JOURNAL OF BALTIC SCIENCE EDUCATION
ISSN 1648-3898

EXPLORING THE RELATIONSHIP BETWEEN COGNITIVE STRUCTURE OUTCOMES AND TEST ACHIEVEMENTS OF PRE-SERVICE SCIENCE TEACHERS ON CHEMICAL BONDING VIA FLOW MAPPING

Elif Atabek-Yigit

Abstract. *The relationship between cognitive structure outcomes of students and their test achievement was examined in this study. A question form and two types of tests (a multiple-choice test (MCT) and a true-false test (TFT)) were used to gather the research data. According to the results of this study, extend, richness and integratedness of students' statements significantly correlated to their scores in TFT. Also, richness of students' statements was significantly correlated to their MCT scores. Describing and comparing were significantly correlated with MCT scores, while describing, comparing and inferring were significantly correlated with the students' TFT scores. Therefore, it can be said that tests reflect students' cognitive structures. Furthermore, students with higher order thinking skills can be identified by TFT rather than with MCT. Students' misconceptions about the research topic were also examined, and they were generally on the classification and types of chemical bonds.*

Key words: *chemical bonding, cognitive structure, flow map, pre-service science teachers, test achievement.*

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Introduction

Every student learns in a different way, i.e., by using different methods and techniques to organize the knowledge in his/her mind, and his/her existing knowledge is essential to the formation of new knowledge. Learning involves an active process in which learners construct meaning by linking new ideas with their existing knowledge (Naylor & Keogh, 1999). Therefore, it is very important in teaching and learning processes to have a better understanding about "how to determine pre-existing knowledge" and "how we learn" in order to construct new knowledge.

Structured knowledge (or cognitive structure) provides a stable and organized framework to construct new knowledge. A well-organized ideational network also facilitates problem solving by providing an ordered set of generalizations and principles that can be efficiently mobilized and applied to new problem situations (Anderson, Randle & Covotsos, 2001). Cognitive structure is an indication of an individual's organization of concepts in memory and the relationships between them (Tsai & Huang, 2002; Oskay & Dincol, 2011; Tsai, 2001; Bischoff, Avery, Golden & French, 2010; Dhindsa & Anderson, 2004). Probing the cognitive structures of learners can enlighten learning processes. By exploring students' cognitive structures, educators can understand students' conceptions, interrelationships between concepts, and scientifically incorrect understandings, i.e., misconceptions, and, therefore, help students to enhance their learning outcomes. Hence, "what the students learn" and "how they learn" can be revealed by investigating the cognitive structures of students. Thus, educators can design better learning settings according to the findings.

There are five common methods of representing cognitive structures: free word association, controlled word association, tree construction, concept map and flow map (Tsai & Huang, 2002). They provide evidence of the network organization of information of a respondent, thus an insight into the respondents' organization of knowledge; though not all of them preserve the sequential organization of information recall. Since sequential organization may be related to the meaning of categories and concepts, it is important to get respondents' thoughts in an order (Anderson et al., 2001). Among other methods, flow maps are not only easily adapted, but are also a valuable approach to represent both the sequential and network features of peoples' thoughts in a non-directive way (Anderson & Demetrius, 1993; Tsai, 2001). A flow map is constructed either from respondents' written narrative or spoken discourse. It starts by entering the statements of the respondents in a sequential order and then every uttered statement is given a number. Thereafter, linear and recurrent linkages are examined. A linear linkage shows the sequential flow of respondents' ideas and a recurrent linkage shows the connections among relational ideas i.e., revisited ideas. Recurrent arrows are drawn back to the earliest step where the revisited statement appears.

Respondents' misconceptions are also examined throughout the flow maps since misconceptions represent the part of cognitive structure. A number of quantitative variables such as extend, richness, integratedness and misconceptions, representing cognitive structure, can be obtained from flow map analysis (Tsai, 2001; Tsai & Huang, 2002; Tsai, 1998; Yang, 2004). Extend shows the number of statements present in the flow map, richness shows the number of recurrent linkages and integratedness gives the proportion of recurrent linkages.

Flow maps can also be used to conduct a series of content analyses of the students' information processing operations. Information processing, that is "how the students organize their ideas" mainly concerns the cognitive reasoning accompanying each idea in the learners' cognitive structures and can be categorized as: defining (definition of a concept), describing (picturing a concept or a phenomenon), comparing (comparison of two or more concepts or situations) and inferring (describing what will happen under certain circumferences) modes. Defining and describing modes are, as *"require"* low thinking skills, whereas comparing and inferring require higher order thinking skills (Tsai, 2001).

