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REMEDIATING MISCONCEPTIONS CONCERNING CHEMICAL BONDING THROUGH CONCEPTUAL CHANGE TEXT

KİMYASAL BAĞLARLA İLGİLİ KAVRAM YANILGILARININ KAVRAMSAL DEĞİŞİM METİNLERİ KULLANILARAK DÜZELTİLMESİ

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ABSTRACT: The purpose of this study was to explore the effects of conceptual change texts oriented instruction on 9th grade students' understanding of chemical bonding concepts. in this study, the main aim of the preparation of conceptual change texts was to activate students' prior knowledge and misconceptions and to help them to understand the chemical bonding concepts through the use of explanations, analogies and examples. Analogies were used in the conceptual change texts to deal with students' misconceptions more effectively. The results revealed that conceptual change texts oriented instruction produced a positive effect on students understanding of scientific conceptions related to chemical bonding and elimination of misconceptions. The mean scores of both groups showed that students in the experimental group performed betler with respect to chemical bonding concepts.

Keywords: misconception, conceptual change, conceptual change text, analogy, chemical bonding.

ÖZET: Bu çalışmanın amacı kavramsal değişim metinlerinin 9. sınıf öğrencilerinin kimyasal bağlarla ilgili kavramları anlamalarına etkisini incelemektir. Bu çalışmada, kavramsal değişim metinlerinin hazırlanmasının temel amacı öğrencilerin sahip olduğu ön kavramaların ve kavram yanılgılarının fark edilmesini sağlamak ve onların kimyasal bağlarla ilgili kavramları öğrenmelerine açıklamalar, analojiler ve örnekler kullanarak yardım etmektir. Kavramsal değişim metinlerinin içinde analojilerin kullanılmasının sebebi öğrencilerin sahip oldukları kavram yanılgılarını daha etkili bir şekilde düzeltebilmektir. Sonuçlar kavramsal değişim metinleri kullanılarak uygulanan öğretim yönteminin öğrencilerin kimyasal bağlarla ilgili kavramları anlamalarında ve kavram yanılgılarının giderilmesinde olumlu bir etkisi olduğunu göstermiştir. Her iki gurubun başarı ortalamaları karşılaştırıldığında, deney gurubunun kimyasal bağlarla ilgili kavramlarda daha fazla başarı gösterdiği görülmüştür.

Anahtar Sözcükler: kavram yanılgısı, kavramsal değişim, kavramsal değişim metni, analoji, kimyasal bağlar

1. INTRODUCTION

In recent years, student understanding of scientific knowledge became the most important subject of the science education researchers (Fisher, 1985; Chambers and Andre, 1997). The aim of these studies is to improve students' understanding of science concepts and use them for intended purposes. Unfortunately, most of these research studies on science education have revealed that many students tend not to learn meaningfully and thus may have difficulty relating what is taught to them in science with other science ideas, and with real world experiences (Novak, 1988). The construction and reconstruction of meanings by learners requires that they actively seek to integrate new knowledge with knowledge already in their cognitive structure (Novak, 2002). That is, meaningful learning involves students in constructing integrated knowledge structures, which contain their prior knowledge, experiences, new concepts, and other relevant knowledge (Tsai, 2000). Many researchers studied the connection between meaning and learning. These studies have consistently shown that students come to school with varying experience with, ideas about, and explanations of the natural world. The ideas and explanations that students generate are

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often different from those of scientists. Some researchers have been described these differing frameworks as misconceptions (e.g., Fisher, 1985; Griffiths and Grant, 1985). Throughout this article, the term misconception was also used to refer to students' conceptions that are different from scientific conceptions. Characteristics of misconceptions can be summarized as follows: Misconceptions are resistant to change, persistent, well embedded in an individual's cognitive ecology, and difficult to extinguish even with instruction designed to address them (Fisher, 1985). Since new knowledge is linked to the existing conceptions, the misconceptions learners may hold generally hinder their subsequent learning (Taber, 2000; Palmer, 2001). Thus, misconceptions are really big obstacles to promote meaningful learning.

