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The Analysis of Prospective Chemistry Teachers' Cognitive Structure: The Subject of Covalent and Ionic Bonding

Senar Temel & Özgür Özcan
Hacettepe University, TURKEY

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This study aims to analyse prospective chemistry teachers' cognitive structure related to the subject of covalent and ionic bonding. Semi-structured interviews were conducted with the participants in order to determine their cognitive structure, and the interviews were audio recorded to prevent the loss of data. The data were transcribed and transferred into the computer medium. Furthermore, a flow map was prepared for each prospective chemistry teacher and then was analysed firstly in terms of quantitative variables used in presenting cognitive structure in quantitative statements. Secondly, the statements in the flow maps were analysed in terms of comprehension level. In consequence, it was found through flow maps that prospective chemistry teachers were not very different from each other in terms of cognitive structure and that their cognitive structures were full of inadequacies and misconceptions. Having analysed the statements in the flow maps in terms of the levels of comprehension, the scope and richness of prospective chemistry teachers' cognitive structures were exhibited in more details.

Keywords: cognitive structure, covalent bonding, flow map, ionic bonding, and comprehension level

INTRODUCTION

Due to the fact that chemistry is a science containing abstract topics and concepts (Burrows & Mooring, 2015), students have difficulty in understanding the concepts and the principles of chemistry. Below the difficulties are listed by Pendley, Bretz and Novak (1994):

1. Students rely on learning by memorisation instead of understanding the topics,
2. Students are not aware of the key concepts and the relations between the concepts necessary for understanding the topics,
3. As a result of the failures of education in regards to presenting the key concepts and the relations between those concepts to students, they seem

Correspondence: Özgür Özcan,
Hacettepe University, Department of Secondary Science and Mathematics Education, 06800, Beytepe, Ankara, Turkey.
E-mail: ozcano@hacettepe.edu.tr

incomprehensible to students.

Considering these problems, comprehending the subjects and concepts of chemistry requires that students understand the related concepts and ideas, which in turn, develops compatible and consistent knowledge structures (Burrows & Mooring, 2015). In other words, students need to prefer meaningful learning instead of rote learning so that they can build a well-organised conceptual framework, because meaningful learning necessitates them to set up conceptual ties between current knowledge and new knowledge presented to them (Ausubel, 1968). Learning new material becomes difficult if students have inadequacies in comprehension (Taber & Coll, 2003). At this point, students' comprehension of the fundamental concepts and the way they connect these concepts are important (Burrow & Mooring, 2015). Cognitive structure is also a theoretical structure, in the way it portrays, inter-conceptual relations in students' long-term memory (Shavelson, 1974). From this aspect, the analysis of students' cognitive structure is an important indicator in assessing what they know (Tsai, 2001). Analyses of cognitive structure enable educators to notice students' learning difficulties and to facilitate teaching (Snow, 1989).

State of the literature

- Due to the fact that chemistry is a science containing abstract topics and concepts, students have difficulty in understanding the concepts and the principles of chemistry.
- Cognitive structure is also a theoretical structure, in the way it portrays, inter-conceptual relations in students' long-term memory. From this aspect, the analysis of students' cognitive structure is an important indicator in assessing what they know.
- Different dimensions of students' cognitive structure can be assessed through quantitative analysis of flow maps, and the information obtained is informative in terms of the scope, richness, connections and accuracy of knowledge structures.

Contribution of this paper to the literature

- Determining the prospective chemistry teachers' cognitive structures through flow maps and analysing the statements in flow maps separately in terms of comprehension level makes significant contributions to the literature related to covalent and ionic bonding.
- The findings reveal that the prospective chemistry teachers' cognitive structures were not very different from each other and that their cognitive structures were full of inadequacies and misconceptions.
- The results of the study shows that the comprehension levels and flow maps of prospective chemistry teachers using scientific approaches in their explanations about chemical bonding differ considerably from those who make unscientific explanations.

Flow maps are used in presenting information on the complexity and the structural properties of cognitive structure (Bischoff & Anderson, 2001). They are also one of the most influential methods used in presenting students' cognitive structures (Anderson & Dimetrius, 1993; Tsai & Huang, 2002), and were first developed by Anderson and Dimetrius (1993). Flow maps are formed through diagramming oral statements of students' thoughts. The sequenced order of ideas in students' narratives and the cross connections between these ideas are represented in these schemes (Tsai, 2001). While examining flow maps from the top to the bottom, information concerning the sequenced development of ideas and linear connections of the ideas is obtained; and while examining flow maps diagonally, information on cross relational ideas is obtained (Anderson & Dimetrius, 1993). Although students' written descriptions are normally used in preparing flow maps, generally oral statements made by students during interviews are used (Anderson, Randel & Covotsos, 2001). Tsai (2001) lists the benefits to science educators from analysing students' cognitive structures through flow maps below:

1. Presenting students' cognitive structure quantitatively,
2. Content analysis of students' information processing strategies,
3. Content analysis of fundamental concepts that students remember.

