PRE-SERVICE CHEMISTRY TEACHERS' CONCEPTUAL UNDERSTANDINGS OF SOLUTION CHEMISTRY IN THE CONTEXT OF MULTI-REPRESENTATIONAL INSTRUCTION

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ABSTRACT

PRE-SERVICE CHEMISTRY TEACHERS' CONCEPTUAL UNDERSTANDINGS OF SOLUTION CHEMISTRY IN THE CONTEXT OF MULTI-REPRESENTATIONAL INSTRUCTION

This study aimed to explore the effectiveness of Multi-Representational Instruction in pre-service chemistry teachers' conceptual understandings of solution chemistry and to identify the characteristics of individual participants' conceptual understandings of the types of solutions from before beginning the instruction to immediately after completing the instruction to five-months after completing the instruction. This study was conducted with third-year pre-service chemistry teachers at a state university in Istanbul in the fall of 2010. There were a total of 14 participants, including 10 female and four male. It was a mixed method study combined with quantitative and qualitative research methods. Quantitative part of the study included a one-group quasi-experimental design with pre, post, and delayed post-interview. Qualitative part of the study involved verbal data (e.g., interviews, collection of student artifacts, field notes) and descriptive data analysis procedures, but the main data source was interviews. During the interviews, the questions were asked according to an interview protocol which was modified from a two-tailed diagnostic instrument developed by Adadan and Savasci (2012). In the quantitative analysis, the numeric points were given to each participant's responses about the different aspects of solution chemistry. Their total scores were calculated for the pre, post, and delayed post-interview. In the qualitative analysis, each participant's kinds of conceptual understandings about the types of solutions were identified for the pre, post and delayed post-interview, and the changes in each participant's kinds of conceptual understandings from pre to post and then to delayed post-interview were examined. According to data analysis results, it was concluded that the Multi-Representational instruction were effective for developing the participants' conceptual understandings of solution chemistry from pre to post-instruction and maintaining such conceptual understandings over a five-month period.

ÖZET

HİZMET ÖNCESİ KİMYA ÖĞRETMENLERİNİN ÇOKLU GÖSTERİM ÖĞRENME ORTAMINDA ÇÖZELTİLER İLE İLGİLİ KAVRAMSAL ANLAMALARI

Bu çalışma çoklu gösterim uygulamasından önce, tamamlandıktan hemen sonra ve beş ay sonra hizmet öncesi kimya öğretmenlerinin çözeltiler hakkındaki kavramsal anlamalarının nasıl etkilediğini ortaya çıkarmayı ve her bir katılımcının çözelti türleri ile ilgili kavramsal anlama çeşitlerini belirlemeyi amaçlamıştır. Bu çalışma 2010 yılı güz döneminde İstanbul'daki bir devlet üniversitesinin üçüncü sınıf hizmet öncesi kimya öğretmenleri ile yapılmıştır.10'u kadın, dördü erkek olmak üzere çalışmaya toplamda 14 katılımcı katılmıştır. Çalışmada nitel ve nicel yöntemler birlikte kullanılmıştır. Çalışmanın nicel bölümünde, çoklu gösterim uygulamasından önce, hemen sonra ve beş ay sonraki görüşmeleri içeren deneysel yöntem uygulanmıştır. Çalışmanın nitel bölümünde ise, sözel veriler (örneğin, görüşmeler, alan notları, öğrenci çalışma kağıtları) ve tanımlayıcı veri analiz prosedürleri uygulanmıştır. Görüşmeler süresince katılımcılara daha önceden Adadan and Savaşçı (2012) tarafından geliştirilen görüşme protokolündeki çözeltiler kimyası ile ilgili sorular sorulmuştur. Veri analizinden önce görüşme transkriptlerinin tamamı okunmuştur. Nicel analiz yapılırken, herbir katılımcının çözeltiler kimyası ve çözelti türleri ile ilgili açıklamalarına sayısal puanlar verilmiştir ve katılımcıların çoklu gösterim uygulamasından önce, hemen sonra ve beş ay sonraki görüşmelerindeki toplam puanları hesaplanmıştır. Nitel analiz yapılırken, herbir katılımcının çözelti türleri ile ilgili kavramsal anlama düzeyleri ve katılımcıların çalışma boyunca kavramsal anlamalarındaki ilerleyişleri belirlenmiştir. Çalışmada toplanan verilerin analizi sonucunda, çoklu gösterim uygulamasının katılımcıların çözeltiler kimyası ile ilgili kavramsal anlamalarını geliştirmede etkili olduğu ve bu etkinin uzun süre devam ettiği sonucuna varılmıştır.

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LIST OF ACRONYMS/ABBREVIATIONS

MR	Multi-Representations
PNM	Particulate Nature of Matter

1. INTRODUCTION

"The whole of science is nothing more than the refinement of everyday thinking" (Einstein, 1954).

As Einstein suggested in the above quotation, science derives from the *refinement of* our conceptions about daily life. Since scientists use their pre-existing knowledge in the process of making science, science educators should also pay attention to students' existing knowledge before constructing the scientific knowledge. However, Duit and Treagust (2003) found that students' pre-existing knowledge is not generally in harmony with the science views or even it contradicts with them, and resistant to change. Students even enter the university with these alternative conceptions about a phenomenon. Pre-service teachers also have different alternative conceptions about the diverse phenomena. It is important to identify these conceptions, because pre-service teachers should be aware of their own alternative conceptions and change such nonscientific ideas with the scientific ones before teaching these concepts to their students. They should also learn how to change them with scientific explanations through a well-designed instruction.

