forming the compound. Based on these contents, 10 MB-CK draft questions were prepared. While preparing these questions, interviews were held with teacher educators (experts) who have been conducting Chemistry I course for a long time in two of the universities where the application was made for content validity. These experts gave feedback on the appropriateness of the prepared MB-CK questions to the PSTs and the scientific language used. In these evaluations, experts were also asked to choose so that the prepared MB-CK questions could be used in the relevant test. Experts were asked to rate the questions they deem appropriate for the test using a rating scale from 1 to 5. The experts were asked to consider five questions for the model-based content knowledge dimension of the test, so they should take this into account in their scoring. By taking the average of the scores given by the experts to each question, the average scores for all questions were ordered from largest to smallest. In this context, the MB-CK questions to be applied to the high school students and PSTs were decided by considering the averages of the points given by the two experts for each question. In order to evaluate the PSTs' MB-KSUs on chemical bonds, five questions on the same subject content were prepared (this section was created based on the answers given to the MB-CK questions applied to high school students). One of the MB-CK questions in the test is as follows:

“Q1. What kind of chemical bond is formed between the A^{+3} B^{-2} ions? Show the model by drawing it.”

Alongside traditional approaches such as interviews and surveys in educational research, the drawing technique is frequently used as an innovative data collection approach (Hsieh & Tsai, 2018; Yeh et al., 2019). A drawing is defined as a visual representation that depicts an event, structure, relationship or process related to content. Drawings are the visual languages of science (Quillin & Thomas, 2015). As a data collection tool, drawing can provide rich, creative and colorful data for researchers. As a form of visual-based data collection, drawing has become increasingly accepted as a valid method of making students' thinking visible (Bland, 2018). Also, in science, drawings allow individuals to represent many complex ideas that they cannot express. Drawings used in science; they are supported by symbols, labels and text (Hsieh & Tsai, 2018). In the context of this study, it was ensured that PSTs were able to represent their MB-CK understanding of chemical bonds with the drawings. The aim here was to provide access and exploration of PSTs' thoughts on chemical bonds through drawings. Again, it was aimed to reveal the thoughts that the PSTs did not construct and define correctly during their high school and university education with their model drawings regarding chemical bonds. While preparing the MB-KSU questions, the previously prepared MB-CK questions were applied to 36 students studying in the 12th grade of a high school. In terms of model drawings and ideas in high school students' answers to these questions, incorrect model drawings were used in the preparation of MB-KSU questions. Each of the MB-KSU questions consisted of model drawings taken from the student and an open-ended question root regarding this drawing. An example of an MB-KSU question in CBMKT is as follows (see Figure 3):

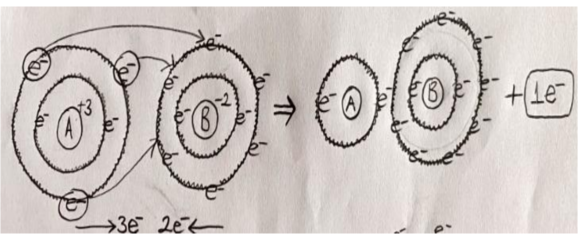


Figure 3. Student's model of the chemical bond formed between A^{+3} B^{-2} ions

“On the left, a student's drawings and ideas regarding the chemical bond model formed between A^{+3} B^{-2} ions in his/her Chemistry course are given. How would you evaluate the quality of the models and ideas drawn by the student regarding the bond formed between these ions? In other words, how do students learn about the chemical bond model formed between A^{+3} and B^{-2} ions? Please explain.

MB-KSU prepared the questions with the "paper-pencil test" technique in the related literature. The questions prepared in this context were presented to the evaluation of a chemistry educator working on the professional knowledge of science teachers. The researchers sent the "paper-pencil test" samples in the related literature along with the questions to the teacher educator. As a result of the evaluation, the teacher educator approved each MB-KSU question in the test by pointing to some language corrections. In this context, each question of CBMKT included five questions in a two-stage structure aiming to measure MB-CK and MB-KSU. In order to determine the validity of the test, the ideal response time and the understandability of the questions, CBMKT was applied as a pilot study to 16 PSTs studying in the third year of the science teaching program of the university where one of the researchers worked. Within the scope of the pilot study, one of the researchers and a chemistry educator from the same university independently scored the answers of the PSTs based on the previously developed rubrics in order to ensure the reliability of the CBMKT. As a result of these scorings, a high degree of inter-rater consistency was found in terms of MB-CK ($r=.941$, $p<0.01$) and MB-KSU ($r=.904$, $p<0.01$) dimensions. This result indicates that CBMKT makes a reliable measurement. In addition, within the scope of the pilot application, the feedback from the students was taken into account, and minor adjustments were made to the questions, and the test was given its final form.

Within the scope of this study, a period of approximately sixty minutes was determined for PSTs to answer the CBMKT. The researchers themselves participated in the data collection process at three of the four different universities (A, C and D) where the original study was conducted. The data collection process at university B was carried out by the teacher in charge of an elective course taken by the PSTs. Care was taken to ensure that the data collection process in all four universities was carried out in a way that would not disrupt the undergraduate education programs of the PSTs. In this context, the most ideal day and time to apply the test was determined by contacting the lecturers who are teaching in the last year of the science teaching program at the universities where the study will be conducted. One week before the application of the test, the instructors responsible for the courses selected for the application to the PSTs informed about the study and data collection process to be carried out the next week. Within the scope of this information, the PSTs were informed that the participation was voluntary and the study aimed to examine the professional knowledge of the PSTs. However, on the day of the application, both the researchers who will administer the test at A, C and D universities and the lecturer at B university made detailed explanations about the purpose of the test and the points to be considered while answering it. Although the total number of PSTs registered in the four universities where the study was conducted was 268, data were collected from 237 of them. The content distribution of the questions in the final form of CBMKT is given in Table 1.

Table 1. Focus of Questions in CBMKT

Question	Content Topic
Q1a.	The chemical bond model that will form between A^{+3} and B^{-2} ions
Q2a.	The chemical bond model in the formation of the CO_2 compound
Q3a.	The chemical bond model that will form between the ${}_{12}X$ and ${}_{9}Y$ elements
Q4a.	The chemical bond model forming the OF_2 compound
Q5a.	The chemical bond model that will form between ${}_{12}Mg$ and ${}_{17}Cl$ elements
Question	Pedagogical Topic
Q1b-Q5b.	Model Based-Knowledge of Student Understanding

Development of the Rubrics and Data Analysis

We developed two separate rubrics to reveal the MB-CK and MB-KSU of the MB-PCK components of PSTs on chemical bonds. While preparing these rubrics, firstly, model knowledge evaluation tools in science in the existing literature (Kaberman & Dori, 2009; Namdar & Shen, 2015; Nicolaou & Constantinou, 2014; Taskin et al., 2017) and rubrics prepared to evaluate KSU from PCK components were examined (Chan et al., 2019; Heller et al. 2004; Kellogg, 2010; Park et al., 2018). As a result of these examinations, it was understood that there was a need to develop new rubrics to evaluate both the MB-CK and MB-KSU of PSTs. After this determination, we worked on determining the scope of the rubrics. In this context, we conducted studies on what kind of criteria the rubrics would contain. For both rubrics, we set a set of criteria based on theoretical knowledge of chemical bonds. These criteria included the visual, symbolic, and verbal structure of the model, the octet rule, electron transfer, electron sharing, ion structure, compound structure, and chemical bond type. For both rubrics, we created a scoring system by scanning the relevant literature. In order to test the operability of the draft form of the rubrics, one of the questions written for the draft form of CBMKT and not used in the final form of this test was applied to 22 PSTs studying in the 3rd year of science teaching at the university where one of the researchers works. Here the choice of question did not contain a specific purpose. The researchers randomly chose this question, which was not in the final form of the CBMKT, to determine how the rubrics worked on one of the questions. Data from this question was scored by two of the researchers based on rubrics. In these scorings, zero points were given to the answers that did not have model drawings and did not provide any information about student model understanding, or that only included an answer as "no" or "I do not know". The answers given by the PSTs to the MB-KSU questions were scored when they included student knowledge errors in the models and their sources (preliminary knowledge, misconceptions and learning difficulties). Throughout the entire scoring, the researchers independently refereed blindly. The results of the scoring made by two researchers indicate a high level of inter-rater reliability in terms of MB-CK ($r=.963$, $p < 0.01$) and MB-KSU ($r=.914$, $p < 0.01$) dimensions. In addition, the results indicated that there was no significant difference between the scores of both raters: MB-CK [t (21) = 1.51, p= .168] ve MB-KSU [t (21) = 1.95, p= .082]. These results pointed to strong evidence for the operability of the rubrics. The researchers also discussed the reasons for the inconsistencies in their scoring and revised the resulting glitches in the rubrics. In order to strengthen the structural features (scoring structure, level and classification) and content validity (model content and model error criteria for chemical bonds) of the first forms of the rubrics, we submitted it for review by a panelist group consisting of three departments (chemistry education, science education and measurement) in the university where one of the researchers is located. As a result of these evaluations, the deficiencies regarding the rubrics were eliminated and we gave the rubrics its final version. The structural features of the prepared rubrics are as follows:

Model Based-Content Knowledge (MB-CK) Rubric

This rubric aimed to evaluate the PSTs' ability to prepare a scientific chemical bond model based on the criteria stated above. In order to evaluate the quality of the answers given by the PSTs, MB-CK Rubric has a triple category and scoring system as "right model (Scoring of 1), wrong model (Scoring of 0) and no model represantation (Scoring of 0)" in terms of the scientific suitability of the model. According to the MB-CK Rubric, if the PST's model drawing for the chemical bond question shows a scientific harmony in visual, symbolical and verbal and if it exhibits a scientific structure about the octet rule, electron configuration, transfer or electron sharing, it is included in the "right model" category. On the other hand, if the drawn model does not show a complete and correct fit in terms of visual, symbolic and verbal, and the drawing contains errors in octet rule, electron configuration, transfer or electron sharing, it is included in the “wrong model” category (see. Appendix B for MB-CK Rubric.). If the PST did not include any drawings and labeling in his answer about the chemical bond model, he/she is included in the "no model represantation" category. That is, the "wrong model" and "no model represantation" classifications indicate that no evidence of a scientific model is presented in the PST's response. For a scientific model, the PST's drawing was required to be a Lewis or Shell Model. In addition, if the Shell Model is used in the drawings, the presence of inner shell, inner shell electrons and core codes are among the criteria of the "right model" drawing category. If the model drawings of the PST include drawings that are not relevant to the question, they are included in the “wrong model” category.