Different dimensions of students' cognitive structure can be assessed through quantitative analysis of flow maps, and the information obtained is informative in terms of the scope, richness, connections and accuracy of knowledge structures (Tsai, 2001).

It is found that studies on cognitive structure are consistent with the constructivist learning approach (Anderson, 1992; Bodner, 1986). According to the constructivist learning approach, individuals structure knowledge in a manner peculiar to them, and they construct knowledge actively in order to make sense of the world and to interpret the knowledge according to their cognitive structure (Taber & Watts, 1997). Thus, meaningful learning occurs. Meaningful learning involves students' formation of integrative knowledge structures containing their prior knowledge and experiences, new concepts and other relevant knowledge (Tsai, 2000). In this process of learning, students regulate new knowledge with their experiences, mental structures, capabilities and beliefs; thus they form meanings consistent with their prior knowledge (Nakhleh, 1992; Osborne & Freyberg, 1985; Osborne & Wittrock, 1983). For that matter, the importance of prior knowledge available in students' cognitive structure becomes apparent. Probable lacks, mistakes or errors in students' prior knowledge concerning the relevant topics and concepts can influence their later learning. Students' such mistaken perceptions based on the meaning of concepts, are opposed to scientific facts; these are defined as misconceptions (Novak, 1990; 1997). Although the topic of chemical bonding is one of the most important subjects of chemistry at undergraduate level (Fensham, 1975), it is a subject which students find problematic and in which they develop several misconceptions (Coll & Taylor, 2002). Due to the fact that it is an abstract subject, nonrelated to their experiences in daily life, students have difficulty in learning the subject and the related concepts. Thus creating a potential for the formation of misconceptions (Tan & Treagust, 1999). Based on the facts mentioned above the current study aims to analyse prospective chemistry teachers' cognitive structure related to chemical bonding.

Review of the literature demonstrates that there are studies analysing students' understanding of and misconceptions in the subject of chemical bonding. Baker (2000) analysed students' understanding of chemical bonding and thermodynamics. The researcher concluded that even though the majority of students understood the basic ideas about covalent, hydrogen bonding, they have difficulty in the subject of ions and ionic bonding. Robinson (1998) pointed out the general misconceptions about chemical bonding. Butts and Smith (1987) reported that students had confusion about ionic, covalent bonding and such structures. Peterson and Treagust (1989) concluded that students were weak in understanding covalent bonding and structures. Boo (1998) studied students' misconceptions about chemical bonding. Goh, Khoo and Chia (1993); Peterson (1986); Peterson and Treagust (1989); Peterson, Treagust and Garnett (1989) analysed students' understanding through diagnostic tests and they found that students' have difficulty in understanding bond polarity, molecular shapes, molecular polarity, intermolecular forces, and octet rule. Acar and Tarhan (2008) studied the effects of cooperative learning on students' understanding of metallic bonding and they determined the misconceptions related to the subject. Coll and Taylor (2001) through data obtained from interviews found that students had general misconceptions and misunderstandings in relation to chemical bonding. Özmen (2008) investigated the effect of a computer-assisted instruction on student attitudes toward chemistry, and their understanding of chemical bonding and their remediation of alternative conceptions. Ünal, Coştu and Ayas (2010) determined students' misconceptions about covalent bonding. Luxford and Bretz (2013) identified students' misconceptions about covalent, ionic bonding. Luxford and Bretz (2014) determined students' understanding of, and misconceptions about, covalent, ionic bonding representations through analysis of both student-created and expert-generated representations.

Also, review of literature related to cognitive structure shows that there are studies generally concerning high school students' cognitive structures (Anderson &

Dimetrius, 1993; Bischoff & Anderson, 1998, 2001; Chang, Yeh, & Barufaldi, 2010; Tsai, 2001) related to various subjects (Anderson & Dimetrius, 1993; Bischoff, 2006; Chang, Yeh, & Barufaldi, 2010; Chin-Chung & Chao-Ming, 2001; Oskay et al. 2012; Selvi & Yakışan, 2005). Moreover, the fact that the number of studies concerning the subject of chemistry is limited, (Bischoff, Avery, Golden, & French, 2010; Dhindsa & Anderson, 2004; Oskay & Dinçol, 2011; Tsai, 2001; Zhou, Wang, & Zheng, 2015) especially the number of studies conducted in Turkey is limited (Karagöz Şahin, 2004; Oskay & Dinçol, 2011; Oskay et al. 2012; Selvi &Yakışan, 2005).

Taking all these into consideration, the fact that there are almost no studies analysing prospective chemistry teachers' cognitive structure related to chemical bonding through flow maps in literature and the number of studies investigating students' levels of comprehension and their misconceptions about chemical bonding, especially in recent years is a very small amount, demonstrates the importance of our study. Along with this, determining prospective chemistry teachers' cognitive structures through flow maps and analysing the statements in flow maps separately in terms of comprehension level makes significant contributions to the literature related to covalent, ionic bonding. In addition to that, this study has important findings and goes more in depth about demonstrating the scope and richness of cognitive structure that prospective chemistry teachers have in relation to covalent, ionic bonding.