Misconceptions cover a large range of science concepts, so science educators in many countries have focused their attention upon students' misconceptions at science concepts (Osborne and Wittrock, 1983). Studies focusing on students' understanding of chemical bonding indicated that students had a considerable degree of misconceptions in various grade levels and these misconceptions are resistant to change by traditional teaching methods because most of current traditional teaching is focused on the content of the curriculum and on knowledge and information transmission. Although this will remain an essential aspect of teaching, it is no longer enough for an effective and stimulating learning process because knowledge cannot be transmitted to the learner's mind by the teacher. Therefore it should be used instructional strategies other than the traditional methods to remediate students' misconceptions. in the current study, we try to create meaningful learning in students about chemical bonding, and eliminate their misconceptions. Chemical bonding is fundamental to subsequent learning of various topics in chemistry (Boo, 1998). For example, it is essential to comprehend the nature of thermodynamics, molecular structure, chemical equilibrium, chemical reactions and some physical properties such as boiling points. Up to now, there have been numerous studies done to determine students' understanding and misconceptions about chemical bonding concepts (i.e., Birk and Kurtz, 1999; Boo, 1998; Harrison and Treagust, 2000; Nicoll, 2001; Taber, 2003). These studies revealed that most of the students have difficulty in understanding the concepts in chemical bonding (Tan, and Treagust, 1999). One possible reason of that understanding chemical bonding requires prerequisite knowledge such as the particulate nature of matter, electronegativity, energy and force in which students have difficulty in understanding. in addition, misconceptions can develop because chemical bonding involve relatively large number of abstract concepts (Coll and Taylor, 2001) and it includes words from everyday language are used with different meanings. in a study reported by Boo (1998), it was stated that everyday experiences and language usage can lead to arise misconceptions in chemical bonding. Boo (1998) reported that meaning of the term "bond" varied in daily life, and in school. in daily life, the term "bond" is often used in the sense of a physical link (i.e., a glue which holds two pieces of materials together), which entails the idea that energy is needed to make a link. Boo (1998) also suggested that the other source of misconceptions in chemical bonding would be the lack of understanding of the particulate nature of matters. Stili another source of students' misconceptions in chemical bonding concepts may comes from inappropriate language used by textbooks in explaining these concepts (De Posada, 1999). For instance, De Posada (1999) analyzed high school chemistry textbooks from 1974 to 1998 for grades 9-12 in terms of metallic bonding, how metallic bond is taught and whether textbooks are enough to cause meaningful learning. He designed a questionnaire to analyze textbooks and to fmd out whether they give opportunity for meaningful learning. Results showed that only a few textbooks' approach is constructivist. Moreover, analogies used in the textbooks present more differences between target and source than similarities, thus these analogies cause misconceptions in students who cannot think in abstract terms and students couldn't understand the relationship between the theoretical model and experimental facts. These fındings about sources of misconceptions in chemical bonding are crucial because by taking them into account, removing of misconceptions could be achieved.

Although the need to identify students' misconceptions concerning chemical bonding concepts has been widely expressed in science education literatüre, there are few studies on how these misconceptions can be treated. However, to promote meaningful learning, ways must be found to eliminate ör prevent misconceptions. Several research studies suggested that instructional strategies leading to conceptual change could be employed to eliminate students' misconceptions. Conceptual change implies that a learner actively and rationally replaces existing prescientific conceptions with scientifically acceptable explanations as new propositional linkages are formed in his conceptual framework. Many constructivist science educators have chosen the use of conceptual change approaches in science education (Abd-El-Khalick and Akerson, 2004; Dhindsa and Anderson, 2004; Luera, Otto and Zitzewitz, 2005). The best-known conceptual change model has been that of Posner, Strike, Hewson, and Gertzog (1982), which describes the conditions of conceptual change. This model suggested that four conditions must exist before conceptual change likely to occur: (1) students must experience dissatisfaction with their existing conception; (2) they must be able to understand the new conception; (3) the new conception must seem plausible to them; and (4) the new conception must appear to be betler at explaining their experiences and observations than their previous conception. Only after these conditions have been met are students more likely to experience conceptual change, discarding their naive conception for a scientifically accepted öne.