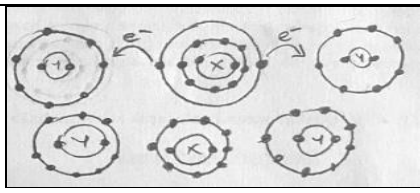
Model Based-Knowledge of Students’ Understanding (MB-KSU) Rubric

This rubric aimed to evaluate the knowledge errors in the chemical bond models drawn by secondary school students according to the above criteria, and the ability of teacher candidates to understand. In order to evaluate the quality of the answers given by the PSTs, “MB-KSU Rubric” was composed of four-level structure and scoring: “examplary identification (Scoring of 3), acceptable identification (Scoring of 2), weak identification (Scoring of 1) and invalid/missed identification (Scoring of 0)” (See Appendix B for the MB-KSU Rubric.). According to the MB-KSU Rubric, if the PST's understanding of the student model regarding the chemical bond question includes detecting visual, symbolic and verbal errors in the student's model and if it fully reflects the learning errors and sources in the student model regarding the octet rule, electron configuration, transfer or electron sharing, it is accepted at the “examplary identification” level. If the PST's answer includes most of the learning errors and sources about the octet rule, electron configuration, transfer or electron sharing in the student model, it is accepted at the "acceptable identification" level. The PST's response is considered to be at the "weak identification" level if it reveals little idea about the learning errors and sources of the octet rule, electron configuration, transfer, or electron sharing in the student model. Finally, if the PST's answer does not contain any correct determinations about the information errors in the student model or is left blank, it is accepted at the “invalid/missed identification” level.

Researchers perform three benchmarks for MB-CK Rubric: *Right model*, *wrong model*, and *no model represantation*; four benchmark performances for the MB-KSU Rubric: *Examplary identification*, *Acceptable identification*, *Weak identification* and *Invalid/Missed identification*. The research team spent a significant amount of time thinking about what differentiates (eg “*Weak identification*” performance instead of “*Acceptable identification*” performance) PSTs' performance between these levels and coming up with clear indicators, especially with regard to performance levels on the MB-KSU Rubric. These discussions and evaluations contributed significantly to the further improvement and clarification of the performance indicators of the MB-KSU Rubric. Everyone on the research team had the opportunity to review and provide feedback on both rubrics. Afterwards, the relevant rubrics were finalized. In addition, two external science educator experts spent a significant amount of time improving both the indicators of the rubrics and the scoring system, thus further increasing the validity of the rubric. We created the scoring structure in both rubrics to verify the structural validity of the rubrics and to ensure the analysis reliability of the data obtained from PSTs. Therefore, it does not include scoring the PSTs in this study regarding their MB-CK and MB-KSU. The classification structure including "*right model, wrong model* and *no model represantation*" was used to analyze the MB-CKs of PSTs on chemical bonds, and a level structure including "*examplary identification, acceptable identification, weak identification* and *invalid/missed identification*" was used to analyze MB-KSU data.

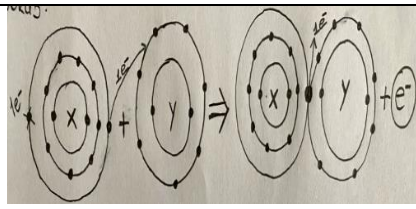
Data collected from PSTs with CBMKT were analyzed using "MB-CK Rubric" and "MB-KSU Rubric". Two of the researchers analyzed each question in CBMKT in terms of MB-CK and MB-KSU. The test papers were deemed invalid when it was determined that the model drawings of the PSTs regarding the content knowledge in CBMKT were copied from the drawings of someone else. Eight of the PSTs were not included in the data analysis because this situation was detected in the answers they gave to the questions in the CBMKT. Therefore, the data of 229 out of 237 PSTs participating in the study were included in the analysis. In this context, the MB-CK and MB-KSUs of 229 PSTs on chemical bonds were analyzed according to the category and level in the rubrics. Afterwards, the frequencies and percentage distributions of the PSTs' MB-CK and MB-KSU in terms of categories and levels were determined in the context of each question in CBMKT. Obtained values are presented through graphics. An example analysis is as follows:

Q3a. How is a chemical bond formed between elements $_{12}X$ and $_{9}Y$? Show the model by drawing it.

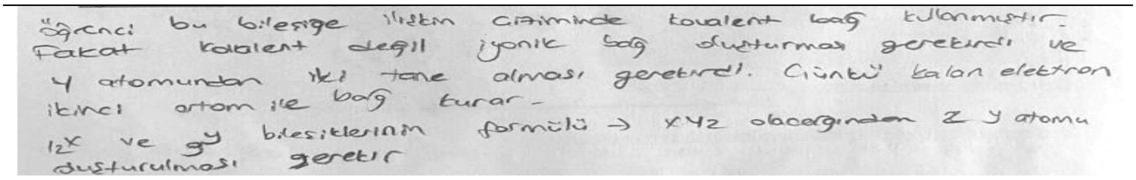


*(*Model Drawing produced by PST$_{11}$)

Q3b. On the right, there are the drawings and ideas of a student about the chemical bond model he created between the elements $_{12}X$ and $_{9}Y$ in his Chemistry class. How would you evaluate the quality of the models and ideas drawn by the student regarding the bond formed between these elements? In other words, how do students learn about the chemical bond model formed between $_{12}X$ and $_{9}Y$ elements? Please explain.



(Model Drawing produced by student)


"Öğrenci bu bileşiğe ilişkin çiziminde kovalent bağ kullanmıştır. Fakat kovalent değil iyonik bağ oluşturması gerekirdi ve Y atomundan iki tane alması gerekirdi. Çünkü kalan elektron ikinci atom ile bağ kurar. $_{12}$X ve $_{9}$Y bileşiklerinin formülü → XY2 olacağından 2 Y atomu oluşturulması gerekir

*"The student used a covalent bond in his drawing of this compound. But it should have formed an ionic bond, not a covalent bond. There should be two of the Y atoms. Because the remaining electron bonds with the second Y atom. Since the formula for compounds $_{12}X$ and $_{9}Y$ would be XY_2, they should have formed 2Y atoms." (*PST$_{49}$'s knowledge of students' understanding answer)

Figure 4. Model Drawing and Knowledge of Students' Understanding Answer Produced by PSTs

When the drawing of the chemical bond model of $_{12}X$ and $_{9}Y$ elements in Figure 4 formed by PST_{49} is examined, it is seen that he/she prefers a shell model; he/she shows inner shell electrons and it is understood that he/she forms an ionic bond structure and exhibits a scientific structure in electron exchange. In the model, it is seen that the PST gave the $2e^-$ in its outermost orbit to the $_{9}Y$ element which has $7e^-$ in its last orbit, in order to reach the $_{12}X$ element in a stable electron configuration. The scientific model should represent the compound XY_2 (consisting of X^{+2} and Y^{-1} ions). Because here, when the X atom, which tends to give $2e^-$, and the Y atom, which tends to take $1e^-$, enter into a reaction, the atoms with an electrostatic attraction force between them form the ionic bond XY_2. Therefore, the PST had to give the excess $2e^-$ of the X atom to 2 separate Y atoms in the model he/she drew. It is seen that the PST took this into account in his/her drawing. In this context, we evaluated the model drawing of the PST in the "right model" category according to the MB-CK Rubric. When the level of student understanding of the PST regarding the model drawn by the student is examined in Figure 4, it is seen that,

> *He/She emphasizes that the student prefers covalent bond over ionic bond in hi/hers drawing of this compound and this is wrong. In addition, he/she stated that 2 Y atoms are needed in this chemical bonding, however, in the model drawn by the student, she preferred a bond structure based on a single Y atom and an e^- was left idle in this way.*

This answer of the PST regarding the student model shows that the PST was able to detect inaccuracies in the model student created between the $_{12}X$ and $_{9}Y$ elements. It is understood that the PST was able to analyze the errors in the bond structure and electron exchange in the student model. The PST detected the error in the knowledge that the bond structure in the student model should be an ionic bond that occurs with electron exchange, not an electron sharing, that is, not a covalent bond. However, the PST could not reveal that the student did not have the scientific idea that the element $_{12}X$ represents a metal element in the 2A group in the periodic table and that the number of valence electrons of this element is +2, so it can become stable when it gives these two electrons in its outermost orbit.

Likewise, the PST could not put forward that the student could not have a scientific explanation that the element $_{9}Y$ is a nonmetal element in the 7A group of the periodic table and that the valence electron number of this element is -1, therefore the outermost orbit of the Y atom needs $1e^-$ in order to get a more stable structure. The PST could not make a determination that the student has a scientific explanation like "according to the octet rule, all orbitals of atoms must be full and if they are not full, they will try to provide this, in which case the atom will face two different events, either by getting rid of the electrons in its outer shell and turning the already filled lower shell into the last cap or by completing the outer shell by obtaining electrons from outside".

In addition, in the chemical reactions between $_{12}X$ and $_{9}Y$ elements, the pre-service teacher could not make a determination that the mistaken thought by student that X^{+2} ion could be formed if the X atom lost $2e^-$ electrons and Y^{-2} ion could be formed if the Y atom gained $2e^-$ electrons. The PST could not determined that the student did not have the understanding that in order to become more stable for the $_{9}Y$ element, $1e^-$ need will be met from the $_{12}X$ element for its outermost orbital, but in this case, the remaining $_{11}X$ element will not be able to exhibit a stable structure because of $1e^-$ in its last orbit. The PST could not determine that the student did not have the understanding that both atoms would exhibit a stable structure that in the compound XY_2 formed by ionic bonds between X and Y atoms, the electrons gained by Y should be equal as much as the electron lost by X, and in this context, the X atom should give its extra 2e$^-$ electrons to 2 separate Y atoms. As a result, it is seen that the PST could not reveal an understanding of what the reasons for faulty information on the student's model (the sources of these information errors) might be. When we evaluated the PST's answer to this question according to the MB-KSU Rubric, it was found that the the PST was partially successful in detecting the visual and symbolic errors in the chemical bond formed between the $_{12}$X and $_{9}$Y elements through student model and he/she could not analyze the learning errors in the student model in depth on the octet rule, electron configuration and electron transfer.

Especially in the student model, PST could not interpret the use of one-to-one of X and Y elements and leaving 1e$^-$ of X element exposed. He/She could not make any inferences about both the errors in the model and the reasons for these errors. Therefore, we evaluated the PST's knowledge of students understanding at the level of "*weak identification*" according to the MB-KSU Rubric. Both researchers evaluated the quality of the PST's Q3 responses with the same consistency. All data collected from teacher candidates with CBMKT were evaluated jointly by the same two researchers.

Reliability of Data Analysis

To ensure the analysis reliability of the data collected by CBMKT, an evaluation team consisting of two researchers and a chemistry educator at the university, where one of these researchers is located, independently scored the responses of 23 PSTs (about 10% of the sample). Separate scores were made for 5 questions in CBMKT. Responses to each question in the CBMKT were scored as two separate section (a. MB-CK and b. MB-KSU). The correlation matrix for the scores of the three raters is presented in Table 2.