Purpose

This study aims to analyse prospective chemistry teachers' cognitive structure related to the subject of covalent and ionic bonding. We focused on the following research questions. These research questions are as follows;

- How is the cognitive structure determined via a flow map method of prospective chemistry teachers related to covalent and ionic bonding?
- What are the comprehension levels of prospective chemistry teachers related to covalent and ionic bonding according to the classification of Abraham, Gryzybowski, Renner, and Marek (1992)?

METHOD

Case study – one of the qualitative research methods – was used in this study. Case study is a research method which is based on the questions of how and why, and which enables researchers to investigate in depth a phenomenon or an event that they cannot control (Yıldırım & Şimşek, 2011).

Study group

10 prospective chemistry teachers from a group of students who had taken General Chemistry and Analytical Chemistry courses participated in the study. All of them have come from different high schools where common program was applied and were accepted into University by undergoing the University Entrance Exam. The participants, nine of whom were female and one of whom was male, were in the 20-22 age range. The purposeful sampling method was used in the selection of the samples. Purposeful sampling method makes it possible to analyse in-depth the cases which have rich information and sheds more lights as to the questions of which the research is focused on (Patton, 2002).

All of the participants have taken the General Chemistry course. Approximately 20-25 undergraduate students take this course in each semester. The number of participants was limited to 10 so as to focus in more details on their cognitive structures for covalent and ionic bonding. Despite this, it might be said that 10 prospective chemistry teachers represented the number of students in classes considering the number of participants. All of the participants took part in the study on the basis of volunteering. Prior to the study, they were informed of and assured that their identity would be kept confidential and that the data would be used only for study purposes. Even though they participated in the study voluntarily, they were told that they could give up whenever they wished in the process of data collection.

Description of the course setting

Prospective chemistry teachers are taught in details the subject of chemical bonding as a part of General Chemistry I during the first year of University education. The subject is taught theoretically in the course, and no laboratory work is done on the subject. General Chemistry I is mostly taught in traditional teaching method; that is to say, the instructional methodology of the course is mainly instructor-centered. Instructional techniques such as analogy, questioning, or examples from daily life are employed in teaching the course.

Data collection tools

Semi-structured interviews

The interview questions were formed by one of the researchers, by reviewing various textbooks on general chemistry, which aims to analyse prospective chemistry teachers' cognitive structures related to covalent and ionic bonding. The questions appropriate for the purposes of this study were selected by taking into consideration the learning difficulties and the lacks of it in terms of chemical bonding, which were identified through observations and investigations. After that, semi-structured interviews were conducted with the participants, and the data obtained was audio recorded in order to prevent the loss of data. Interviews are one of the methods used to obtain information on misconceptions (Osborne & Gilbert, 1980) and to assess students' comprehension of concepts (Carr, 1996).

Flow map method

Prospective chemistry teachers were asked questions about covalent and ionic bonding through semi-structured interviews. The questions are as follows:

1. What is chemical bonding? Why do atoms form bonds? What can you say about this?
2. What can you say about covalent and ionic bonding and about the forces keeping these bonds together? What do you think of about the types of bonds available in the compounds H_2, HCl and NaCl?

The data obtained through semi-structured interviews were transcribed by one of the researchers and was transferred into the computer medium, and flow maps were prepared for each participant based on the data obtained. While preparing the flow maps, the major ideas declared by the participants were inserted as column headings as mentioned by Anderson and Dimetrius (1993). The sequential flow of prospective chemistry teachers' ideas about the subject was represented with linear arrows while the linkages between related ideas were demonstrated with recurrent arrows in the flow map. The recurrent arrows were used in the direction of the ideas that the prospective chemistry teachers had previously stated. Misconceptions providing information about the accuracy of cognitive structure were also shown in flow maps.

The reliability of the flow map method

The reliability of the flow map method was secured by asking an independent researcher to diagram the participants' narratives because the reliability of the method may be secured by asking a second independent researcher to diagram the students' narratives (Tsai, 2001). For the current study, inter-coder agreement for sequential statements was around 0.90 and for recurrent linkages was around 0.87.

Data analysis

Firstly, the flow maps prepared for prospective chemistry teachers were analysed in terms of quantitative variables used in presenting cognitive structure in quantitative statements. The quantitative variables included in the analysis are as follows:

- Extent: The total number of ideas in the flow map (the number of linear linkage),
- Richness: The number of recurrent linkages in the flow map,
- Integratedness: The number of recurrent linkages in the flow map/total number of ideas + the number of recurrent linkages,
- Accuracy: The number of misconceptions in the flow map (Tsai, 2001).