Several science education researchers (Hynd, McWhorter, Phares, and Suttles, 1994) have showed that conceptual change approach provided a better acquisition of scientifıc conceptions and removing alternative conceptions. One of the conceptual change instructional strategies is the use of conceptual change texts. These texts are designed to make readers aware of the inadequacy of their intuitive ideas and help students understand and apply the target scientifıc concept through the use of explanations and examples (Hynd et.al.1994). in other words, the meaning of the textual information is not derived wholly from the reading of these texts, but from the interaction of the reader with textual information. in these texts, the identifıed misconceptions of the students are given fırst and then students are informed of the scientifıc explanations supported by examples to create dissatisfaction. Several researchers reported the effectiveness of conceptual change texts on creating conceptual change and promoting meaningful learning (i.e., Chambers and Andre, 1997; Tekkaya, 2003). For example, Hynd et.al (1994) used conceptual change texts to create conceptual conflict and meaningful learning in students about Newton's law of motion. During their instruction, the teacher directs students to read the conceptual change text silently, and, at the end of the paragraph in which a question is posed, students are asked to stop reading. The evidence is presented that a misconception is incorrect ör a concept is explained signifıcantly. Then the teacher discusses the statements in the text with students. After their study, Hynd et.al (1994) found that conceptual change text facilitated conceptual understanding of Newton's law of motion. in separate studies, Wang and Andre (1991) and Chambers and Andre (1997) also showed that conceptual change text led to better understanding of electricity concepts compared to traditional text. in the current study, conceptual change texts were chosen to remove students' misconceptions because teachers often rely on texts to promote learning (Chambers and Andre, 1997), and students can use texts when the teacher is unavailable. So, learning from textbooks is an important part of the educational process. Moreover, conceptual change texts can be used effectively in both small and large classrooms to facilitate conceptual change (Chambers and Andre, 1997).

Many researchers agree that using analogies as explanatory devices can be a useful way to teach science (i.e., Glynn, 1997; Rule, and Furletti, 2004; Yanowitz, 2001), and facilitate text learning (Glynn and Takahashi, 1998). These studies revealed that analogies provide the learners opportunities to work with their existing concepts and construct their knowledge (Beall, 1999). As they construct knowledge, learners seek to give meaning to the information they are learning, and the comparative nature of analogies promotes meaningful learning. Moreover, the linkage between new understandings and the real world motivates students to learn more (Heywood, 2002), and analogies are perceived as effective ways to arouse students' interest and curiosity. Duit (1991) also stated that analogies are believed to help student learning by providing visualization of abstracts concepts, by helping compare similarities between objects and events in the students' world and the phenomenon under discussion. Thus, we used analogies in the conceptual change texts to help students to make science interesting and to explain the abstract concepts of chemical bonding. During the study, the limitations of each analogy given in the conceptual change texts also discussed in the classroom.

As a summary of many research studies, it was found that students have many misconceptions about chemical bonding concepts, and these misconceptions are resistance to change. Also, if these misconceptions could not be eliminated, they affect further learning negatively. For this reason, in the present study, we concerned with students' misconceptions and with instructional strategies (conceptual change texts and analogies) to improve the understanding of chemical bonding concept.

2. METHODOLOGY

2.1 Subjects

The subjects of this study consisted of 41 ninth grade students enrolled in a chemistry course in a private high school. The age of the students was about 14-15 years old. Students were selected from the two intact classes whose teacher volunteered to participate in this study. One of two instructional methods was randomly assigned to each class. The data were obtained from 21 students in the experimental group using conceptual change texts oriented instruction accompanied with analogies and 20 students participating in the control group receiving traditional instruction.