Table 2. Correlation Values between Raters in the Preliminary Analysis to Ensure Data Analysis Reliability

		R1	R2			R1	R2
Q1a.	R2	.805**		Q1b.	R2	.719*	
	CE	.806**	.731*		CE	.772**	.851**
Q2a.	R2	.884**		Q2b.	R2	.802**	
	CE	.911**	.820**		CE	.867**	.740*
Q3a.	R2	.700*		Q3b.	R2	.771**	
	CE	.896**	.734*		CE	.750*	.738*
Q4a.	R2	.712*		Q4b.	R2	.689*	
	CE	.725*	.822**		CE	.658*	.710*
Q5a.	R2	.709*		Q5b.	R2	.701*	
	CE	.742*	.785**		CE	.687*	.694*

*** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).*

N=23, Q: Question, a-b: Question Section, R1: Researcher 1, R2: Researcher 2, CE: Chemistry Educator

Table 2 shows the inter-rater consistency values of the answers given for the MD-CK (a) and MD-KSU (b) sections of each question. When these values are examined, it is understood that there is a high consistency between the raters in the scoring of the parts of each question in the CBMKT. In scoring the answers to the MD-

CK (a) section of all questions of the CBMKT, the consistency among the raters seems to have a much higher degree of consistency and significance compared to the MD-CSU (b) sections. In scoring the answers to the MB-CK section of each question, raters had little hesitation about whether the model was scientific drawing. Therefore, it is understood that the scores of this component result in a high correlation. That is, the raters were in consistent about the category and level of the PSTs' answers. These results indicate that validity and reliability are provided in the analysis of all data.

Results

The current results consist of two parts (1) The results about PSTs' MB-CK on chemical bonds and (2) The results about PSTs' MB-KSU on chemical bonds. The results for each section are presented in graphs to represent the proportional (%) distribution.

Figure 5. The Results of Analysis of PSTs' MB-CK on Chemical Bonds

It is seen that the proportional distribution of the questions regarding PSTs' MB-CK on chemical bonding in Figure 5. When the MB-CK of PSTs in each question is examined, it is understood that they make the correct modeling (scientific drawing) in the chemical bond model question (Q2a) in the formation of the CO_2 compound with a rate of 37.12%. On the other hand, it is seen that the PSTs make the incorrect modeling (non-scientific drawing) with a rate of 54.59% in the question (Q5a) of the chemical bond that will form between $_{12}Mg$ and $_{17}Cl$ elements. It is observed that the MB-CK of the majority of the PSTs participating in the study on chemical bonds is in the form of wrong modeling or inability to model (the PST's inability to draw a model). It also shows that the PSTs' knowledge about chemical bonds is quite inadequate. According to these results, it can be said that the majority of PSTs do not represent images suitable for scientific modeling on chemical bonds, in other words, they are unable to draw "*Lewis*" and "*Shell*" models between various ions, elements and in the formation of compounds. The examples of PSTs' correct modeling (scientific drawing), incorrect modeling (non-scientific drawing) and scientific modeling of researchers are shown in Figure 6.

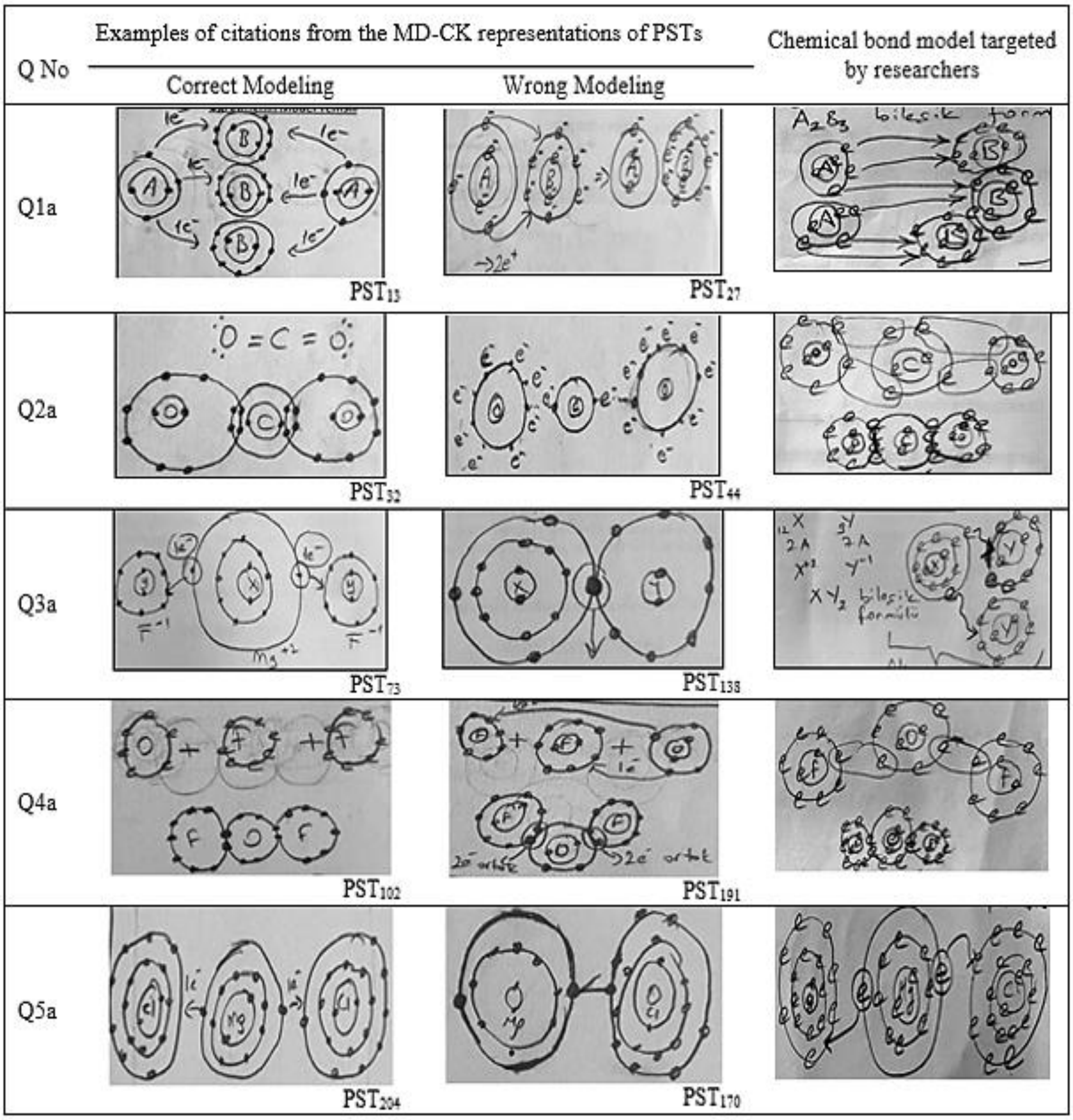


Figure 6. Examples of Scientific Model and PSTs' MB-CK on Chemical Bonds

The explanations of the incorrect chemical bond models in Figure 6 are as follows: When the model created by PST_{27} between A^{+3} and B^{-2} ions in Q1a is examined, the PST could not think that there should be two of A atoms and three of B atoms for the A_2B_3 compound forming between both ions. That's because, first of all, the valences of the ions that will form the compound are crossed in the form of coefficients. The PST has prepared a chemical bond model over single A and B atoms in his/her drawing. The PST has thought that the A atom should give the extra $3e^-$ in its shell to the B atom in order to become more stable. However, the B atom needs only $2e^-$ to become more stable, so a single B atom can only take $2e^-$ from the A atom, and s/he could not make an accurate model about what the other e^- would be. When the chemical bond model created by PST_{44} for the CO_2 compound in Q2a is examined, s/he could not think that a bond should be made between the C and O atoms with the common use of electrons. S/he has also thought that in her/his model, the C atom would be more stable by leaving only $2e^-$ in its orbit. When the chemical bond model formed by PST_{138} between ${}_{12}X$ and ${}_{9}Y$ elements is examined, it is understood that element X can't be considered as a 2A metal and $+2e^-$ valence, and element Y cannot be considered as a 7A nonmetal and $+1e^-$. The PST could not think that it should give the $2e^-$ in its final orbital to two separate Y atoms, each of which needs only one e^- in order for the X atom to become more stable. Instead, s/he has made electron sharing between an X atom and a Y atom and has increased the e^- number in the last orbit of X to +4. When the chemical bond model created by PST_{191} for OF_2 compound is examined, it is thought that O and F, which are nonmetals, will form a chemical bond with electron sharing and two F and one O atoms are needed in the model. However, s/he could not model correctly that the O atom would become stable by completing two e^- and the F atoms would become stable by completing one e^-. It is observed in the model drawn by the PST that the F atoms have become stable by completing their final orbits with electron sharing from the O atom, whereas the O atom could not complete the number of electrons in its final orbit to become stable. Consequently, when the chemical bond model created by PST_{170} between $_{12}Mg$ and $_{17}Cl$ elements is examined, it is seen that the PST could not give the extra $2e^-$ in the last orbit of the Mg atom to two separate Cl atoms that need 1e- in the final orbit to become more stable. Instead, s/he has added $1e^-$ to the last orbital of the single Cl atom and has drawn a model in which she has kept the e- number in the final orbital of the Mg atom constant. When the incorrect chemical bond models in Figure 7 are examined, it is understood that the PSTs' shell models do not contain appropriate images and represent non-scientific models. In addition, it can be said that the flaws in the PSTs' models are mostly due to misunderstandings in electron transfer and sharing, atomic number and compound formation. This shows that the PSTs' knowledge of chemical bonds are insufficient.

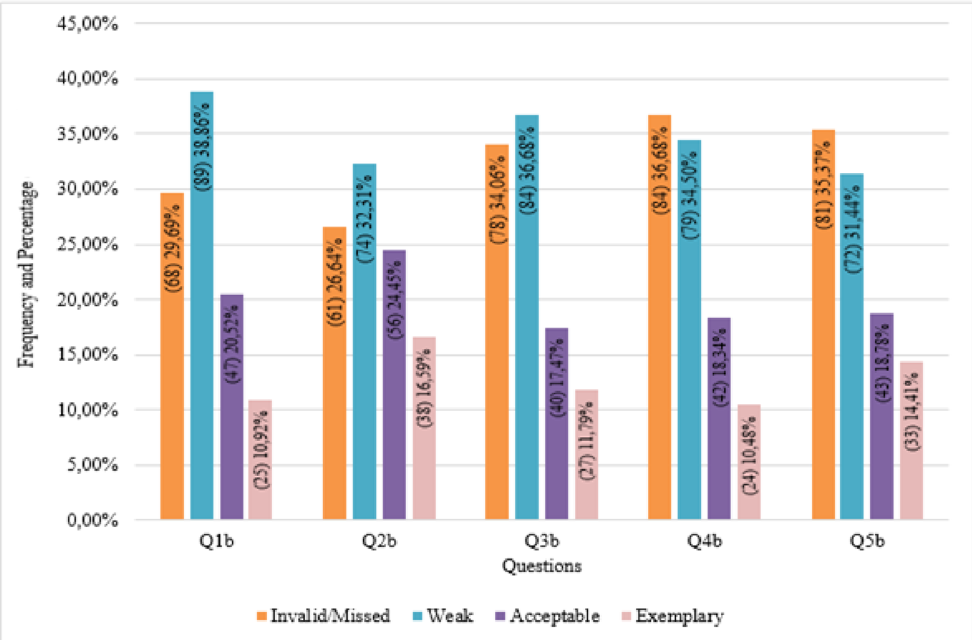
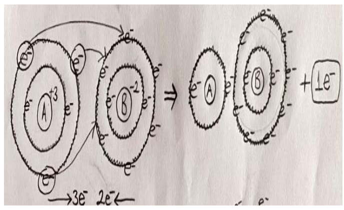
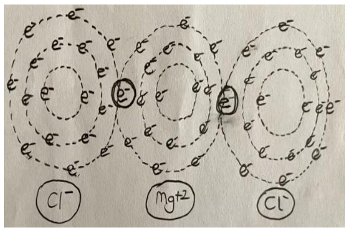