Secondly, the statements in the flow maps were analysed in terms of comprehension level according to the classification of Abraham, Gryzybowski, Renner, and Marek (1992). Thus, attempts were made to analyse each statement in flow maps in more details. The symbols, content and scoring used in this classification are as follows:

- No Understanding (NU) (empty answer, correct answers-no explanations, correct answers-no comprehensible explanation),
- Incorrect Concept (Specific Alternative Conception) (SM) (scientifically unacceptable answer or explanation),
- Partial Understanding but Incorrect Concept (Partial Understanding with Specific Alternative Conception) (PUSM) (while the answer is correct, the explanation is incorrect or answer is incorrect but explanation is correct),
- Partial Understanding (PU) (correct answer, explanation is not complete),
- Sound Understanding (SU) (correct answer, full explanation).

FINDINGS

Related to the first research question of the study, the flow maps prepared for prospective chemistry teachers were analysed according to the mentioned quantitative variables in this study. Additionally, related to the second research question of the study, the statements in the flow maps were analysed in terms of comprehension level. The results obtained are shown in Table 1 and Table 2.

On examining Table 1, it was observed that the number of linear linkages providing information on the scope of knowledge that prospective teachers remember (extent) is between 7 and 11 whereas the number of recurrent linkages (richness) providing information about the richness of knowledge linkages is between 5 and 18. It was evident that the quantitative variable of integratedness receives values between 0.38 and 0.63, and that the number of misconceptions providing information about the accuracy of cognitive structure (accuracy) is 6 at the maximum.

Table 2 was analysed on the basis of the questions the prospective chemistry teachers were asked during semi-structured interviews. It was found that

Table 1. The cognitive structure outcomes of prospective chemistry teachers

Variables	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P10
Extent	11	7	10	8	10	9	10	9	11	11
Richness	18	7	10	5	16	11	15	15	13	9
Integratedness	0.62	0.5	0.5	0.38	0.61	0.55	0.6	0.63	0.54	0.45
Accuracy	5	4	5	5	6	6	4	3	5	5

Table 2. Comprehension levels of prospective chemistry teachers

Comprehension levels	P 1	P 2	P 3	P 4	P 5	P 6	P7	P 8	P 9	P10
NU	0	0	0	1	0	0	0	0	0	0
SM	5	4	5	5	6	6	4	3	5	5
PUSM	2	0	0	1	2	1	1	1	1	1
PU	4	3	5	1	2	2	5	5	3	4
SU	0	0	0	0	0	0	0	0	2	1

participants gave answers to the first question (What is chemical bonding? Why do atoms form bonds? What can you say about this?) in the SM, PUSM and PU categories.

When the answers in the SM category were examined, it was found that prospective chemistry teachers used the following statements in describing chemical bonding and why atoms form bonds:

• Chemical bonding is a structure formed through electrons' connection,

• Chemical bonding connects elements to each other,

• Chemical bonding is a structure formed between two elements,

• Chemical bonding is a bridge between atoms,

• Chemical bonding keeps atoms together,

• Chemical bonding is a force for keeping two atoms together.

According to the answers in the PUSM category, it was found that prospective chemistry teachers used the following statements in describing chemical bonding and why atoms form bonds:

• Atoms acquire noble gas structure by forming bonds,

• Chemical bonding is an interaction between two atoms based on electron sharing or electron transfer,

• Atoms form bonds to transform each other into noble gas structure,

• Atoms form bonds to complete the number of electrons in their outermost orbit up to eight,

• Atoms complete the number of electrons in their outermost orbit up to eight in order to acquire octet and noble gas atom structure, and thus they become stable,

• Elements form bonds in order to complete themselves to octet.

When the answers in the PU category were examined, it was found that prospective chemistry teachers used the following statements in describing chemical bonding and why atoms form bonds:

• Atoms form bonds in order to become stable,

• Atoms form bonds in order to make compounds.

The answers given by prospective chemistry teachers to second question (What can you say about covalent and ionic bonding and about the forces keeping these bonds together? What do you think of about the types of bonds available in the compounds H_2, HCl and NaCl?) fall into two groups.

Firstly, prospective chemistry teachers' answers in relation to covalent bonding were analysed. It was found that the answers were in the NU, SM, PUSM, PU and SU categories.

According to the answers in the NU category, it was found that prospective chemistry teachers used the following statement in describing covalent bonding, the forces in these bonds and the types of bond:

• There is a nonpolar covalent bond in the H_2 compound.