The flow map method has been used in many studies. For instance, Bischoff et al. (2010) studied the development of pre-service science teachers' knowledge structures regarding redox chemistry. Dhindsa and Anderson (2004) investigated the effect of the conceptual change approach to the reorganization of pre-service chemistry teachers' knowledge structures and they used flow map analysis prior and after a conceptual change intervention. Yang (2004) aimed to explore students' use of theory and evidence in evaluating a socio-scientific issue and used the flow map method to analyse participants' conceptual knowledge. Tsai (2001) used the flow map method to probe eight grader students' cognitive structures on atomic theory. Similarly, Wu and Tsai (2011), Selvi and Yakisan (2005), and Oskay, Temel, Ozgur and Erdem (2012), also used the flow map method in their studies to determine students' cognitive structures. Tsai (1998) investigated the relationship between eight grader students' science achievement, scientific epistemological beliefs and their cognitive structure outcomes. Students' science achievement was obtained via science tests, their scientific epistemological beliefs via a scale and their cognitive structures by interviewing and then transforming the recordings into a flow map format.

Misconceptions are misunderstandings of concepts or having scientifically wrong conceptions. They are vital in learning processes since they hinder meaningful learning. Teachers having misconceptions is one possible reason for students' misconceptions; therefore, it is especially important to prevent pre-service teachers' misconceptions (Oskay et al., 2012). Hence, pre-service science teachers were chosen as participants in this study.

Testing, which has been primarily considered as an evaluation tool (Roediger & Karpicke, 2006; Chang, Yeh & Barufaldi, 2010), can promote learning and conceptual change. Reading the choices in a test or retrieving information by cues might activate relative memory, modify the memory trace of target items, and increase the probability of a successful retrieval later (Kang, McDermott & Roediger, 2007). Since tests promote conceptual change the aim of this study was to investigate how they reflect the cognitive structures of students.

In this study, "chemical bonding" was used as the research topic. Students can relate to many basic chemistry subjects and better understand many concepts by deeply understanding this topic.

The main purpose of this study was to determine the cognitive structures of the students on chemical bonding and to explore the relationships between cognitive structure outcomes and test achievements. Therefore, the results of this study can be helpful for science educators to determine if students who receive high grades in tests are richer in cognitive structure. More specifically, the study aimed to obtain answers to the following questions:

1. What are the cognitive structure outcomes of science education students regarding chemical bonding?
2. What are the relationships (if any) between cognitive structure outcomes and test achievements?
3. Which types of tests better reflect students' cognitive structures?
4. What are the misconceptions of the students regarding chemical bonding?

ISSN 1648–3898

Methodology of Research

This study is a correlation study that aims to determine the relationship between cognitive structure outcomes and the test achievements of students. The data were gathered in a period of two weeks.

Participants and the Research Topic

The participants of this study were 68 freshmen (52 female and 16 male) attending the General Chemistry I course during the fall semester of 2014-2015 at a university's (located in the south west of Turkey) Science Education Department. They can be regarded as relatively homogeneous on relevant academic dimensions because they were all taught the research subject at a high school with a similar curriculum, and they had taken an entrance exam before admittance to university and were appointed to a certain school based on the exam results. All of the participants were informed about the study (by explaining its aim, design and procedure) and participated voluntarily.

The research topic chosen in this study was "chemical bonds". "Chemical Bonds" is one of the major topics within General Chemistry courses. Students can relate to many of the topics (formation of compounds, reactions, etc.) well by deeply understanding this topic (Nahum Mamlok-Naaman, Hofstein & Taber, 2010; Burrows & Mooring, 2015). Research also shows that students have many misconceptions about chemical bonding (Morgil, Erdem & Yilmaz, 2003, Burrows & Mooring, 2015, Ozmen, 2004). Therefore, probing cognitive structures about this topic can enlighten misconceptions.

Instruments

Data were gathered through two different types of tests (multiple-choice test and true-false test) and a question form. The types of tests used in this study were chosen because they are commonly used types in educational settings (Roediger & Karpicke, 2006; Zimmerman, 2003; Chang et al., 2010). A detailed description about the instruments used in this study is described as follows.