Figure 7. Percentage Distribution of PSTs' Levels of MB-KSU on Chemical Bonds

It is seen that the proportional distribution of the questions regarding PSTs' MB-KSU on chemical bonding in Figure 7. When the PSTs' MB-KSU status in each question is examined, it is seen that they have reached the "Exemplary" and "Acceptable" levels in the chemical bond model question (Q2b) prepared by the students for the CO_2 compound with a total frequency rate of 42.04%. In this question, the PSTs explain the mistakes better and the source of these mistakes compared to the other questions in the model drawn by the student. So, KSU levels are better. However, it is seen that the levels of "Weak" and "Invalid/Missed" are reached in the chemical bond model question (Q4b) prepared by the students for the OF_2 molecule with the total frequency rate of 71.18%. When the PSTs' understanding of the models drawn by the students on chemical bonds (KSU) is evaluated, it is seen that the vast majority of them are quite inadequate and they are weak to describe the mistakes in the student's model and the sources of these mistakes. According to these results, it can be said that the majority of PSTs are quite unsuccessful to detect unscientific student model drawings and understandings about chemical bonds. It is clear that the vast majority of PSTs have a very inadequate knowledge (KSU) of the octet rule, electron configuration, electron transfer or electron sharing in the Lewis and Shell chemical bond models drawn by the students and to detect accurately the theoretical knowledge inaccuracies of the student regarding the type of chemical bond (Ionic and Covalent Bond). It can be said that the inability of many PSTs to identify the inaccuracies and sources in student models is due to the inadequacy of their image they have about chemical bonds. The examples of MB-KSU citations in the answers given by the PSTs to the questions Q1b and Q5b are shown in Table 3.

Table 3. The Examples of PSTs' MB-KSU on Chemical Bonds

<table>
<tr><th>Q No</th><th>MB-KSU Level</th><th>Example of quotation from the PST's answer</th><th>Examples of students' drawing/ scientific explanation of the student model on the basis of MB-KSU</th></tr>
<tr><td rowspan="2">Q1b</td><td>Exemplary</td><td>"I can say that there are many mistakes in the student's drawing.... First of all, I think that the student does not know the compound that will form between the A^{+3} and B^{-2} ions. The student could not understand that A_2B_3 compound would form between these two ions. Because she could not get this, s/he did not think that she needed two A atoms and three B atoms for a correct chemical bond in her/his model. Therefore, the student created a chemical bond between single A and B atoms in the model s/he drew. When the student's model is examined in detail, it is seen that the student knows the electron distribution in the final orbits of the A and B ions correctly but makes serious mistakes in electron transfer while forming the ionic bond. Therefore, I can say that the student has wrong information about the atomic numbers of A and B and electron transfer…"
(PST_{181}'s answer to KSU)</td><td rowspan="2">
In ionic compounds, the e- numbers received and given should always be equal. The student has taken $2e^-$, has given $3e^-$ in her/his model. In the student's model, s/he could not think that the A_2B_3 compound would emerge by crossing the valence coefficients of both ions. Therefore, the student could not model that he could give the excess of $6e^-$ in two A^{+3} ions to three B^{-2} ions in order for them to become more stable.
This model shows that the student has important misconceptions about the octet rule, electron configuration, electron transfer, and the electrical</td></tr>
<tr><td>Acceptable</td><td>"There are significant mistakes in the student's model drawing. The student has thought correctly about the electron transfer from the A ion to the B ion, but this electron transfer between single A and B ions is not correct. In the student's model, three electrons from the A atom cannot be donated to a single B atom. That's because a single B atom needs two electrons. The student could not predict this in his model…"
(PST_{119}'s answer to KSU)</td></tr>
</table>

	Weak	*"Electrons begin with two electrons while dispersing into layers and continue with 8 electrons in element. While the student should give 2 electrons to element B in the model, she gives 3 electrons. Therefore, there are 9 electrons in the second layer of element B in the student's model. I think the student's opinion is wrong."* (PST$_{73}$'s answer to KSU)	attraction force of positively and negatively charged particles.
	Invalid/ Missed	*"The student has given the electron in the A atom to the B atom and formed a bond between them. However, the student could not form the interaction.* (PST$_{17}$'s answer to KSU)	
Q5b	Exemplary	"*I can see many mistakes in the student model. In the student model, s/he could not understand the chemical bond that would form between Mg and Cl.* *Because the student has made a covalent bond between two elements instead of an ionic bond. I can understand this from the electron sharing between Mg and Cl. However, I think that the student has made a model based on the $MgCl_2$ compound in his/her model. Because he has made a drawing consisting of two Cl, one Mg atoms. This shows me that the student has understood the $MgCl_2$ compound. But it is very clear that s/he cannot transfer evenly the $2e^-$ of the final orbital of Mg into Cl atoms. I think the student has seriously misunderstood the type of chemical bond. Moreover, the student could not understand correctly how the electron exchange should be based on the number of valence electrons in the atoms. The student has drawn a fully charged orbit with $8e^-$, while Mg should have $2e^-$ in its third orbit. It is also striking that the student has lack of knowledge about the octet rule and electron configuration.*" (PST$_{160}$'s answer to KSU)	 In this chemical bond model, although the student has known that $_{17}Cl$ is a nonmetal with group 7A and valence of -1 (Cl^-), she could not think of $_{12}Mg$ as a metal with group 2A and +2 valence (Mg^{+2}). The student has represented Mg with a shell model of 18 e^-, whereas it is clear that there is $12e^-$ in the structure of Mg. In other words, the student has drawn the number of electrons in the third orbit of Mg^{+2} incorrectly. In addition, the student has thought of a covalent bond model instead of the ionic bond forming between Mg and Cl, and therefore s/he has made a drawing based on electron sharing in the model. The student has correctly understood that 2 Cl is needed in the model, but she has not thought that Mg should transfer $2e^-$ into two separate Cl- ions in its final orbit in order for Mg to become more stable. This model shows that the student has important misconceptions about the
	Acceptable	"*When I look at the student's drawing, I can see important mistakes. In the student's model, s/he made electron sharing between Mg and Cl atoms, which is not true. The student has correctly considered the number of two Mg and one Cl atoms in his/her model. However, the student fails that, s/he must distribute them one by one to the Cl atoms in order to get rid of extra $2e^-$ in third orbit of Mg in her model. "* (PST$_{22}$'s answer to KSU)	
	Weak	"*In the student's model, the electron configuration of Mg is modelled incorrectly. The electrons of Mg are given to the Cl^- side, they are not shared. The student could not think of them…"* (PST$_{80}$'s answer to KSU)	

Invalid/ Missed	*"There are no flaws in the student's drawing, e^-s are clear and atomic packing is correct…"* (PST$_{203}$'s answer to KSU)	octet rule, electron configuration, electron transfer, and the electrical attraction force of positively and negatively charged particles.

We have showed the examples from PSTs' MB-KSU levels on chemical bonds in Table 3. The excerpts from the MB-KSU of PSTs regarding "Exemplary" and "Acceptable" levels show that the student's model reveals the excess and deficiency of octets, the type of chemical bond, compound formation, the use of valence electron numbers and the inaccuracies in electron transfer or sharing, nonscientific drawings. At this level, PSTs have been able to point out many inaccuracies in the students' non-scientific alternative models about chemical bonding and their sources. On the other hand, the answers at the "Weak" and "Invalid/Missed" levels indicate that the PSTs have an insufficient KSU for understanding and non-scientific images of the chemical bond model drawn by the student. Moreover, PSTs at this level show that the students are not able to provide effective diagnosis of mis-learning, conceptualization difficulties, comprehension difficulties, and modeling weaknesses in chemical bonding topics.

Discussion

We investigate CK and KSU, which are among the dimensions of professional knowledge of PSTs on chemical bonds in the context of model knowledge in this study. Our study provides an assessment of the gaps in PSTs' model-based knowledge of chemical bonds and provides a diagnosis for PSTs' CKs and KSUs that they will take with them when starting the profession. In general, our findings reveal that the undergraduate education of science teachers on chemical bonds in Turkey is problematic and weak. This result points to the need to design an undergraduate curriculum that can improve PSTs' model-based professional knowledge and understanding of chemical bonds. Chemical bonds are a vital topic in science education and form the basis for many future chemistry topics about which students will learn. In addition, the fact that the subject of chemical bonds has conceptually intense content makes it difficult to both teach and learn. Chemical bonds are a very abstract and difficult subject to understand (Levy Nahum et al., 2010). Therefore, teachers need to have an effective professional knowledge structure in this regard. Teachers must have advanced model-based knowledge to facilitate especially the students' learning about chemical bonds. (Bergqvist et al., 2016; Toerien, 2017). Because chemical bonds deal with the nature of substances, which are abstract concepts (Justi & Gilbert, 2002; Taber & Coll, 2002). Since we cannot see how the atoms or other particles that makeup matter are held together, this subject is only taught by using effective models (Bergqvist, 2017; Taber, 2011). However, one of the major challenges in teaching chemical bonds is the use of problematic models (Özmen, 2004). It can be thought that this situation is directly related to both the chemical bond model knowledge of science teachers and the course sources that are used.