In the SM category, the prospective chemistry teachers used the following statements while they are describing covalent bonding, the forces in these bonds and the types of bond:

• Covalent bonding is formed by electron sharing between nonmetal elements,

• Covalent bonding is formed by electron sharing between nonmetal atoms,

• Covalent bonding is formed by electron sharing between two nonmetals,

• Covalent bonding is formed by electron sharing, valence electrons are shared,

• If there are two different nonmetals, polar covalent bonding is formed; the bond in the HCI compound is polar since the attraction powers between electrons are different,

• Since different atoms attract each other with differing forces in the HCI compound, there is polar covalent bonding, and it is the force of atom nuclei to attract the external electron,

• There are polar covalent bonding in the HCI compound, these bonds are formed between different elements,

• The HCI compound contains polar covalent bonding because it is composed of different nonmetal atoms,

• The H_2 compound has nonpolar covalent bonding because the attraction forces of the same atoms are the same,

• The H_2compound has nonpolar covalent bonding because it has the same element atoms,

• The H_2 compound has nonpolar covalent bonding because the same two nonmetal atoms share electrons,

• The same nonmetals share electrons in the H_2 compound,

• The H_2 compound has nonpolar covalent bonding; these bonds are formed between two nonmetals of the same kind,

• The H_2compound has nonpolar covalent bonding, these bonds are formed when similar elements are combined,

• The force keeping the atoms together in a covalent bonding is the force of attraction between electrons,

• The force keeping the atoms together in a covalent bonding is the forces of attraction arising due to the electronegativity difference,

• The force keeping the atoms together in a covalent bonding is the force of atom nuclei to attract the external electron,

When the answers in the PUSM category were examined, it was found that prospective chemistry teachers used the following statement in describing covalent bonding, the forces in these bonds and the types of bond:

• Because the electronegativity of Cl is greater in the HCI compound, it attracts the electron of H, and the bond is polar since partially positivity, negativity is formed.

According to the answers in the PU category, it was found that prospective chemistry teachers used the following statements in describing covalent bonding, the forces in these bonds and the types of bond:

• The force keeping the atoms together in covalent bonding is the attraction force. Nuclei attract electrons,

• The force keeping the atoms together in covalent bonding is the attraction between the + and the – charges. The electrons between atoms are negatively charged, they are attracted by positive charges,

• The force keeping the atoms together in covalent bonding is the force of attraction between negatively charged electrons and protons in atom nuclei,

• Nonpolar covalent bonding is available between the same nonmetal atoms in the H_2 compound because there are no electronegativity differences,

• Polar covalent bonding is available in the HCl compound; different kind of nonmetals do not share electrons equally, the electrons of bonding are closer in distance to Cl,

• Different nonmetals in the HCl compound share the electrons; because the electronegativity of Cl is greater than H, Cl attracts bonding electrons to itself more.

• Because the electronegativity of Cl is greater in HCl compound, it attracts bonding electrons more; Cl is partially negative charged.

• The HCI compound contains polar covalent bonding; the electron affinity of Cl is greater. Because the electronegativity of Cl is greater, it attracts shared electrons more.

The answers in the SU category showed that the prospective chemistry teachers used the following statements in describing covalent bonding, the forces in these bonds and the types of bond:

• Bonding electrons are closer in distance to Cl in the HCl compound; Cl attracts electrons more. There is also an ionic character in HCl compound due to partial polarisation. Cl is partially negative charged, H is partially positive charged, and because the electronegativity of Cl is greater; polar covalent bonding is formed,

• The protons in the nuclei of H attracts the bonding electrons in H2 compound,

• Shared electrons in covalent bonding attract protons in the atom nuclei.

Secondly, prospective chemistry teachers' answers in relation to ionic bonding were analysed. It was found that the answers were in the SM and PU categories.

When the answers in the SM category were examined, it was found that prospective chemistry teachers used the following statements in describing ionic bonding, the forces in these bonds and the types of bond:

• The force keeping the Na^{+} and Cl^{-} ions together is partial negativity and partial positivity in the NaCl compound,

• Ionic bonding is formed by electron transfer between metal and nonmetal elements,

• Ionic bonding is formed by electron transfer,

• Ionic bonding is formed by electron transfer between atoms,

• Ionic bonding is formed by electron transfer between metal and nonmetal atoms,

• Ionic bonding is formed by the transfer of valence electrons.

According to the PU category, it was found that prospective chemistry teachers used the following statements in describing ionic bonding, the forces in these bonds and the types of bond:

• The force keeping the Na^{+} and Cl^{-} ions together is the attraction between the + and the – charges in the NaCl compound,

• Ionic bonding is strong bond, it has electrostatic attraction,

• The force keeping the ions together is the attraction between the $Na^{+}$and Cl^{-} in the NaCl compound; the + and the – charges attract each other,

• Na loses electron, thus Na^{+} is formed; Cl gain electron, thus Cl^{-} is formed in the NaCl compound; Na and Cl acquire noble gas structure,

• Na is a metal in the NaCl compound, it loses one electron, thus Na^{+} is formed, Cl is a nonmetal, it gains this electron, thus Cl- is formed,

• Na, which is a metal, loses electron, Cl, which is a nonmetal gains electron from the Na atom to turn itself into a noble gas. The Na+ and Cl^{-} are formed.