2.2 Instruments

In this study, Chemical Bonding Concepts Test (CBCT) was developed by the researchers to determine students' understanding of chemical bonding concepts. The content of the test was determined by examining textbooks, instructional objectives for the chemical bonding unit and related literatüre. During the developmental stage of the test, the instructional objectives of chemical bonding unit were determined to investigate whether the students achieved the behavioral objectives of the present study. The test included 21 items based on the two-tier multiple-choice format. The first tier of each item examined the content knowledge with two, three ör four alternatives. The second tier consisted of four reasons for the first tier. These reasons include öne scientifically acceptable answer supporting the desired content knowledge in the first tier and three misconceptions identified from the literatüre related to students' misconceptions with respect to chemical bonding concepts (Birk and Kurtz, 1999; Coll and Taylor, 2001; Nicoll, 2001) and opinions of chemistry teachers. A students' answer to an item was considered correct if the students selected both the correct content choice and the correct reason. For the content validity, each item in the test was examined by a group of experts in science education, chemistry and by the classroom teachers. The internal consistency reliability of this test was found to be 0.73. The following is an example of the test items:

Example 1. What can be said about the polarities of CCl_4 and $CHCl_3$?

(I) Both of them are polar

(II) Both of them are nonpolar

(III) $CHCl_3$ is polar and the other CCl_4 is nonpolar

Reason:

A) A molecule is nonpolar, only if atoms of molecule have same electronegativities.

B) If molecule has tetrahedral shape, it is nonpolar.

C) If molecule contains polar bonds it is a polar molecule.

D)Polarity of molecule depends on the polarity of its bonds and shape of the molecule.

Some misconceptions obtained from related literatüre and opinion of chemistry teachers are given in Table 1. Those misconceptions were used in the test items as distractors.

Table 1. Some misconceptions in chemical bonding

1. Bonds are material connections rather than forces.
2. Bonds are only formed between atoms that donate \ accept electrons
3. Metals and nonmetals form molecules
4. Ionic charges determine the polarity of the bond.
5. Equal sharing of the electron pair occurs in ali covalent bonds so that ali covalent bonds are nonpolar
6. Polar molecules form when it has polar bonds
7. Atoms are bonded together to fiil their octets.
8. Nitrogen atoms can share five electron pairs in bonding.
9. Intermolecular forces are forces within a molecule.

2.3. Procedure

The purpose of this study was to explore whether the conceptual change texts oriented instruction produced a positive effect on 9th grade students' understanding of chemical bonding and elimination of their misconceptions. This study was conducted over a period of 8 weeks. The same chemistry teacher gave the classroom instruction for both groups. A total of 41 ninth grade students from two intact science classes were involved, and the quasi-experimental design was used in the study. One of the classes was assigned as the experimental group instructed through the conceptual change texts and the other group was assigned as the control group instructed through traditional instruction. Both groups were instructed on the same content of the chemistry course. The topic related to chemical bonding concept was covered as a part of the regular curriculum in the chemistry schedule course.

In the control group, the teacher used lecture and discussion methods to teach chemical bonding concepts without consideration of the students' misconceptions. The students studied the textbooks on their own before the class hour. The instruction was teacher centered. The teacher explained each concept and asked questions by directing students' answers. Also, the students were provided with the worksheets. Worksheets developed specifically for each lesson were used as practice activities; they required written responses and reinforced the concepts presented in the classroom sessions. They were collected and corrected by the teacher, and the students reviewed their sheets after correction.