This study consists of two main results. The first is that the vast majority of PSTs' MB-CK is mismodeling or inability to model on chemical bonds. This result can be interpreted as insufficient conceptual knowledge and model images of PSTs on chemical bonds. The PSTs' responses to MB-CK include modeling failure, mainly based on the inability to relate to the concepts of chemical bond type, the octet rule, electron configuration, electrostatic force, electron transfer, and sharing. Moreover, it can be said that the serious lack of knowledge of PSTs on these issues prevents them from presenting a scientific chemical bond model. Teachers cannot teach complex subjects like chemical bonds to their students in a comprehensible and reasonable manner without understanding the models (Joki & Aksela, 2018; Oh & Oh, 2011; Papadouris & Constantinou, 2017). An argument commonly used in the relevant literature is that the better the science teachers' knowledge of the subject is, the better their teaching is (Bergqvist, 2017; Kind, 2009). This is because MB-CK is the basis for the development of teachers' professional knowledge and therefore influences their teaching. (Nixon et al. 2016). The reason why PSTs are inadequate in the MB-CK on chemical bonds can be in the way the subject is taught, textbooks, and other sources in high school (Bergqvist, 2017; Levy Nahum et al., 2013; Sibanda, 2018). This is also supported by Bergqvist (2017). Moreover, it can be said that incomplete and incorrect learning about chemical bonds originating from the teaching style and textbooks prevents students from having effective scientific model knowledge on this subject. Teachers must be familiar with models that not only simplify complex ideas but are also scientifically valid to provide a solid foundation for students' future learning (Nilsson, 2014). It is reported in many studies in the related literature that the students' and the teachers' conceptual misconceptions about model based chemical bonds on electron transfer and sharing are quite common (Bergqvist, 2017; Bergqvist et al., 2013; Eymur & Geban, 2017; Joki & Aksela, 2018). The main reason why the students have less modeling knowledge about chemical bonds can be shown as the inadequacy of model-based explanations made on only a few known chemical bond examples (such as H_2O, CO_2, NaCl, and HCl). The re-teachings on chemical bond models by both teachers and teacher educators at all levels, from secondary school to university education, are made up of memorization based on these compounds. This situation is similar to the textbooks. Textbooks also present ionic and covalent bond models largely based on the compounds described above. However, it can be argued that modeling studies on how and why various chemical bonds occur on different compounds and molecules remain rather weak at all levels of education. This situation causes students and PSTs to have difficulties to model different chemical bonds in terms of electron transfer and electron sharing. Berqouvist (2017) states that this may be due to their tendency to generalize the structure of only a few chemical models, which leads to incorrect modeling information for other chemical compounds. The results of the present study for MB-CK indicate that such a situation is valid. This reveals that PSTs are not sufficiently supported to represent CK on chemical bonds through a model in their pre-professional preparation. It can be thought that this may be teaching based on problem solving and theoretical explanations is preferred rather than model-supported teaching, especially in field education courses. Our result shows that many PSTs have model knowledge and representational understanding that will make it difficult for their students to learn about chemical bonds in the future. It can be stated that PSTs with incorrect chemical bond model knowledge have a lack of professional knowledge that may prevent students from understanding and explaining many chemical formations in nature in the future. In the MB-CK questions of this research, chemical bond models (such as the CO_2 model), which are explained to the students at every stage in science education starting from secondary school to university education, and which are constantly prominent in textbooks, are discussed. Therefore, PSTs' inaccuracies about these more familiar and simple chemical bond models also mean that they have a limited understanding of complex models. This situation needs to be confirmed separately by different research. The PSTs' MB-CK on chemical bonds is shaped by the incorrect modeling information they brought from the past during the undergraduate period. In addition, the fact that teacher educators teach a difficult and complex subject such as chemical bonds for candidates excessively superficially can be a reason for this inadequacy. It should be known that this will cause PSTs both to teach their students wrongly in the future and to be insufficient in overcoming the learning difficulties of the students, and it can be the source of student learning mistakes.

The second result of the study shows that the vast majority of PSTs have remained at the level of weak and have invalid MB-KSU knowledge on chemical bonds to detect inaccuracies in the student model drawings and their sources. According to this result, it can be said that undergraduate education is insufficient to understand the model images of students on the chemical bonds of PSTs. Chemistry is considered a difficult subject for students to learn since the subjects of chemistry are quite abstract. This contributes to the learning difficulties experienced by the students. The way of understanding chemistry is to conceptualize the nature of the chemical bond (Toerien, 2017). Today, many discussions about the awareness of professional knowledge are carried out beyond the subject of KSU which prevents the student from truly learning. If a teacher believes that the causal factors of student failure may be external to the student or that the teacher shares responsibility for the student's failure, he or she must have an adequate understanding of the source of their mislearning or hindering student learning regardless of the student's ability or level of effort (Woodcock et al., 2019). A teacher must understand student knowledge to teach science effectively (Magnusson et al. 1999; Park et al., 2018; Sibanda, 2018). If PSTs develop an in-depth understanding of students' reasoning about chemical bond models and can correctly identify the ideas that the students form, they are more likely to be effective in helping students achieve targeted learning outcomes. De Jong et al. (2005) argue that teaching a particular subject is more effective if the teacher is knowledgeable about the difficulties which the students face to understand the subject. When teachers do not have sufficient knowledge about alternative non-scientific learning of students and the possible sources of this learning, they can lead to weaknesses in the teaching of many following science subjects. This is especially true for chemistry matters. Many subjects in chemistry form the basis for another subject. It can be said that a teacher will not be successful in teaching many chemistry subjects effectively if she has not developed her professional knowledge of students' alternative understandings of chemical bonds.

Chemical bonding is predominantly taught by using models and is a complex subject. Student learning difficulties in chemical bonds are partly due to the inherent complexity of the subject and partly due to the way it is taught by teachers and presented in textbooks (Bergqvist, 2017). Students' understandings of the chemical bond model include describing objects (atoms, electrons, and protons) and both attractive and repulsive forces between objects (Zohar & Levy, 2018). It seems that there may be a lack of opportunities to understand students' failure about chemical bonding models and to capture the possible source of these alternatives and learning difficulties because of the lack of experience of the PSTs in this study. That's because it is known that teachers with more teaching experience have better knowledge to grasp student ideas. In this research, it is more meaningful to discuss the MB-KSU deficiencies of many of the PSTs in the context of the quality of their undergraduate education. Supporting the students to understand the nature of models as part of an understanding of the nature of science can be seen as an important goal of science education (Gogolin & Krüger, 2017). We are disappointed that many PSTs could not identify students' difficulties in understanding chemical bond models and possible sources of these difficulties in the most basic bond model questions. For instance, many PSTs have been quite inadequate about what kind of incorrect information the students have and what the source of this information is even in the question of a chemical bond model that they have learned since middle school such as the CO2 compound. Most of the PSTs are insufficient in reporting the alternative ideas and sources of the students regarding the concepts of covalent bonds, ionic bonds, the octet rule, electron configuration, electrostatic force, electron transfer, and sharing in each MB-KSU question in the test. De Jong and Taber (2014) summarize the students' conceptual difficulties in three interrelated factors: "the student factor", "the chemistry content factor" and "teacher/textbook factor". They argue that the student factor relates to the students' existing concepts often deeply ingrained in their daily lives. The chemistry content factor relates to the students' lack of knowledge of models as representations, and the teacher/textbook factor relates to the fact that teachers tend to use professional language in classrooms, and textbook authors are not always aware of students' alternative concepts (Schultze, 2018). Students' model knowledge of chemical bonds can be explained by the factor originating from both the teacher and the textbooks (Bergqvist, 2017; Levy Nahum et al., 2013). For example, the sort of different types of bonds, the use of the octet rule and excessive focus on electronic configurations, the inability to explain why bonds occur, and the tendency to present ionic and covalent bonds as a contradiction, (Taber & Coll, 2002). The most important reason for this situation can be explained by the fact that PSTs have insufficient subject knowledge about chemical bonds, and they have alternative ideas on this subject. This result has also been reported by other studies in the related literature (Bergqvist et al., 2016; Vladušić et al., 2016). Advanced subject matter knowledge is seen as a prerequisite for teaching a subject as a component of teacher professional knowledge (Rollnick & Mavhunga, 2016). Therefore, subject area knowledge is central and important. If this knowledge structure of teachers and PSTs is not sufficiently developed, the development of other professional knowledge components will also be inadequate (McConnell et al., 2013; Murphy & Smith, 2012). The related literature draws attention to the fact that PSTs can be considered subject experts since they have just completed their undergraduate education and that students should not have difficulty identifying their inadequacy in chemical bond models (Toerien, 2017). Hence, MB-CK inadequacies of PSTs, which have emerged in the first finding of our study, can be seen as the most important factor that fosters MB-KSU deficiencies. Accordingly, the relevant literature emphasizes that KSU and CK are key components to shaping the PCK structure that represents teachers' professional knowledge (De Jong et al., 2005; Gess-Newsome, 2015; Park & Chen, 2012).

Our results show that both PCK components must be improved and the two components must be linked. Furthermore, it can be said that PSTs are not adequately supported by teacher educators with appropriate pedagogical skills in addressing student understanding of chemical bonds based on the result of the research. Moreover, PSTs do not have enough awareness of the importance of using models for chemical bonds in student learning. During the undergraduate period, PSTs learn the subject of chemical bonds in chemistry courses mostly through the theoretical definitions of the teacher educator and problem solving. Lewis or Shell model for chemical bonds may be limited in this process. However, when professional knowledge courses are considered, the studies that will make PSTs understand the importance of model-based learning processes such as chemical bonds, or examine student learning on this subject are quite limited. We can say that most of the PSTs in the preparatory period go through an insufficient process in understanding the nature and purpose of chemical bond models. Moreover, it can be said that both the education of PSTs in the faculty and school internship practices are far from a professional knowledge structuring of student understanding and questioning students' model understanding.

This finding is reflected in the results of the research. They should question the student's background knowledge and the knowledge structures they will form during teaching and evaluate the sources behind these thoughts for PSTs to carry out the model-based teaching of chemical bonding for students in the most effective way in the future. PSTs with this professional knowledge can only develop the right pedagogical skills to reveal and correct the problematic information about student models. In addition, the result of our research shows that teacher educators pay less attention to the confusion or alternative ideas of students on this subject in the future when they teach about chemical bonds. This may be an indication that teacher educators do not view their students' daily experiences and related potential confusions as important in the planning phase of an instructional process when PSTs plan their lessons in the future (Schultze & Nilsson, 2018). Diagnosing students' understanding of models and modeling poses a major challenge for teachers as it requires both effective assessment and valid interpretation of diagnostic information. It emphasizes that teachers should attend teacher training courses based on student understanding knowledge to develop their understanding of modeling, and to prepare future teachers with relevant skills and diagnostic information about their students' understanding of models to overcome this challenge (Gogolin & Krüger, 2017). Bergqvist et al. (2016) emphasize that teachers should be aware of; how models are presented; which model representations may be the source of students' learning difficulties; and the nature of the models and their relevant purposes. As the PSTs' experience in model-based learning of students on chemical bonds in vocational preparation increases, they will be able to identify many factors that cause students' failure in this subject and comprehend the most effective pedagogical ways of how they can contribute to students' success. After gaining this knowledge and skills, PSTs will be able to more consciously guide their students' understanding of the importance, nature, and epistemological status of chemical bond concepts and models.