CONCLUSION AND DISCUSSION

The flow maps were formed for prospective chemistry teachers in relation to the first research question, and then the maps were analysed. On the other hand the cognitive structures of the participants were also analysed in terms of the quantitative variables (extent, richness, integratedness and accuracy) put forward by Tsai (2001). According to Table 1, it was observed that the number of linear linkages providing information on the scope of knowledge prospective chemistry teachers remember (extent) is between 7 and 11 whereas the number of recurrent linkages (richness) providing information about the richness of knowledge linkages is between 5 and 18. It was evident that the quantitative variable of integratedness received values between 0.38 and 0.63, and that the number of misconceptions providing information about the accuracy of cognitive structure (accuracy) is 6 at the maximum. These numerical data obtained show that prospective chemistry teachers' cognitive structures were not very different in scope and in richness. Accordingly, it is evident that the numbers of linear linkages showing sequential flow of how prospective chemistry teachers state their opinions and recurrent linkages demonstrating the ties between the associated statements take on values very similar to each other. It was also found that prospective chemistry teachers' cognitive structure was full of inadequate knowledge and misconceptions. Yet, according to Table 1, it is clear that prospective chemistry teachers differ slightly in their cognitive structures. For example, it was observed that one of the prospective chemistry teachers (P8) had the most extensive cognitive structure (extent: 9, richness: 15, integratedness: 0.63) and the smallest number of misconceptions (accuracy: 3), and that another prospective chemistry teacher (P4) had the least extensive cognitive structure (extent: 8, richness: 5, integratedness: 0.38, accuracy: 5). The flow maps prepared for both participants are given in Appendix (see Appendix1 and 2).

In order to analyse prospective chemistry teachers' cognitive structures in more details, each statement included in the flow maps was analysed according to the level of comprehension on the basis of the second research question. At this point, prospective chemistry teachers' answers to the first question were analysed and some conclusions were reached through the answers in the SM category. The statement "chemical bonding is a bridge between atoms" shows that prospective chemistry teachers consider the bonds as a physical entity. In a similar vein, knowledge fragments like "chemical bonding is a structure formed through electrons' connection", "chemical bonding connects elements to each other", "chemical bonding is a structure formed between two elements", and "chemical bonding keeps atoms together" demonstrate that prospective chemistry teachers describe bonding as a material connection. Boo (1998) also obtained similar findings. According to the answers in the PUSM category, it was found that prospective chemistry teachers stated that atoms formed bonds in order to acquire noble gas structure and to complete the number of electrons in their outermost orbit up to eight, and thus they acquire octet. From these statements, it was found that prospective chemistry teachers consider the formation of bonds only as completion of atoms' octets, that they had no ideas about the electrostatic nature of bond formation, and that they made no mention of attraction between atoms in the formation of bonds. These lacks are also mentioned in the literature (Boo, 1998; De Posada, 1997; Harrison & Treagust, 1996; Taber, 1995). When the answers in the PU category were examined, on the other hand, it was found that prospective chemistry teachers stated that atoms formed bonds in order to become stable and to form compounds. However, it was found that they did not mention how stability was attained, or its' relation with energy especially. Nicoll (2001) concluded in a similar way that students stated incorrect explanations on the formation of bonds and on the causes for it, and that they could not explain bonding in terms of stability or energy.

The answers that the prospective chemistry teachers gave in relation to the second question fell into two groups, and firstly the answers concerning covalent bonding were analysed. On examining the findings, it was seen that a prospective chemistry teacher stated that the H_2 compound contain nonpolar covalent bonding (in an answer in category NU), but that she could not offer any explanations about the formation of the bond. On examining prospective chemistry teachers' answers in the SM category, it was found in their statements (covalent bonding is formed by electron sharing between nonmetals and the force keeping atoms together in covalent bonding is the force of atom nuclei to attract the external electron, the force of attraction between electrons, forces of attraction arising due to the electronegativity difference) that they had misconceptions about covalent bonding.