Multiple-Choice Test (MCT): The researcher developed a multiple-choice test about the research topic. First, 32 questions were involved in the pre-test, which was reviewed by two field experts (a researcher in the field of chemistry education and a researcher in the field of chemistry) regarding the students' appropriateness and the adequacy of the tests' chemistry content. After their examination, some questions were eliminated and some questions were modified. Thereafter, a pre-test was applied to 100 students studying science education. The Cronbach alpha validity of this test was calculated as .83. The Multiple-Choice Test consisted of 25 four-choice questions. Each question was allocated 4 points. Two examples from MCT are given as follows:

Which one is the strongest intermolecular bond?

a) *Hydrogen bond*
b) *Van der Waals bond*
c) *Ionic bond*
d) *Dipole-dipole bond*

How does the metallic bond form?

a) *One metal gains an electron and the other one loses an electron.*
b) *It forms by sharing valence electrons of two metals.*
c) *It forms due to instant dipole moment of metallic atoms.*
d) *It forms by delocalization of the valence electrons of the interacting metal atoms.*

True-False Test (TFT): After the development of the MCT, a total of twenty-five true and false statements parallel to the questions in the MCT were written and a True-False Test was formed. Students were told to read each statement and write "T" for the statements they thought true, and "F" for the statements they thought false. The TFT consisted of 25 statements (14 true and 11 false) and each right answer scored 4 points. Examples from TFT are given as follows:

Van der Waals interactions are the weakest intramolecular interactions.
Metallic bond forms due to the instant dipole moment of metallic atoms.

Question form: A question form consisting of five questions to analyse the cognitive structures of the students was prepared. Another researcher was asked to review the form and some minor modifications were made after his examination. Students were told to read each question and write down their responses. Questions on the form were:

- What is a chemical bond? Why and how does it form?
- What are the types of chemical bonds? Can you explain them?
- What is Lewis structure of a molecule? Can we draw a Lewis structure for all types of molecules?
- What is the octet rule? Can you explain?
- What is the VSEPR model? Can you explain?

Students' responses were analysed via the flow map method using four different parameters (extend, richness, integratedness and misconceptions). Each statement in the flow maps was also categorized into one of the following four levels of information processing modes: defining, describing, comparing, and inferring.

A different researcher (a professor in the field of science education) also performed an analysis of 10 students' responses (randomly selected) and the inter-coder agreement was calculated as .89. Therefore, flow map analyses were thought to be reliable.

Design and Procedure

A detailed design and procedure of the research is given as follows:

Step 1: Question form administration:

First of all, the participants were informed about the study. The question form was given to the students and they were asked to write down their answers to five questions. The purpose of this form was to determine the cognitive structures of the students. There was no time limit in this step and it took students about 45 minutes to complete their answers.

Step 2. Test administration

One week after the question form, students were asked to respond to the true-false test. This test was composed of 25 statements and students were asked to decide whether the statements were true or false. All of the students completed the test in about 25 minutes.

One week after the true-false test, the multiple-choice test was given to the students and they were asked to respond to 25 four-choice questions. It took students about 25 minutes to complete this test.

Both tests needed to be of a similar difficulty as the aim was to relate test scores and cognitive structure parameters. For this reason, questions and statements in TFT and MCT were made similar; but this may lead to another situation, which is called the testing effect. If students are tested on a subject they may remember it in the future. This phenomenon is known as the testing effect and it has generally been studied in the field of cognitive psychology (Carrier & Pashler, 1992; Roediger & Karpicke, 2006; Butler & Roediger, 2007; Chang et al., 2010). In order to minimize the testing effect on the results, there was a time gap of a week (which was thought to be enough) between the tests' administrations.

Step 3. Evaluation of the data

Data obtained via the question forms were evaluated by the flow map method. The flow map method is a valuable approach to show the sequential and multi-relational ideational frameworks of learners (Tsai, 2001). According to this method, narratives of each student to each question were transformed into consequent sentences and flow maps were formed for each student separately. A sample flow map can be seen in Figure 1. All statements were numbered and linear and recurrent linkages were formed. Linear linkages show the flow of student narrative, and recurrent linkages show revisited ideas among the statements. Statement 3 in Figure 1, for example, "*Chemical bonds are formed in order for? an atom to reach to max stability and min orderliness*", includes one major revisited idea "*chemical bonds*". Consequently, a recurrent arrow was drawn back to statement 1, where the revisited idea appeared first. After examining the flow maps from this point of view, four quantitative variables, e.g., extend, richness, integratedness, and misconceptions, representing the cognitive structures of the students, were calculated for

ISSN 1648–3898

each flow map. Extend is given as the total number of ideas represented in the flow map. For instance, there were 17 statements in the flow map shown in Figure 1, therefore, extend was determined as 17 for this flow map. Richness is given as the total number of recurrent linkages, i.e., 17 in Figure 1. Integratedness is the proportion of recurrent linkages and calculated as (recurrent linkages)/(linear linkages+recurrent linkages). Integratedness was calculated as 0.50 in Figure 1. Misconception is the number of misconception in the flow map, i.e., 4 in Figure 1 below.