Students in the experimental group worked with the conceptual change texts through teacher lecture. Prior to the beginning of treatment, teacher mentioned the characteristics of conceptual change texts and analogies. The researchers in light of the information obtained from a literatüre review prepared conceptual change texts. The conceptual change texts were written on the following topics: the defınition of a bond, types of bonds, polarity of bonds and molecules, and electron pair repulsion theory. They were given to students to be read 2 days before the class hour when the related topic would be covered. The main aim of the preparation of conceptual change texts was to suggest conditions in which misconceptions can be replaced into scientifıc conceptions. So, conceptual change texts were constructed by use of Posner et al.'s (1982) conceptual change model. Firstly, students were asked questions to make them aware of their naive conceptions. Some questions in the texts were: What is the chemical bond? Why does chemical bond occur? Does bonding occur only between atoms that give and accept electrons? How two hydrogen atoms are held together? Firstly, students were allowed to discuss these questions in the conceptual change text by using their previous knowledge related to chemical bonding concepts. During discussions, they had cognitive conflict when their ideas were not adequate to answer these questions and they dissatisfıed with their existing conceptions. This situation supported the fırst condition of Posner et al.'s (1982) model. Then, the teacher directed students to read the paragraph in which the evidence was presented that the typical misconception was incorrect ör a scientifically correct explanation of the concept was provided. Since chemical bonding is an abstract topic, analogies were also used to explain the concept in the conceptual change texts. For example, most students thought that bonds are "things" that holds atoms together but they could not explain exactly what the "thing" is. They believed \vrongly that chemical bonds are material connections simply. However, there are forces that hold the atoms of elements together in a compound. These forces are called as "chemical bonds". in other words, the "thing" between atoms you mentioned is the electrostatic forces that hold atoms together. in the text, magnet analogy was used to explain this. Students were familiar with magnets. The like poles of magnets repel each other, \vhile the unlike poles attract each other. Also, atoms are electrically charged, thus attract and repel like the "poles" of a magnet. Attractions between particles of atoms lead to chemical bond and holds structure together. Thus, bond means electrostatic forces between the atoms. By using analogies in the conceptual change text, we also accomplished Posner et al.'s (1982) conditions of intelligibility and plausibility because it helps to stress on the students' preconceptions, and make relationship between their conceptions and scientific knowledge. Finally, it was suggest students to replace ör integrate the newly learned concepts with their existing conceptions. Moreover, students saw usage of information they obtained in explaining other situations. Therefore, Posner et al.'s (1982) last condition (fruitfulness) was also achieved.

Homework questions were also given to the students in conceptual change texts. These questions required students create their own analogies for real model and then discuss the like and unlike points of their analogies with real model. For example, borrowing a book from a library was used as an analogy to explain how two hydrogen atoms are held together in H_2 molecule. it was stated that when you get the book from library, you are treated as if it belongs to you; yet at the same time, it is counted as being part of the library collection. Then students discussed the shared and unshared points of this analogy with reality. For shared point, they stated that when you borrow a book from a library, library and you possess a book simultaneously. it is similar to electrons between hydrogen atoms, which are possessed simultaneously by two nuclei of hydrogen atoms and they have been counted twice. For unshared point, they said that in H_2 partide, both H atoms simultaneously attract electrons and equally share them but when you borrow a book, only you use a book .Also, in H_2 partide, electrons spend most of their time in the overlap area of the shells that is shared, but book is mostly with you. Lastly, they pointed that in H_2 partide, both H atoms share their öne electron with the other öne, but you do not have to share your own book with library for borrowing a book from library. Ali of these answers of students were discussed in the classroom. Because, the use of classroom discussions of analogies has been advocated as a way to increase awareness of their limitations and encourage critical thinking (Webb, 1985; Orgill and Bodner, 2004).

3. RESULTS

Chemical Bonding Concepts Test (CBCT) was given to ali subjects of the study as pre-and post-test. Independent-samples t-test was used to analyze the pre- and post- test data at a significance level of 0.05. The result of the pre-test showed that there was no significant mean difference at the beginning of the treatment between the experimental and the control group in terms of students' understanding of chemical bonding concepts ($t = 0.53$, $p>0.05$). The results of the post-test indicated that there was a significant mean differences between the performance of the students in the experimental and the control group ($t= 3.23$, $p < 0.05$). That is, using conceptual change texts oriented instruction caused a better acquisition of chemical bonding concepts.