It was also found that they had misconceptions about the formation of polar and nonpolar covalent bonding. The prospective chemistry teachers attributed the causes for the formation of polar covalent bonding to the differences between attraction forces of electrons and the differences between attraction forces of different atoms while they attributed the causes for the formation of nonpolar covalent bonding to the same attraction forces of same atoms- which were defined as misconceptions. It was also found that prospective chemistry teachers having misconceptions considered the formation of covalent bonding only as electron sharing, that they did not consider it as an attraction force, and that they did not take the concept of electronegativity into consideration in the formation of such bonds. According to the answers in the PUSM category, it was found that a prospective chemistry teacher takes the electronegativity differences into consideration in the formation of polar covalent bonding, but that she had misconceptions about the definition of the concept of electronegativity. Boo (1998) concluded that students had no proper concept of electronegativity and hence no concept of electronegativity difference. When the answers in the PU category were examined, it was found that prospective chemistry teachers had partial understanding in relation to the forces keeping the atoms in covalent bonding, that they stated that the forces were the attraction forces, but that they could not explain these forces properly. For instance, some of the prospective chemistry teachers claimed that the attraction forces were between nuclei and electrons, some claimed they were between electrons and positive charges, and some claimed they were between electrons and protons in the atom nuclei- which were incomplete explanations. Prospective chemistry teachers said in relation to the formation of polar covalent bonding that different nonmetals did not share electrons equally, that the nonmetals with more electronegativity attracted bond electrons more; but it was found that they did not mention polarisation – that is to say, partial positivity and partial negativity - due to the differences in electronegativity, and thus they could not make complete explanations. In relation to the formation of nonpolar covalent bonding, they said that there were no electronegativity differences between the same nonmetal atoms, but they did not explain how influential it was in the formation of bonds. According to the answers in the SU category, it was found that a prospective chemistry teacher takes the concept of electronegativity into consideration in the formation of polar covalent bonding and that he mentions polarisation, and that another prospective chemistry teacher takes attraction forces between bond electrons and atom nuclei into consideration in the formation of covalent bonding. On generally evaluating these findings, the fact that prospective chemistry teachers base the formation of covalent bonding only on electron sharing is a misconception, which is also mentioned in the literature (Robinson, 1998). Peterson, Treagust and Garnett (1989) demonstrated that students could not develop appropriate conceptual understanding in relation to covalent bonding and structures. Besides, they also pointed out that students associated covalent bonding with electron sharing but that they did not take the effects of electronegativity and the resultant unequal electron sharing into consideration. Treagust (1988); Peterson and Treagust (1989) also concluded that students were weak in comprehension covalent bonding.

Secondly, prospective chemistry teachers' answers in relation to ionic bonding were analysed. According to the findings, it was found through the answers in the SM category that prospective chemistry teachers stated that ionic bonding was formed through electron transfer between metals and nonmetals and that the bonding occurred with metal's losing electrons and nonmetal's gaining the electrons. When the answers in the PU category were examined, it was seen that prospective chemistry teachers explained the formation of bond in the NaCl compound only with the electron transfer between Na and Cl. It was stated by prospective chemistry teachers that the Na^+ and the Cl^- ions attracted each other just like the + and the – charges. Yet, it was found that prospective chemistry teachers had inadequacies such as: they did not see the formation of ionic bonding as electrostatic attraction between opposite charged ions, they did not mention the three dimensional structure of ionic bonding in the NaCl compound, they did not set up associations between ionic bonding and ionic crystal, they stated that the NaCl compound was composed of only one Na^+ and Cl^- ion, and they did not take the number of these ions into consideration. Butts and Smith (1987); Taber (1994); Tan (1994); Tan and Treagust (1999) found also similar inadequacies. Boo concluded that comprehension of ionic bonding seemed difficult to students. Taber (1997) analysed students' misconceptions especially about ionic bonding, and concluded that they had difficulty in comprehension the subject of ionic bonding. Taber (1997) found students' misconception about ionic bonding stated as "bonds are formed only between atoms losing and gaining electrons". Robinson (1998) reported that students see ionic bonding as electron transfer rather than interaction between ions, and labeled this as a misconception.

According to the findings obtained from this study, prospective chemistry teachers use some incomplete knowledge structures while making explanations on covalent and ionic bonding. In other words, prospective chemistry teachers make explanations by setting up connections between some knowledge fragments that can be regarded as nonoperational definitions of chemical bonding. Thus, their inappropriate use of such knowledge structures concerning chemical bonding has led to unscientific explanations and descriptions. Therefore, the comprehension levels and flow maps of prospective chemistry teachers using scientific approaches in their explanations about chemical bonding differ from those who make unscientific explanations (see Appendix 1 and Appendix 2).

IMPLICATIONS FOR TEACHING

The results of the study point to the fact that prospective chemistry teachers' cognitive structure is full of inadequacy of knowledge and misconceptions in relation to covalent and ionic bonding, and that it is an important issue that must be considered. Because course books in particular, teachers' inadequacies in terms of instructional methods and techniques, diagrams, things students brought to learning environments, and overgeneralisations can be the causes of misconceptions; certain points should be taken into consideration while teaching the topic of chemical bonding. For example, content and contexts to facilitate students' learning scientific knowledge related with chemical bonding in particular should be prepared. At this point, advance organisers such as concept maps or conceptual frameworks should be used both at the beginning of the courses to determine their prior knowledge and possible knowledge inadequacies or misconceptions. Also these advance organisers will encourage students to set up connections between concepts. Important concepts should be listed at the end of each chapter in course books, and a sample concept map containing the concepts should be added to the end of each chapter. Besides, connections between concepts should be emphasised during lessons or the emphasis should be included in course books. This will make sure that students set up connections between concepts in a coherent way, and thus it will help students to organise their knowledge elements about related subjects. For individuals to have scientific knowledge about concepts will encourage the development of complex organised knowledge about the phenomena.