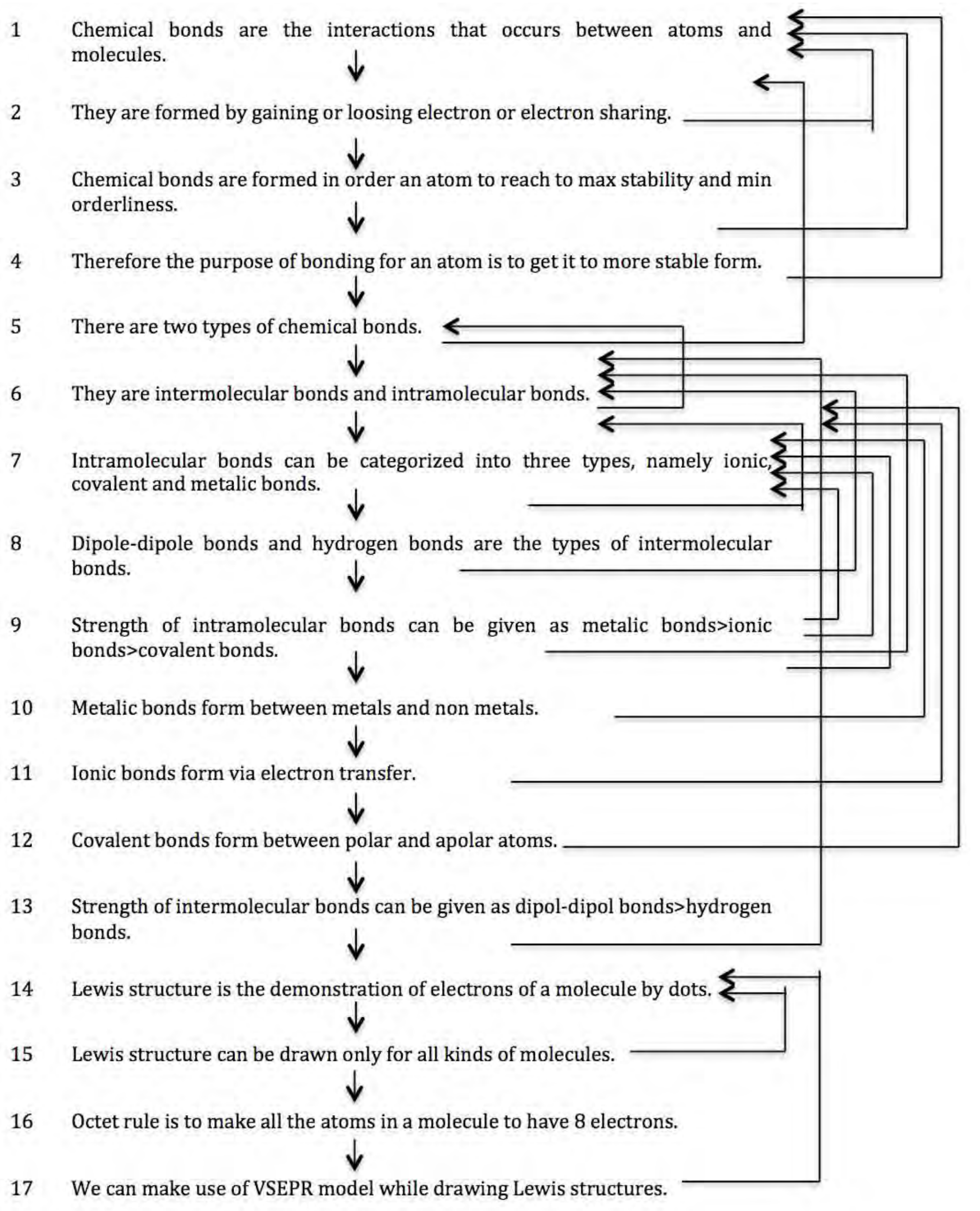

Figure 1: A sample flow map.

Further analysis to obtain a deeper understanding about students' information processing strategies was accomplished by categorizing the statements in the flow maps into one of the following four levels of information processing modes, e.g., defining, describing, comparing, and inferring. Statements giving definition of a concept were categorized as "Defining mode". Statement 14 in Figure 1, "*Lewis structure is the demonstration of electrons of a molecule by dots*", for instance, gives a definition of Lewis structure. Therefore, this statement was categorized as defining. "Describing" is picturing a phenomenon or a fact. Statement 2 in Figure 1, *They are formed by gaining or losing an electron or electron sharing*, was categorized as describing mode, as it depicts the formation of chemical bonds. If two subjects or things were compared as in statement 9, in Figure 1 for instance, "*Strength of intramolecular bonds can be given as metallic bonds>ionic bonds>covalent bonds",* then it was categorized as comparing mode. Statements describing what will happen under certain conditions or interpreting phenomenon, for instance, statement 17 in Figure 1, "*We can make use of VSEPR model while drawing Lewis structures*", were categorized as inferring mode.