4. DISCUSSION AND CONCLUSION

Many students have difficulty in learning science because much of their learning tends to involve memorization of facts in which newly learned materials is not related in ways that make sense to the learner (Novak, 1988). However, learning in science requires more than just adding new concepts to the knowledge. it often requires realignment in thinking and construction of new ideas that may be in conflict with earlier ideas. Additionally, research studies have consistently shown that students do not come to classroom with blank slates (Posner, et.al., 1982). in fact, students from the moment of birth infants need to make sense of their world. They construct their own explanations for how and why things behave as they do. So, long before they begin formal schooling, children have made meaning of their everyday experiences. And, they will construct new knowledge on their previous conceptions. As accepted by many scientists, when these students' previous conceptions are different from the views of scientists, these differing frameworks affect further learning negatively. Throughout this article, the term misconception was used to refer to students' conceptions that are different from scientific conceptions. Since new knowledge is linked to the existing conceptions, misconceptions are really big obstacles to promote meaningful learning. So, to promote meaningful learning, ways must be found to eliminate ör prevent misconceptions. Conceptual change approach could be employed to eliminate students' misconceptions. Conceptual change implies that a learner actively and rationally replaces existing prescientific conceptions with scientifically acceptable explanations as new propositional linkages are formed in his conceptual framework. The model of conceptual change developed by Posner et al.(1982) proposed that four conditions must occur before students can replace an existing misconception. This theory holds that learners must become dissatisfied with their existing conceptions as well as fmd new concepts intelligible, plausible, and fruitful, before conceptual restructuring will occur. The conceptual change text used in this study was designed according to Posner et al.'s (1982) instructional theory. in the experimental group, the main aim of the preparation of conceptual change texts was to activate students' prior knowledge and misconceptions and to help them to understand and apply the chemical bonding concepts through the use of explanations, analogies and examples. We used analogies in the texts to deal with students' misconceptions more effectively. However, we observed that some student misconceptions are very resistant to instructional change, and some students persist in giving answers consistent with their misconceptions even after instruction. Some examples of students' misconceptions were presented in the Table 1. For example, both group students showed low achievement for the question related to electrical conductivity of graphite. After the treatment, none of the students in the control group gave correct answer to the two parts of this question whereas only 11.8% of the students in the experimental group answered it correctly. Among control group students, the common misconceptions were that electrons escape from the covalent bonds in graphite and are free to move within the molecule (41.2%). And, most of the experimental group students thought that graphite could conduct electricity because it has layers of carbon atoms (41.2%). This misconception might because they were taught that mobile electrons and ions conduct electricity and therefore the layers of atoms could also electricity because they could move. Although both groups had some misconceptions even after the treatment, this study also showed that more students in the experimental group removed their misconceptions after instruction than students in the control group. For example, at the end of the study, most experimental group students change their wrong conceptions about electron pair repulsion theory, the polarity of molecules, and Van der Waals forces, but most control group students did not change their misconceptions in these topics. in this study, it can be stated that traditionally designed chemistry instruction did not facilitate conceptual change because teacher strategies were dependent on teacher exploration without consideration of students' misconceptions. Additionally, students in the control group were passive listeners and they are not constructing their knowledge whereas students in the experimental group were allowed to construct their knowledge by using conceptual change approach. This might cause the difference in the concept tests scores of students in control and experimental groups. However, in the present study, the research method was barely adequate for understanding the effects of conceptual change text instruction on elimination of students' misconceptions about chemical bonding because the subjects were limited to 41 students in two classrooms.

In summary, this study showed that conceptual change text instruction led to better understanding of chemical bonding concepts and elimination of students' misconceptions than traditionally designed instruction. Also, it was found that students have difficulties in understanding chemical bonding concepts, and misconceptions of students about these concepts are resistance to change. If these misconceptions could not be eliminated, they affect further learning negatively.

Therefore, teachers, curriculum developers and textbook writers must be aware of students' misconceptions in chemical bonding and try to prevent them from occurring.

REFERENCES

AAbd-El-Khalick, F., & Akerson, V. L. (2004). Learning about nature of science as conceptual change: Factors that mediate the development of preservice elementary teachers' views of nature of science. *Science Education*, 88(5), 785-810.

Beall, H. (1999). The ubiquitous metaphors of chemistry teaching. *Journal of Chemical Education*, 76, 366-368.

Birk, J.P. and Kurtz, M.J. (1999). Effect of experience on retention and elimination of misconceptions about molecular structure and bonding. *Journal of Chemical Education*, 76(1), 124-128.

Boo, K. H. (1998). Students' understanding of chemical bond and the energetic of chemical reactions. *Journal of Research in Science Teaching*, 35(5), 569-581.

Chambers, S. K. & Andre, T. (1997). Gender, prior knowledge, interest, and experience in electricity and conceptual change text manipulations in learning about direct current. *Journal of Research in Science Teaching*, 34(2), 107-123.

Coll, R.K. and Taylor, T.G.N. (2001) Using constructivism to inform tertiary chemistry pedagogy. *Chemistry Education: Research and Practice in Europe,* 2 (3), 215-226.