Conclusion

This research provides important evidence of model-based teaching understandings that PSTs can provide the students to regard chemical bond models in the future. Our results indicate that the majority of PSTs have very insufficient model-based professional knowledge of chemical bonds, which is a special and difficult subject in the secondary school science curriculum in Turkey. In particular, many of the PSTs are unaware of how chemical bond models can contribute to students' comprehension difficulties. Our results reveal the need for professional development of PSTs in terms of both content and understanding of the subject of chemical bonds. It can be said that a science teacher's ability to evaluate the student model is closely related to the content knowledge he or she has on that subject. Therefore, as PSTs gain experience in questioning student models on chemical bonds during the undergraduate period, they may become more conscious of what alternative concepts and ideas the model creator (student) might have about chemical bonding. Bergqvist, Drechsler, and Chang Rundgren (2016) emphasize that opportunities should be created for teachers to explore students' understanding of chemical bonds and then select appropriate representations to help students understand the subject. Diagnosing PSTs' understanding of both their models and student models supports improving their professional preparation and developing their understanding of science. Therefore, PSTs' critical approach and questioning of student models can be seen as an important step to reduce the inadequacies in the teaching of chemical bond subjects in the future. Thus, PSTs can use appropriate models for their students to learn chemical bonds in the future. The students can only understand the difficult and complex scientific language of chemical bonds and easily reach the desired learning goals in this regard. If PSTs are expected to provide more effective model-based teaching on chemical bonds in their classrooms in the future, there is a need for studies in which they will comprehend both their model-based subject knowledge and student learning mistakes related to the models during the preparation process. This can be done by changing the content of chemistry field education courses in teacher education and the practices of teacher educators.

Implications

In the light of our evaluation findings regarding the model-based knowledge of PSTs on chemical bonds, we offer the following suggestions: Teacher educators should encourage PSTs to create their own models of chemical bonds. In addition, educators should create more opportunities for PSTs to evaluate student models. This will enable PSTs to recognize the insufficiencies and unscientific images in their model knowledge, as well as to predict models that will make it difficult for students to learn, and to become familiar with the mistakes in student models. Only 229 PSTs have participated in this research. The limited number of participants and the tests prevent broad generalizations. Therefore, this study should be supported with more participants and interviews on model-based teaching. Awareness of PSTs should be increased on subjects such as past learning and model examples in textbooks, which are seen as the source of students' mistakes in chemical bond models.

References

Akaygun, S. (2016). Is the oxygen atom static or dynamic? The effect of generating animations on students' mental models of atomic structure. *Chemistry Education Research and* Practice, *17*(4), 788-807. https://doi.org/10.1039/C6RP00067C

Akkuş, H., Tüzün, Ü. N., & Eyceyurt, G. (2013). Determining students' images and misconceptions about covalent bonds. *Ahi Evran University Journal of Kırşehir Education Faculty, 14*(1), 287-303.

Anderson, D., & Clark, M. (2012). Development of syntactic subject matter knowledge and pedagogical content knowledge for science by a generalist elementary teacher. *Teachers and Teaching*, *18*(3), 315-330. https://doi.org/10.1080/13540602.2012.629838

Barendsen, E., & Henze, I. (2019). Relating teacher PCK and teacher practice using classroom observation. *Research in Science Education*, *49*(5), 1141-1175. https://doi.org/10.1007/s11165-017-9637-z

Becerra, B., Núñez, P., Vergara, C., Santibáñez, D., Krüger, D., & Cofré, H. (2022). Developing an instrument to assess pedagogical content knowledge for evolution. *Research in Science Education*, 1-17. https://doi.org/10.1007/s11165-022-10042-0

Bergqvist, A. (2017). *Teaching and learning of chemical bonding models: Aspects of textbooks, students' understanding and teachers' professional knowledge* (Doctoral dissertation, Karlstads universitet).

Bergqvist, A., & Chang Rundgren, S. N. (2017). The influence of textbooks on teachers' knowledge of chemical bonding representations relative to students' difficulties understanding. *Research in Science & Technological Education, 35*(2), 215-237. https://doi.org/10.1080/02635143.2017.1295934

Bergqvist, A., Drechsler, M., & Chang Rundgren, S. N. (2016). Upper secondary teachers' knowledge for teaching chemical bonding models. *International Journal of Science Education*, *38*(2), 298-318.

https://doi.org/10.1080/09500693.2015.1125034

Bergqvist, A., Drechsler, M., De Jong, O., & Rundgren, S. C. (2013). Representations of chemical bonding models in school textbooks—Help or hindrance for understanding? *Chemistry Education Research and Practice, 14*(4), 589–606. https://doi.org/10.1039/C3RP20159G

Berry, A., Friedrichsen, P. J., & Loughran, J. (Eds.). (2015). *Re-examining pedagogical content knowledge in science education* (pp. 28-42). Routledge.

Bland, D. (2018). Using drawing in research with children: lessons from practice. *International Journal of Research & Method in Education, 41*(3), 342-352. https://doi.org/10.1080/1743727X.2017.1307957

Campbell, T., & Fazio, X. (2020). Epistemic frames as an analytical framework for understanding the representation of scientific activity in a modeling-based learning unit. *Research in Science Education, 50*(6), 2283-2304. https://doi.org/10.1007/s11165-018-9779-7

Chan, K. K. H., Rollnick, M., & Gess-Newsome, J. (2019). A grand rubric for measuring science teachers' pedagogical content knowledge. In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 253-271). Springer.

Chan, K. K. H., & Yung, B. H. W. (2018). Developing pedagogical content knowledge for teaching a new topic: More than teaching experience and subject matter knowledge. *Research in Science Education*, *48*(2), 233-265. https://doi.org/10.1007/s11165-016-9567-1

Cheng, M. F., & Lin, J. L. (2015). Investigating the relationship between students' views of scientific models and their development of models. *International Journal of Science Education*, *37*(15), 2453-2475. https://doi.org/10.1080/09500693.2015.1082671

Clement, J. (2000). Model based learning as a key research area for science education. *International Journal of Science Education*, *22*(9), 1041-1053. https://doi.org/10.1080/095006900416901

Coll, R. K., & Lajium, D. (2011). Modeling and the future of science learning. In *Models and modeling* (pp. 3-21). Springer.

Coll, R. K., & Treagust, D. F. (2003). Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching*, *40*(5), 464–486. https://doi.org/10.1002/tea.10085

Cokadar, H. (2006). Chemical bonds. In H. Bag (Ed.), *General Chemistry I* (pp. 139-164). Pegem Publishing

Coetzee, C., Rollnick, M., & Gaigher, E. (2020). Teaching electromagnetism for the first time: A case study of pre-service science teachers' enacted pedagogical content knowledge. *Research in Science Education*, *52*, 357–378. https://doi.org/10.1007/s11165-020-09948-4

Czerniak, C., & Chiarelott, L. (1999). Teacher education for effective science instruction—A social cognitive perspective. *Journal of Teacher Education, 41*(1), 49–58. https://doi.org/10.1177/00224871900410010

De Jong, O., & Taber, K. S. (2014). The many faces of high school chemistry. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (pp. 457–480). Routledge.

De Jong, O., Van Driel, J. H., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching*, *42*(8), 947-964. https://doi.org/10.1002/tea.20078

Dhindsa, H. S., & Treagust, D. F. (2014). Prospective pedagogy for teaching chemical bonding for smart and sustainable learning. *Chemistry Education Research and Practice, 15*(4), 435-446.

https://doi.org/10.1039/C4RP00059E

Evens, M., Elen, J., Larmuseau, C., & Depaepe, F. (2018). Promoting the development of teacher professional knowledge: Integrating content and pedagogy in teacher education. *Teaching and Teacher Education, 75*, 244-258. https://doi.org/10.1016/j.tate.2018.07.001

Eymur, G., & Geban, Ö. (2017). The collaboration of cooperative learning and conceptual change: Enhancing the students' understanding of chemical bonding concepts. *International Journal of Science and Mathematics Education, 15*(5), 853-871. https://doi.org/10.1007/s10763-016-9716-z

Fadillah, A., & Salirawati, D. (2018, October). Analysis of misconceptions of chemical bonding among tenth grade senior high school students using a two-tier test. *In AIP Conference Proceedings* (Vol. 2021, No. 1, p. 080002). AIP Publishing LLC.

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

Gess-Newsome, J., Taylor, J. A., Carlson, J., Gardner, A. L., Wilson, C. D., & Stuhlsatz, M. A. (2019). Teacher pedagogical content knowledge, practice, and student achievement. *International Journal of Science Education, 41*(7), 944-963. https://doi.org/10.1080/09500693.2016.1265158

Gilbert, J. K., & Boulter, C. J. (Eds.) (2000). *Developing models in science education*. Kluwer Academic.

Gogolin, S., & Krüger, D. (2017). Diagnosing students' understanding of the nature of models. *Research in Science Education*, *47*(5), 1127-1149. https://doi.org/10.1007/s11165-016-9551-9

Greca, I. M., & Moreira, M. A. (2002). Mental, physical, and mathematical models in the teaching and learning of physics. *Science Education, 86*(1), 106-121. https://doi.org/10.1002/sce.10013

Grünkorn, J., zu Belzen, A. U., & Krüger, D. (2014). Assessing students' understandings of biological models and their use in science to evaluate a theoretical framework. *International Journal of Science Education, 36*(10), 1651-1684. https://doi.org/10.1080/09500693.2013.873155

Harrison, A. G. (2001). How do teachers and textbook writers model scientific ideas for students?. *Research in Science Education, 31*(3), 401-435. https://doi.org/10.1023/A:1013120312331

Heller, J. I., Daehler, K. R., Shinohara, M., & Kaskowitz, S. R. (2004). *Fostering pedagogical content knowledge about electric circuits through case-based professional development*. Paper presented at the annual meeting of the National Association for Research on Science Teaching, Vancouver, B.C., Canada.

Henze, I., & van Driel, J. H. (2011). Science teachers' knowledge about learning and teaching models and modeling in public understanding of science. In *Models and modeling* (pp. 239-261). Springer.

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. https://doi.org/10.1080/09500690802187017

Higher Education Institution (2018). Science teaching undergraduate program. https://www.yok.gov.tr/Documents/Kurumsal/egitim_ogretim_dairesi/Yeni-Ogretmen-Yetistirme-Lisans-Programlari/Fen_Bilgisi_Ogretmenligi_Lisans_Programi.pdf

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education, 36*(15), 2534-2553. https://doi.org/10.1080/09500693.2014.899722

Hsieh, W. M., & Tsai, C. C. (2018). Learning illustrated: An exploratory cross-sectional drawing analysis of students' conceptions of learning. *The Journal of Educational Research, 111*(2), 139-150. https://doi.org/10.1080/00220671.2016.1220357

Joki, J., & Aksela, M. (2018). The challenges of learning and teaching chemical bonding at different school levels using electrostatic interactions instead of the octet rule as a teaching model. *Chemistry Education Research and Practice, 19*(3), 932-953. https://doi.org/10.1039/C8RP00110C

Justi, R. S., & Gilbert, J. K. (2002). Science teachers' knowledge about and attitudes towards the use of models and modelling in learning science. *International Journal of Science Education*, *24*(12), 1273-1292. https://doi.org/10.1080/09500690210163198

Jüttner, M., Boone, W., Park, S., & Neuhaus, B. J. (2013). Development and use of a test instrument to measure biology teachers' content knowledge (CK) and pedagogical content knowledge (PCK). *Educational Assessment, Evaluation and Accountability, 25*(1), 45-67. https://doi.org/10.1007/s11092-013-9157-y

Jüttner, M., & Neuhaus, B. J. (2012). Development of items for a pedagogical content knowledge test based on empirical analysis of pupils' errors. *International Journal of Science Education, 34*(7), 1125-1143. https://doi.org/10.1080/09500693.2011.606511

Kaberman, Z., & Dori, Y. J. (2009). Metacognition in chemical education: Question posing in the case based computerized learning environment. *Instructional Science, 37*, 403–436. https://doi.org/10.1007/s11251-008-9054-9

Käpylä, M., Heikkinnen, J.-P., & 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. https://doi.org/10.1080/09500690802082168

Kaya, Z., Kaya, O. N., Aydemir, S., & Ebenezer, J. (2022). Knowledge of student learning difficulties as a plausible conceptual change pathway between content knowledge and pedagogical content knowledge. *Research in Science Education*, *52*(2), 691-723. https://doi.org/10.1007/s11165-020-09971-5

Kellogg, M. S. (2010). *Preservice elementary teachers' pedagogical content knowledge related to area and perimeter: A teacher development experiment investigating anchored instruction with web-based microworlds* (Publication No. 3424398) [Doctoral dissertation, University of South Florida]. ProQuest Dissertations Publishing.