For reliability of the flow map method, an independent researcher was asked to evaluate a total of 10 flow maps and the inter-coder agreement was calculated as .89 (greater than .80 is generally accepted as the minimum for reliability). Therefore, this method was assumed to be reliable.

Statistical analysis in this study was accomplished through correlation analysis between the quantitative variables obtained from flow maps and the test scores. SPSS 20.0 was used for the data analysis.

Results of Research

Students' Test Achievements

Students' test scores are given in Table 1. According to this table, students' average score in MCT was 62.79, while their average in TFT was 67.21.

Table 1. Test scores of the students.

	N	Minimum	Maximum	Mean	Std. Deviation
MCT	68	28	88	62.79	13.490
TFT	68	32	90	67.21	14.497

Students' Cognitive Structure Outcomes

Regarding the first research question, students' cognitive structure outcomes obtained via the flow map method are given in Table 2. From this table it can be said that the "extend" of students' cognitive structures was, on average, 14.97; that is, students were able to write down an average of 14.97 statements. The "richness" of students' cognitive structures was, on average, 11.81, and the "integratedness of their cognitive structures was, on average, 0.43. Students have an average of 2.21 "misconceptions", which means about 14.8% of their statements were scientifically incorrect.

Table 2. Students' cognitive structure outcomes.

	Minimum	Maximum	Mean	Std. Deviation
Extend	4	31	14.97	5.87
Richness	3	29	11.81	5.86
Integratedness	.29	.53	.43	.051
Misconceptions	0	6	2.21	1.73

Flow maps derived from students' narratives to question forms were also examined from the point of information processing modes. The results are given in Table 3.

ISSN 1648–3898

Table 3. Students' information processing modes.

	Minimum	Maximum	Mean	Std. Deviation
Defining	1	11	4.56	2.31
Describing	0	24	8.82	4.79
Comparing	0	5	.82	1.26
Inferring	0	5	1.29	1.12

According to the results, students have an average of 4.56 statements in "defining" mode, in which they give the definition of a term or concept. They have an average of 8.82 statements in "describing" mode, in which a description of a situation or condition is given. Students gave an average of .82 statements in "comparing" mode and an average of 1.29 statements in "inferring" mode. These results show that students mostly "describe" information and they less frequently "compare" information. Keeping in mind that "comparing" and "inferring" modes require higher order thinking skills, it can be said that students tend to use the information processing modes (defining and describing) that require lower order thinking skills.

Relationship between Test Achievements and Cognitive Structures of the Students

Regarding the second research question, the relationship between test scores of the students and their cognitive structure outcomes was examined through correlation analysis. Table 4 shows the results of this analysis. According to Table 4 extend ($r=0.342$, $p<0.01$), richness ($r=0.505$, $p<0.01$) and integratedness ($r=0.497$, $p<0.01$) of students' statements were significantly correlated to their scores in TFT. From Table 4 it can also be said that richness ($r=0.252$, $p<0.05$) of students' statements was significantly correlated to their MCT scores. The results showed that students with more extended, richer and more integrated statements showed good performance on TFT, and students with richer structures were successful on MCT. In other words, the students who performed well on TFT were the ones with broader extend, richer and more integrated statements. However, students who performed well on MCT were only correlated with their "richness".

Table 4. Correlation between test achievements and cognitive structure outcomes of students.

		MCT	TFT
Extend	Pearson Correlation	.236	.342**
	Sig. (2-tailed)	.053	.004
Richness	Pearson Correlation	.252*	.505**
	Sig. (2-tailed)	.038	.000
Integratedness	Pearson Correlation	.111	.497**
	Sig. (2-tailed)	.366	.000
Misconceptions	Pearson Correlation	-.011	-.065
	Sig. (2-tailed)	.930	.600

Regarding the third research question, since TFT correlated many cognitive outcomes, it can be said that true-false tests better reflect students' cognitive structures.