De Posada, J. M. (1999). The presentation of metallic bonding in high school science textbooks during three decades: science educational reforms and substantive changes of tendencies. *Science Education,* 83, 423-447.

Dhindsa, H.S. & Anderson, O.R. (2004). Using a Conceptual-Change Approach to Help Preservice Science Teachers Reorganize Their Knowledge Structures for Constructivist Teaching. *Journal of Science Teacher Education,* 15(1), 63-85.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education,* 75(6), 649-672.

Fisher, K. M. (1985). A misconception in biology: Amino acids and translation. *Journal of Research in Science Teaching, 22,* 53-62.

Glynn, S. M. (1997). *Learning from science text: Role of an elaborate analogy.* College Park, MD: National Reading Research Center.

Glynn, S. M. & T. Takahashi, (1998). Learning from analogy-enhanced science text. *lournal of Research in Science Teaching, 35,* 1129-1149.

Griffiths, A. K, & Grant, B.A.C. (1985). High school students' understanding of food webs: Identification of a learning hierarchy and related misconceptions. *Journal of Research in Science Teaching, 22,* 421-436.

Harrison, A. G. & Treagust, D. F. (2000). Learning about atoms, molecules, and chemical bonds: a case study of multiple model use in grade 11 chemistry. *Science Education,* 84, 352-381.

Heywood, D. (2002). The Place of Analogies in Science Education. *Cambridge Journal of Education,* 32 (2), 233-247.

Hynd, C. R., McWhorter, J. Y., Phares, V. L. & Suttles, C. W. (1994). The role of instructional variables in conceptual change in high school physics topics. *Journal of Research in Science Teaching,* 31(9), 933-946.

Luera, G.R., Otto, C.A., & Zitzewitz, P.W. (2005). A conceptual change approach to teaching energy & thermodynamics to pre-service elementary teachers. *Journal of Physics Teacher Education Online,* 2(4), 3-8.

Nicoll, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education,* 23(7), 707-730.

Novak, J. D. (1988). Learning science and the science of learning. *Studies in Science Education,* 15, 77-101.

Novak, J.D. (2002). Meaningful learning: The essential factor for conceptual change in limited ör inappropriate prepositional hierarchies leading to improvement of learners. *Science Education,* 86(4), 587-571.

Orgill, M., & Bodner, G. M. (2004). What Research Telis Us About Using Analogies to Teach Chemistry. *Chemical Education: Research and Practice,* 5(1), 15-33.

Osborne, R. J. & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education,* 67(4), 489-508.

Palmer, D. (2001). Students' alternative conceptions and scientifically acceptable conceptions about gravity. *International Journal of Science Education,* 23(7), 691-706.

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. (1982). Accomadation of a scientific conception: toward theory of conceptual change. *Science Education,* 66(2), 211-227.

Rule, A. C. & Furletti, C., (2004). Using form and function analogy object boxes to teach human body systems, *School Science and Mathematics,* 104, 155-169

Taber, K. S. (2000). Multiple frameworks? Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education,* 22, 4, 399 - 417.

Taber, K. S. (2003). Mediating mental models of metals: acknowledging the priority of the learner's prior learning. *Science Education,* 87, 732-758.

Tan, K. D. and Treagust, D. F. (1999). Evaluating students' understanding of chemical bonding. *School Science Review,* 81(294), 75-83.

Tekkaya, C. (2003). Remediating high school students' misconceptions concerning diffusion and osmosis through concept mapping and conceptual change text. *Research in Science & Technological Education,* 21(1), 5-16.

Tsai, C. (2000). Enhancing science instruction: the use of 'conflict maps'. *International Journal of Science Education,* 22, 285-302.

Wang, T. & Andre, T. (1991). Conceptual change text versus traditional text and application questions versus no questions in learning about electricity. *Contemporary educationalpsychology,* 16, 103-1.

Webb, M. J. (1985). Analogies and their limitations. *School Science and Mathematics,* 85, 645-650.

Yanowitz, K.L. (2001). The effects of analogies on elementary school students' learning of scientific concepts. *School Science and Mathematics,* 101, 133-142.