Kenyon, L., Davis, E. A., & Hug, B. (2011). Design approaches to support preservice teachers in scientific modeling. *Journal of Science Teacher Education*, *22*(1), 1-21. https://doi.org/10.1007/s10972-010-9225-9

Krell, M., Upmeier zu Belzen, A., & Krüger, D. (2014). Students' levels of understanding models and modelling in biology: Global or aspect-dependent?. *Research in Science Education, 44*(1), 109-132. https://doi.org/10.1007/s11165-013-9365-y

Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in Science Education*, *45*(2), 169-204. https://doi.org/10.1080/03057260903142285

Kind, V. (2014). A degree is not enough: A quantitative study of aspects of pre-service science teachers' chemistry content knowledge. *International Journal of Science Education, 36*(8), 1313-1345. https://doi.org/10.1080/09500693.2013.860497

Lagowski, J. J. (Ed.). (1997). *Macmillan encyclopedia of chemistry*: Vol. 3. New York, NY: Macmillan Reference

USA.

Lee, S. W. Y. (2018). Identifying the item hierarchy and charting the progression across grade levels: Surveying Taiwanese students' understanding of scientific models and modeling. *International Journal of Science and Mathematics Education*, *16*(8), 1409-1430. https://doi.org/10.1007/s10763-017-9854-y

Levy Nahum, T.., Mamlok-Naaman, R., & Hofstein, A. (2013). Teaching and learning of the chemical bonding concept: Problems and some pedagogical issues and recommendations. In *Concepts of matter in science education* (pp. 373-390). Springer.

Levy Nahum, T., Mamlok-Naaman, R., Hofstein, A., & Taber, K. S. (2010). Teaching and learning the concept of chemical bonding. *Studies in Science Education*, *46*(2), 179-207. https://doi.org/10.1080/03057267.2010.504548

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* (pp. 95–132). Dordrecht: Kluwer

McConnell, T. J., Parker, J. M., & Eberhardt, J. (2013). Assessing teachers' science content knowledge: A strategy for assessing depth of understanding. *Journal of Science Teacher Education*, *24*(4), 717-743. https://doi.org/10.1007/s10972-013-9342-3

Mendonça, P. C. C., & Justi, R. (2011). Contributions of the model of modelling diagram to the learning of ionic bonding: Analysis of a case study. *Research in Science Education*, 41(4), 479-503. https://doi.org/10.1007/s11165-010-9176-3

Mesci, G., Schwartz, R. S., & Pleasants, B. A. S. (2020). Enabling factors of preservice science teachers' pedagogical content knowledge for nature of science and nature of scientific inquiry. *Science & Education*, *29*(2), 263-297. https://doi.org/10.1007/s11191-019-00090-w

Ministry of Education [ME]. (2018). *Science course curriculum (Primary and secondary school grades 3, 4, 5, 6, 7 and 8.).* State Books Printing House

Moodley, K., & Gaigher, E. (2019). Teaching electric circuits: Teachers' perceptions and learners' misconceptions. *Research in Science Education*, *49*(1), 73-89. https://doi.org/10.1007/s11165-017-9615-5

Murphy, C. & Smith, G. (2012). The impact of a curriculum course on pre-service primary teachers' science content knowledge and attitudes towards teaching science. *Irish Educational Studies*, *31*(1), 77-95. https://doi.org/10.1080/03323315.2011.634061

Naah, B. M. (2015). Enhancing preservice teachers' understanding of students' misconceptions in learning chemistry. *Journal of College Science Teaching*, *45*(2), 41-47.

Namdar, B., & Shen, J. (2015). Modeling-oriented assessment in K-12 science education: A synthesis of research from 1980 to 2013 and new directions. *International Journal of Science Education, 37*(7), 993-1023. https://doi.org/10.1080/09500693.2015.1012185

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

Nelson, M. M., & Davis, E. A. (2012). Preservice Elementary Teachers' Evaluations of Elementary Students' Scientific Models: An aspect of pedagogical content knowledge for scientific modeling. *International Journal of Science Education*, *34*(12), 1931-1959. https://doi.org/10.1080/09500693.2011.594103

NGSS Lead States (2013). Next generation science standards: For states by states. Achieve, Inc. Retrieved from: http://www. nextgenscience.org/next-generationscience-standards.

Nicolaou, C. T., & Constantinou, C. P. (2014). Assessment of the modeling competence: A systematic review and synthesis of empirical research. *Educational Research Review, 13*, 52-73. https://doi.org/10.1016/j.edurev.2014.10.001

Nilsson, P. (2014). When teaching makes a difference: Developing science teachers' pedagogical content knowledge through learning study. *International Journal of Science Education*, *36*(11), 1794-1814. https://doi.org/10.1080/09500693.2013.879621

Nixon, R. S., Campbell, B. K., & Luft, J. A. (2016). Effects of subject-area degree and classroom experience on new chemistry teachers' subject matter knowledge. *International Journal of Science Education*, *38*(10), 1636-1654. https://doi.org/10.1080/09500693.2016.1204482

Nowak, K. H., Nehring, A., Tiemann, R., & Upmeier zu Belzen, A. (2013). Assessing students' abilities in processes of scientific inquiry in biology using a paper-and-pencil test. *Journal of Biological Education, 47*(3), 182-188. https://doi.org/10.1080/00219266.2013.822747

Oh, P. S., & Oh, S. J. (2011). What teachers of science need to know about models: An overview. *International Journal of Science Education*, *33*(8), 1109-1130. https://doi.org/10.1080/09500693.2010.502191

Ortiz, C. B. (2019). Students'understanding of pre-organic chemistry concepts: chemical bonding. *International Journal on Language, Research and Education Studies*, *3*(1), 33-42.

Othman, J., Treagust, D. F., & Chandrasegaran, A. L. (2008). An investigation into the relationship between students' conceptions of the particulate nature of matter and their understanding of chemical bonding. *International Journal of Science Education, 30*(11), 1531-1550. https://doi.org/10.1080/09500690701459897

Oversby, J. (2000). Models in explanations of chemistry: The case of acidity. In *Developing models in science education* (pp. 227-251). Springer, Dordrecht.

Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology*, *13*(2), 147-159. https://doi.org/10.1023/B:JOST.0000031255.92943.6d

Papadouris, N., & Constantinou, C. P. (2017). Integrating the epistemic and ontological aspects of content knowledge in science teaching and learning. *International Journal of Science Education*, *39*(6), 663-682. https://doi.org/10.1080/09500693.2017.1299950

Pluta, W. J., Chinn, C. A., & Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching*, *48*(5), 486-511. https://doi.org/10.1002/tea.20415

Park, S., & Chen, Y. C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Teaching*, *49*(7), 922-941. https://doi.org/10.1002/tea.21022

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*(3), 261-284. https://doi.org/10.1007/s11165-007-9049-6

Park, S., Suh, J., & Seo, K. (2018). Development and validation of measures of secondary science teachers' PCK for teaching photosynthesis. *Research in Science Education*, *48*(3), 549-573.

https://doi.org/10.1007/s11165-016-9578-y

Passmore, C., Gouvea, J. S., & Giere, R. (2014). Models in science and in learning science: Focusing scientific practice on sense-making. In *International handbook of research in history, philosophy and science teaching* (pp. 1171-1202). Springer, Dordrecht.

Patton, M. Q. (2002). Two decades of developments in qualitative inquiry: A personal, experiential perspective. *Qualitative Social Work*, *1*(3), 261-283. https://doi.org/10.1177/1473325002001003636

Rollnick, M., & Mavhunga, E. (2016). The place of subject matter knowledge in teacher education. In J. Loughran & M. L. Hamilton (Eds.), *International handbook of teacher education* (pp. 423–452). Springer.

Quillin, K., & Thomas, S. (2015). Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. *CBE Life Sciences Education*, *14*(1), 1–16. https://doi.org/10.1187/cbe.14-08-0128

Sarawan, S., & Yuenyong, C. (2018, January). Thai students' mental model of chemical bonding. *In AIP Conference Proceedings* (Vol. 1923, No. 1, p. 030042). AIP Publishing LLC.

Schmelzing, S., van Driel, J., Jüttner, M., Brandenbusch, S., Sandmann, A., & Neuhaus, B.J. (2013). Development, evaluation, and validation of a paper-and-pencil test for measuring two components of biology teachers' pedagogical content knowledge concerning the "cardiovascular system". *International Journal of Science and Mathematics Education*, *11*(6), 1369-1390. https://doi.org/10.1007/s10763-012-9384-6

Schwarz, C. (2009). Developing preservice elementary teachers' knowledge and practices through modeling-centered scientific inquiry. *Science Education*, *93*(4), 720-744. https://doi.org/10.1002/sce.20324

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., … Krajcik, J. (2009). Developing learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632–654. https://doi.org/10.1002/tea.20311

Schultze, F. (2018*). Coteaching chemical bonding with Upper secondary senior students: A way to refine teachers PCK* (Vol. 104). Linköping University Electronic Press.

Schultze, F., & Nilsson, P. (2018). Coteaching with senior students–a way to refine teachers' PCK for teaching chemical bonding in upper secondary school. *International Journal of Science Education*, *40*(6), 688-706. https://doi.org/10.1080/09500693.2018.1436792

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Sibanda, D. (2018). What sequence do we follow in teaching concepts in chemistry? A study of high school physical science teachers' PCK. *African Journal of Research in Mathematics, Science and Technology Education, 22*(2), 196-208.

Sibanda, D., & Hobden, P. (2015). Planning a teaching sequence for the teaching of chemical bonding. *African Journal of Research in Mathematics, Science and Technology Education, 19*(1), 23-33.

Silberberg, M. S. (2003). *Chemistry: The molecular nature of matter and change*. New York, NY: McGraw-Hill Higher Education.

Taber, K. S. (2011). Models, molecules and misconceptions: a commentary on secondary school students' misconceptions of covalent bonding. *Journal of Turkish Science Education, 8*(1), 3-18.