A correlation analysis between test scores and the data on students' information processing modes was also accomplished, and the results are given in Table 5. According to these results, describing ($r=0.245$, $p<0.05$) and comparing ($r=0.253$, $p<0.05$) were significantly correlated with the MCT scores of the students, while describing ($r=0.326$, $p<0.01$), comparing ($r=0.449$, $p<0.01$) and inferring ($r=0.321$, $p<0.01$) were significantly correlated with TFT scores of the students.

Table 5. Correlation between test achievements and information processing modes of students.

		MCT	TFT
Defining	Pearson Correlation	.009	.055
	Sig. (2-tailed)	.945	.654
Describing	Pearson Correlation	.245*	.326**
	Sig. (2-tailed)	.044	.007
Comparing	Pearson Correlation	.253*	.449**
	Sig. (2-tailed)	.037	.000
Inferring	Pearson Correlation	.166	.321**
	Sig. (2-tailed)	.176	.008

Another correlation analysis was performed between the variables obtained from flow maps and the results are given in Table 6. It can be said from Table 6 that defining ($r=0.363$, $p<0.01$), describing ($r=0.865$, $p<0.01$), comparing ($r=0.584$, $p<0.01$) and inferring ($r=0.510$, $p<0.01$) were significantly correlated with the extend of students' cognitive structures.

Similarly, all information-processing modes (defining ($r=0.367$, $p<0.01$), describing (0.755, $p<0.01$), comparing ($r=0.634$, $p<0.01$) and inferring ($r=0.587$, $p<0.01$)) were significantly correlated with the richness of students' cognitive structures. Also, the comparing ($r=0.325$, $p<0.01$) and inferring ($r=0.409$, $p<0.01$) modes were significantly correlated with the integratedness of the statements.

Table 6. Correlation between the variables obtained from flow map analysis.

		Extend	Richness	Integratedness	Misconceptions
Defining	Pearson Correlation	.363**	.367**	.194	.027
	Sig. (2-tailed)	.002	.002	.112	.828
Describing	Pearson Correlation	.865**	.755**	.191	.292*
	Sig. (2-tailed)	.000	.000	.118	.016
Comparing	Pearson Correlation	.584**	.634**	.325**	-.100
	Sig. (2-tailed)	.000	.000	.007	.419
Inferring	Pearson Correlation	.510**	.587**	.409**	.130
	Sig. (2-tailed)	.000	.000	.001	.291

Misconceptions of the Students about the Research Topic

Regarding the fourth research question, the misconceptions of the students were also analysed through the flow map method. Results of this study showed that students have many misconceptions (an average of 14.8% of their statements) about the topic of chemical bonds. When the data were analysed, misconceptions were generally about the classification of chemical bonds. Confusion arose regarding inter- and intramolecular bonds and their types. Some students stated, "*H bonds, Van der Waals interactions and dipol-dipol interactions were types of intermolecular bonds*". Some others said, "*covalent bonds were a kind of intramolecular bonds*". It was also found that students have difficulties clarifying the octet rule, Lewis structure and VSEPR model. For instance, a student stated, "*Lewis structure of a molecule is to draw lines between atoms to complete all the atoms to 8 electrons in that structure*". Another one said, "*Lewis structure means the geometry of the molecule*". Interestingly, a few students had the misconception that "*Van der Waals interactions are about the bonds between gases*", possibly because they remember the Van der Waals equation from the topic on gases.

ISSN 1648–3898

Discussion

This study aimed to examine the cognitive structures of freshmen students studying science education regarding chemical bonding. It also aimed to investigate, if there was a relationship between students' cognitive structure outcomes and their scores on different types of tests. A question form consisting of five questions was administrated to obtain students' cognitive structures, and two types of tests: multiple-choice and true-false, were used to gather students' test scores. Data obtained from the question form were analysed through the flow mapping technique and quantitative variables regarding students' cognitive structures were formed. In order to obtain a deeper insight into students' cognitive structures, flow maps were also examined from the point of students' information processing.

Students' cognitive structure outcomes with regard to this study's first research question were evaluated and details are given in Table 2. Extend of students' cognitive structures was 14.97 on average; richness and integratedness of their cognitive structures were 11.81 and 0.43, respectively. According to these results, it can be said that students have low to medium cognitive structures about the research topic.