Besides, the findings obtained in this study confirm that flow maps are a method that educators and teachers can use in assessing students' cognitive structures for the learning topic. Especially teachers can check and see whether or not their students have knowledge inadequacies or misconceptions in their cognitive structures in this way, and thus they can take necessary precautions. In other words, information obtained through flow maps can be used in analysing the learning outcomes.

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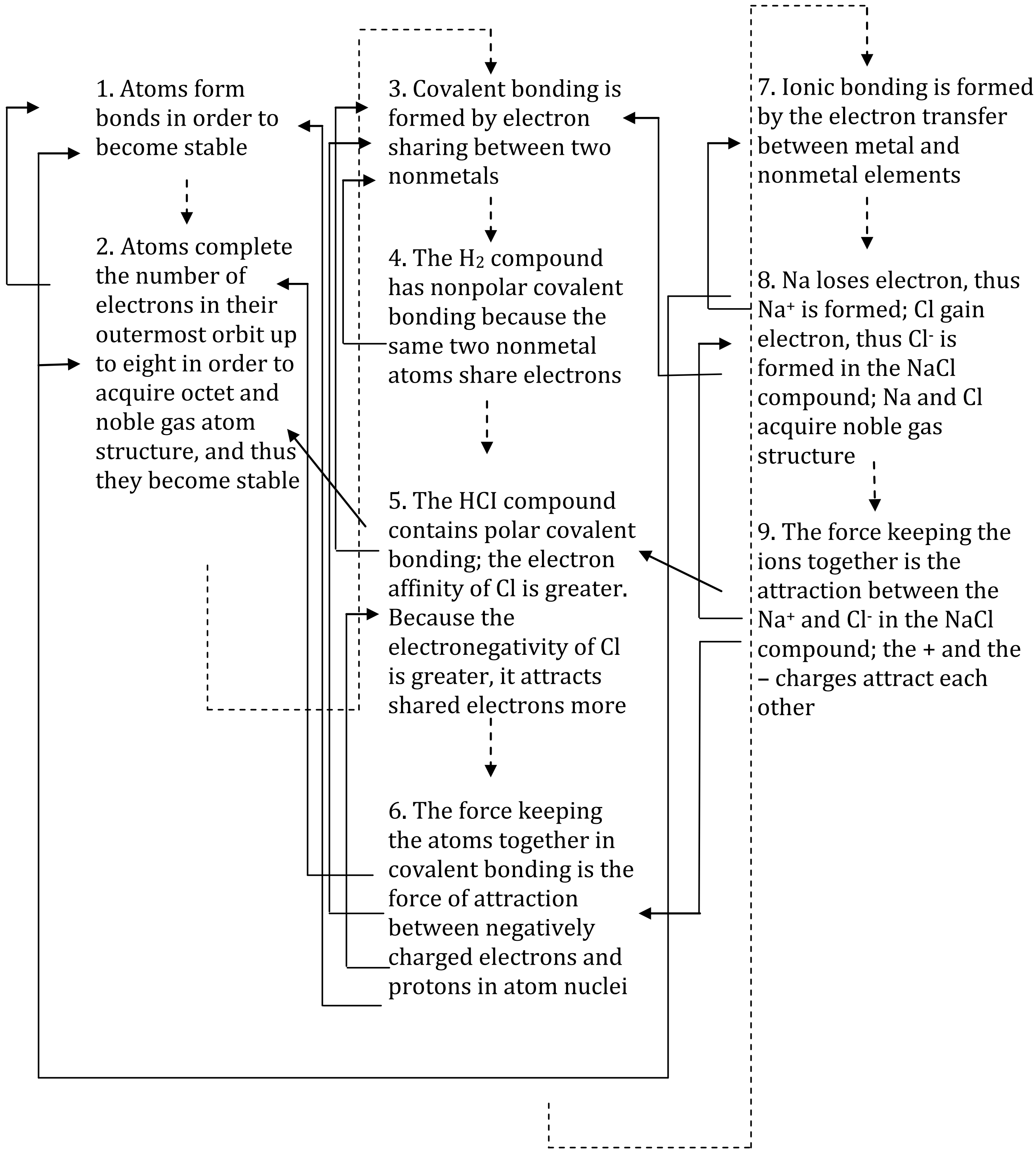
APPENDIX 1. The flow map formed from the written narrative of P8



APPENDIX 2. The flow map formed from the written narrative of P4

1. Chemical bonding is a force for keeping two atoms together

2. Atoms form bonds in order to become stable

3. Atoms acquire noble gas structure by forming bonds.

4. Covalent bonding is formed by electron sharing between two nonmetals

5. There is a nonpolar covalent bond in the H_2 compound

6. If there are two different nonmetals, polar covalent bonding is formed; the bond in the HCI compound is polar since the attraction powers between electrons are different

7. The force keeping the atoms together in a covalent bonding is the force of attraction between electrons

8. Ionic bonding is formed by the electron transfer between metal and nonmetal elements