Taber, K. S., & Coll, R. K. (2002). Bonding. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust & J. H. Van Driel (Eds.), *Chemical education: Towards a research-based practice* (pp. 213–234). The Netherlands:

Kluwer Academic Publishers

Taber, K. S., Tsaparlis, G., & Nakiboğlu, C. (2012). Student conceptions of ionic bonding: Patterns of thinking across three European contexts. *International Journal of Science Education, 34*(18), 2843-2873. https://doi.org/10.1080/09500693.2012.656150

Tan, K. C., & Treagust, D. (1999). Evaluating students' understanding of chemical bonding. *School Science Review, 81*, 75– 84.

Taskin, V., Bernholt, S., & Parchmann, I. (2017). Student teachers' knowledge about chemical representations. *International Journal of Science and Mathematics Education, 15*(1), 39-55. https://doi.org/10.1007/s10763-015-9672-z

Toerien, R. (2017). *Mapping the learning trajectories of physical sciences teachers' topic specific knowledge for teaching chemical bonding* (PhD). University of Cape Town, Cape Town.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education*, *24*(4), 357-368. https://doi.org/10.1080/09500690110066485

Tsaparlis, G., Pappa, E. T., & Byers, B. (2020). Proposed pedagogies for teaching and learning chemical bonding in secondary education. *Chemistry Teacher International*, *2*(1). https://doi.org/10.1515/cti-2019-0002

Upmeier zu Belzen, A. (2013). Modelle [Models]. In H. Großengießer, U. Harms, & U. Kattmann (Eds.), *Fachdidaktik Biologie [Biology education]* (pp. 325–334). Freising: Aulis Verlag.

Upmeier zu Belzen, A., & Krüger, D. (2010). Modellkompetenz im Biologieunterricht [Model competence in biology education]. *Zeitschrift für Didaktik der Naturwissenschaften*, 16, 41–57. Retrieved from http:// www.ipn.uni-kiel.de/zfdn/jg16.htm

Ünal, S., Çalık, M., Ayas, A., & Coll, R. K. (2006). A review of chemical bonding studies: needs, aims, methods of exploring students' conceptions, general knowledge claims and students' alternative conceptions. *Research in Science & Technological Education, 24*(2), 141-172. https://doi.org/10.1080/02635140600811536

Vladušić, R., Bucat, R. B., & Ožić, M. (2016). Understanding ionic bonding–a scan across the Croatian education system. *Chemistry Education Research and Practice*, *17*(4), 685-699. https://doi.org/10.1039/C6RP00040A

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science*, *18*, 123-183.

Vrabec, M., & Prokša, M. (2016). Identifying misconceptions related to chemical bonding concepts in the Slovak school system using the bonding representations inventory as a diagnostic tool. *Journal of Chemical Education*, *93*(8), 1364-1370. https://doi.org/10.1021/acs.jchemed.5b00953

Wang, Z., Chi, S., Hu, K., & Chen, W. (2014). Chemistry teachers' knowledge and application of models. *Journal of Science Education and Technology, 23*(2), 211-226. https://doi.org/10.1007/s10956-013-9455-7

Werner, S., Förtsch, C., Boone, W., Von Kotzebue, L., & Neuhaus, B. J. (2019). Investigating how German biology teachers use three-dimensional physical models in classroom instruction: a video study. *Research in Science Education*, *49*(2), 437-463. https://doi.org/10.1007/s11165-017-9624-4

Windschitl, M., & Calabrese Barton, A. (2016). Rigor and equity by design: Seeking a core of practices for the science education community. In Gitomer, D., Bell, C. (Eds.), *AERA handbook of research on teaching* (5th ed., pp. 1099-1158). Washington, DC: AERA Press.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941-967. https://doi.org/10.1002/sce.20259

Woodcock, S., Hitches, E., & Jones, G. (2019). It's not you, it's me: Teachers' self-efficacy and attributional beliefs towards students with specific learning difficulties. *International Journal of Educational Research*, *97*, 107-118. https://doi.org/10.1016/j.ijer.2019.07.007

Yeh, H. Y., Tsai, Y. H., Tsai, C. C., & Chang, H. Y. (2019). Investigating students' conceptions of technology-assisted science learning: a drawing analysis. *Journal of Science Education and Technology, 28*(4), 329-340. https://doi.org/10.1007/s10956-019-9769-1

Yin, R. K. (2003). *Case study research: Design and methods* (3rd ed.). Thousand Oaks, CA: Sage

Zohar, A. R., & Levy, S. T. (2019). Attraction vs. repulsion–learning about forces and energy in chemical bonding with the ELI-Chem simulation. *Chemistry Education Research and Practice, 20*(4), 667-684. https://doi.org/10.1039/C9RP00007K

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Appendix A. Chemical Bonds Model Knowledge Test (CBMKT)

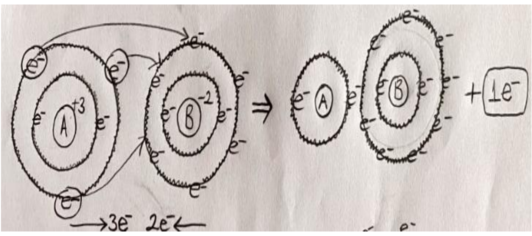
This test consists of two parts. Bunlar: (1) the questions to determine the MB-CK of PSTs on chemical bonds and (2) the questions to determine the MB-KSU of PSTs on "Chemical Bonds" of secondary school students. There are five questions with two separate sections to measure each PST's MB-CK and MB-KSU in this context below.

Section 1: MB-CK Questions

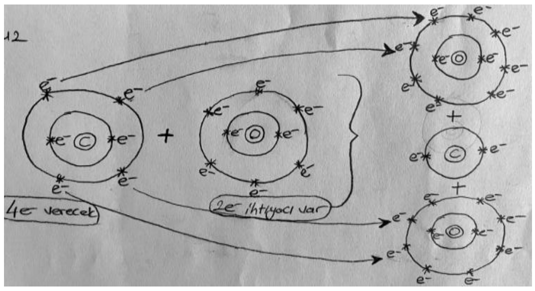
Q1a. What kind of chemical bond is formed between the A^{+3} and B^{-2} ions? Draw the model.
Q2a. What is the chemical bond model in the formation of the CO_2 compound? Draw the model.
Q3a. What is the chemical bond pattern that will form between $_{12}X$ and $_{9}Y$ elements? Draw the model.
Q4a. What is the chemical bond model that forms the OF_2 compound? Draw the model.
Q5a. What is the chemical bond model that will form between $_{12}Mg$ and $_{17}Cl$ elements? Draw the model.

Section 2: MB-KSU Questions

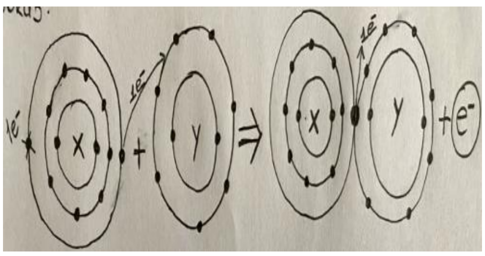
Q1b. There is the chemical bond model formed by a student between A^{+3} B^{-2} ions in his/her chemistry course below. What do you think about the models drawn by the student and their ideas? So, how is the student's learning about a chemical bond model between A^{+3} B^{-2} ions? Please explain.



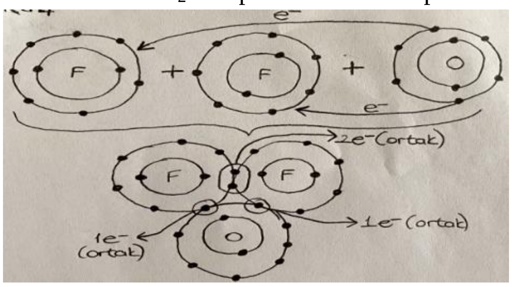
Q2b. There is a model of the chemical bond that a student has created for the CO_2 compound in a chemistry course below. What do you think about the models drawn by the student and their ideas? So, how is the student's learning about the chemical bond model in the formation of CO_2 compound? Please explain.



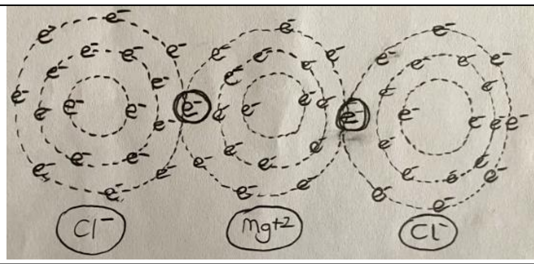
Q3b. There is the chemical bond model created by a student between $_{12}X$ and $_{9}Y$ elements in chemistry course below. What do you think about the models drawn by the student and their ideas? So, how is the student's learning about a chemical bond model between $_{12}X$ and $_{9}Y$ elements? Please explain.



Q4b. There is a model of the chemical bond that a student has created for the OF_2 compound in a chemistry course. What do you think about the models drawn by the student and their ideas? So, how is the student's learning about the chemical bond model in the formation of the OF_2 compound? Please explain.



Q5b. There is the chemical bond model that a student has created between the elements $_{12}Mg$ and $_{17}Cl$ in her/his chemistry course. What do you think about the models drawn by the student and their ideas? So, how is the student's learning about a model of chemical bond between the elements $_{12}Mg$ and $_{17}Cl$? Please explain.



Appendix B. Rubrics

Model Based-Content Knowledge (MB-CK) Rubric

Categories of PSTs' Model Answers	The MB-CK Criteria PST model…
Right Model	▪ It shows a complete and correct harmony in terms of verbal and visual / symbolic aspects. The model represents a scientifically correct understanding. The octet rule and electron configuration have been correctly applied. It accurately represents electron transfer or electron sharing. The type of chemical bond (ionic, covalent and metallic) is evident. It's a scientific drawing.
Wrong Model	▪ It does not show a complete and correct harmony in terms of verbal and visual / symbolic aspects. The model contains many errors. An unscientific drawing.
No Model Represantation	▪ Null (it has been left blank)

Model Based-Knowledge of Students' Understanding (MB-KSU) Rubric

Level	The MB-KSU Criteria PST 's answer...
Examplary identification	▪ A completely correct and well-explained interpretation: It reveals a complete detection of errors in the student model. ▪ It clearly reveals the sources of errors in the student's model. ▪ The student identifies precisely the errors related to the octet rule or electron configuration. ▪ It accurately detects errors in the student model of electron transfer or electron sharing. ▪ Correctly detects the students' theoretical knowledge errors of the type of chemical bond.
Accetable identification	▪ A mostly correct and conceptually based interpretation: Provides an adequate view of the detection of errors in the student model.
Weak identification	▪ It reveals a partial understanding of the errors in the student model. In other words, it reveals an insufficient detection of the student's model errors. Student's model errors could not describe well conceptually.
Invalid/Missed identification	▪ It cannot provide any correct explanation for the errors in the student model. Or it has been left blank.