The results of the study revealed that there was a relationship between students' scores in the tests and some of the quantitative variables of the cognitive structure (with regard to the second research question). Students' MCT scores were significantly correlated with the richness of their cognitive structure outcomes ($r= 0.252$, $p<0.05$). Also, students' scores on TFT were significantly correlated with extend ($r=0.342$, $p<0.01$), richness ($r=0.505$, $p<0.01$), and integratedness ($r=0.497$, $p<0.01$) of their cognitive structures (Table 3). It can be concluded from these results that the tests reflect students' cognitive structures. Similarly, Tsai (1998) found that students' achievement in science was correlated with extend, richness and integratedness of their cognitive structures, and concluded that students' achievement in science is an important predictor in explaining their cognitive structure outcomes. Another study by Tsai (2001) also found a significant positive correlation between students' science achievement (by a multiple-choice test) and extend and richness of their cognitive structures. Oskay et al. (2012) also investigated a significant positive correlation between pre-service chemistry teachers' test scores on a Correct Concept Test and their flow map scores. According to Anderson et al. (2001), there is a significant correlation between the number of complex linkages in flow maps and students' scores from open-ended laboratory observations, scores from unit test and the number of concepts students wrote about in their essays.

The results of this study also state that, while there were significant correlations between students' test scores on TFT with some data (describing ($r=0.326$, $p<0.01$), comparing ($r=0.449$, $p<0.01$) and inferring ($r=0.321$, $p<0.01$)) from the point of information processing modes, students' MCT scores were significantly correlated to describing ($r=0.245$, $p<0.05$) and comparing ($r=0.253$, $p<0.05$) modes of information processing (Table 4). Therefore, it can be concluded that students who mostly describe and/or compare information are higher achievers in both tests. In addition, students who infer information get high scores from TFT. In other words, TFT scores can reveal students who have higher order thinking skills (i.e., inferring). In another study by Tsai (2001) it was also concluded that there was a correlation between students' science achievement and their describing and inferring modes of information processing.

In light of the findings of this study, it can be concluded that TFT tests can be thought of as more reflective of students' cognitive structures, since more correlations were found with TFT scores. Students face the right answer, as well as wrong choices in MCT; they need to discriminate among the options provided in order to choose the correct answer. Therefore, a MCT requires recognition. However, in TFT students are required to retrieve and generate an answer to a question. In other words, a TFT requires response production (Kang et al., 2007; McDaniel, Roediger & McDermott, 2007; Karpicke & Zaromb, 2010). Since it must be thought true-false type tests require more retrieval than multiple-choice type tests, TFT can reveal students who have higher order thinking skills and more cognitive structure outcomes.

It should also be noted that the testing effect was not reflected in the results of the study as students obtained higher scores from TFT (the first administered test). Therefore, the time between the administrations of both tests was thought to be adequate.

Many students have misconceptions regarding the topic of chemical bonding - i.e., they have difficulties about the formation of bonding, types of chemical bonding (Ozmen, 2004), electronegativity and polar covalent bonding (Burrows & Mooring, 2015), octet rule, molecular shape and bond polarity (Nahum et al., 2010). This study revealed that its participants also have some misconceptions about chemical bonding, mostly on the categorization of chemical bond types. This can be related to their lack of comparison and explanation skills as clarified by flow map analysis.

In conclusion, the flow map method is not just a simple method; it is also valuable in gathering the cognitive structure outcomes of the students. These outcomes can be correlated to scores of MCT and TFT. Therefore, it can be said that the tests reflect students' cognitive structures. Furthermore, TFT requires more retrieval process than MCT, and students with higher order thinking skills can be identified by TFT rather than by MCT.

Conclusions

The cognitive structure of students has always been a major concern of educators. Teaching processes are mostly evaluated by tests and students are thought successful if they obtain a good score from testing. Therefore, educators should know if a test reflects a student's cognitive structure. This study revealed that there is a relationship between the cognitive structure outcomes of students and their test scores. The size of the relationship depends on the type of test. Two types of test (MCT and TFT) were used in this study and according to the results TFT tests have a greater correlation with students' cognitive structure outcomes. TFT tests require students to generate an answer to the question; therefore, students need to retrieve the information. This might be the reason for the greater correlation. Therefore, it can be implemented that TFT type tests are applied in order to obtain a deeper insight into students' cognitive structures. However, it should be kept in mind that this study has some limitations. For example, the participants of this study were from one university, i.e., they have a similar academic background; the research topic was one which students have many misconceptions about; and just two types of tests were examined. Therefore, for future research it is recommended that the relationships with larger and different groups, with different research topics, and with different types of tests be examined.

References

Anderson, O. R., & Demetrius, O. J. (1993). A flow map method of representing cognitive structure based on respondents' narrative using science content. *Journal of Research in Science Teaching*, *30*, 953-969.

Anderson, O. R., Randle, D., & Covotsos, T. (2001). The role of ideational networks in laboratory inquiry learning and knowledge of evolution among seventh grade students. *Science Education*, *85* (4), 410-425.

Bischoff, P. J., Avery, L., Golden, C. F., & French, P. (2010). An analysis of knowledge structure, diversity and diagnostic abilities among pre-service science teachers within the domain of oxidation and reduction chemistry. *Journal of Science Teacher Education, 21*, 411-429.

Burrows, N. L., & Mooring, S. R. (2015). Using concept mapping to uncover students' knowledge structures of chemical bonding concepts. *Chemistry Education Research and Practice*, *16*, 53-66.

Butler, A. C., & Roediger, III. H. L. (2007). Testing improves long-term retention in a simulated classroom setting. *European Journal of Cognitive Psychology*, *19* (4), 514-527.

Carrier, M., & Pashler, H. (1992). The influence of retrieval on retention. *Memory and Cognition*, *20*, 633-642.

Chang, C. Y., Yeh, T. K., & Barufaldi, J. P. (2010). The positive and negative effects of science concept tests on student conceptual understanding. *International Journal of Science Education*, *32* (2), 265-282.

Dhindsa, H. S., & Anderson, O. R. (2004). Using a conceptual-change approach to help pre-service science teachers reorganize their knowledge structures for constructivist teaching. *Journal of Science Teacher Education*, *15* (1), 63-85.

Kang, S. H. K., McDermott, K. B., & Roediger III, H. L. (2007). Test format and corrective feedback modify the effect of testing on long-term retention. *European Journal of Cognitive Psychology*, *19* (4/5), 528–558.

Karpicke, J. D., & Zaromb, F. M. (2010). Retrieval mode distinguishes the testing effect from the generation effect. *Journal of Memory and Language*, *62*, 227-239.

McDaniel, M. A., Roediger, H. L., & McDermott, K. B. (2007). Generalizing test enhanced learning from the laboratory to the classroom. *Psychonomic Bulletin and Review*, *14* (2), 200-206.

Morgil, I., Erdem, E., & Yilmaz, A. (2003). Misconceptions in chemistry [in Turkish]. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi*, *25*, 246-255.

Nahum, T. L., 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.

Naylor, S., & Keogh, B. (1999). Constructivism in classroom: Theory into practice. *Journal of Science Teacher Education*, *10* (2), 93-106.

Oskay, O. O., & Dincol, S. (2011). Enhancing prospective chemistry teachers' cognitive structures in the topics of bonding and hybridization by internet-assisted chemistry applications. *World Journal of Educational Technology*, *3* (2), 90-102.

Oskay, O. O., Temel, S., Ozgur, S. D., & Erdem, E. (2012). Determination of preservice chemistry teachers' cognitive structures via flow map method and their knowledge level on "Greenhouse gases and their effects" topic. *Eurasian Journal of Physics and Chemistry Education*, *4* (1), 30-45.

Ozmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology*, *13* (2), 147-159.

ISSN 1648–3898

Roediger III, H. L., & Karpicke, J. D. (2006). Test-enhanced learning. *Psychological Science*, *17* (3), 249-255.

Roediger III, H. L., & Karpicke, J. D. (2006). The power of testing memory. *Perspectives on Psychological Science*, *1* (3), 181-210.

Selvi, M., & Yakisan, M. (2005). Exploring students' cognitive structures through flow maps: Ecological cycles [in Turkish]. *Journal of Turkish Science Education*, *2* (1), 29-30.

Tsai, C. C. (1998). An analysis of taiwanese eight graders' science achievement, scientific epistemological beliefs and cognitive structure outcomes after learning basic atomic theory. *International Journal of Science Education*, *20* (4), 413-425.

Tsai, C. C. (2001). Probing students' cognitive structures in science: The use of a flow map method coupled with a meta-listening technique. *Studies in Educational Evaluation*, *27*, 257-268.

Tsai, C. C., & Huang, C. M. (2002). Exploring students' cognitive structures in learning science: A review of relevant methods. *Journal of Biological Education*, *36* (4), 163-169.

Wu, Y. T., & Tsai, C. C. (2011). High school students' informal reasoning regarding a socio-scientific issue, with relation to scientific epistemological beliefs and cognitive structures. *International Journal of Science Education*, *33* (3), 371-400.

Yang, F. Y. (2004). Exploring high school students' use of theory and evidence in an everyday context: The role of scientific thinking in environmental science decision-making. *International Journal of Science Education*, *26* (11), 1345-1364.

Zimmerman, D. W. (2003). A new look at the influence of guessing on the reliability of multiple choice tests. *Applied Psychological Measurement*, *27* (5), 357-371.

Received: *June 08, 2015* Accepted: *August 20, 2015*

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