Many research studies have been conducted to identify students' conceptions and their roles in teaching and learning science during the past three decades (Blanco and Prieto, 1997; Dahsah and Coll, 2008; Devetak *et al.*, 2007; Ebenezer and Erickson, 1996; Longden *et al.*, 1991; Mulford and Robinson, 2002; Naah and Sanger, 2013; Prieto *et al.*, 1989; She, 2004; Smith and Metz, 1996; Smith and Nakhleh, 2011; Trundle *et al.*, 2002; Trundle *et al.*, 2006). One of the topics in which many researchers were interested was about students' conceptual understandings of solution chemistry (Adadan and Savasci, 2012; Blanco and Prieto, 1997; Devetak *et al.*, 2007; Ebenezer and Erickson, 1996; Longden *et al.*, 1991; Naah and Sanger, 2013; Prieto *et al.*, 1989; She, 2004; Smith and Metz, 1996; Smith and Nakhleh, 2011). Research indicated that students have many alternative conceptions about solution chemistry, because solution chemistry requires deep understanding of the concepts such as particulate theory of matter, volume, weight, density, physical and chemical change (Uzuntiryaki and

Geban, 2005). The solution chemistry is one of the targeted concept at the current high school chemistry curriculum in Turkey (Milli Egitim Bakanligi—Talim Terbiye Kurulu Baskanligi [MEB-TTKB], 2013). However, how such topic is taught for the high school classrooms is unsuccessful in terms of addressing students' alternative conceptions, because it relies heavily on didactic textbook-based approaches (Adadan and Savasci, 2012).

Science educators developed different instructional methods to change students' alternative conceptions of solution chemistry. In doing so, they used a wide variety of intervention such as: ‘conceptual change text’ (Calik *et al.,* 2007a; Uzuntiryaki and Geban, 2005) ‘using particle model of matter with emphasis on discussions’ (Kabapınar *et al.*, 2004), ‘constructivist-based teaching model’ the four step constructivist teaching (Calik *et al.*, 2007b, 2009), and ‘the dual situated learning model’ (She, 2004). There are few studies, although literature suggested that Multi-Representational (MR) instruction would be effective in order to promote conceptual change and to enhance conceptual understanding in chemistry education (Ainsworth, 1999; Gabel, 1999; Johnstone 1991; Kirschner 2002). In addition, such instructions are supported by MR learning theories: (i) Dual Coding Theory (Paivio, 1986; 1991), (ii) Cognitive Theory of Multimedia Learning (Mayer, 2001; 2003), and (iii) Cognitive Load Theory (Sweller and Chandler, 1994).

In the current study, conceptual change is aimed to change pre-service chemistry teachers’ conceptual understanding of the solution chemistry toward a scientific understanding through MR instruction. The reasons for conducting this particular study follow: (i) Solution chemistry concept is very important since it establishes a basis for understanding other chemistry concepts such as the concepts of chemical equilibrium, electrochemistry, acids and bases, and the rate of chemical reactions (Calik, *et al.* 2010; Prieto *et al.,* 1989); and (ii) Pre-service teachers, like other students, also have alternative conceptions about solution chemistry (Pinarbasi *et al.*, 2009; Calik *et al.,* 2007b); (iii) Multiple-representations are useful tools for meaningful learning in chemistry (Ainsworth, 1999; Gabel, 1999; Johnstone, 1991; Kirschner, 2002).

1.1. Purpose of the Study

The main purpose of the current study is to explore the effectiveness of MR instruction on pre-service chemistry teachers' conceptual understandings of solution chemistry. More specifically, this study aimed to identify if there was any difference in pre-service chemistry teachers' conceptual understandings of solution chemistry and types of solutions from the pre-interview to the post to the delayed post-interview. The current study also intended to describe pre-service chemistry teachers' conceptual understandings about the types of solutions according to the solubility of a solute before, immediately after, and five-months after they completed the MR instruction.

1.2. Research Questions

The following research questions guided the current research study:

(i) How do pre-service chemistry teachers' conceptual understandings of solution chemistry differ from before beginning the MR instruction to immediately after completing the instruction to five-months after completing the instruction?

(ii) How do pre-service chemistry teachers' conceptual understandings of types of solutions differ from before beginning the MR instruction to immediately after completing the instruction to five-months after completing the instruction?

(iii) What kinds of conceptual understandings held by pre-service chemistry teachers about the types of solutions before, immediatey after, and five-months after completion of the MR instruction?

1.3. Significance of the Study

Since chemistry tries to explain the structure, behavior, and properties of matter, and the changes it undergoes, understanding chemistry depends on understanding it at the molecular level which is not possible to observe by naked eye or even a microscope. Students have experiments in the school in order to observe how the chemical reactions happen. However, they observe it at the macroscopic level, and they are unable to observe the behavior of the atoms, molecules, and ions during the reaction. Thus, chemistry concepts are complex to understand for many students (Gabel, 1999). In addition, using symbolic expressions, such as graphs, mathematical symbols, formulas, and reaction equations, molecular structure diagrams to express relationships at the macroscopic and submicroscopic levels make chemistry more complex to understand (Gabel, 1999). However, using multiple representations in the instructional designs can help students to translate information expressed in symbolic representation to another one (Gabel, 1999). Three levels of representation (macroscopic, submicroscopic, and symbolic) were used in the current instructional design for promoting pre-service chemistry teachers conceptual understandings of solution chemistry.

The topic of solution chemistry was chosen for the current study, because solution chemistry establishes a basis for understanding other chemistry concepts such as the concepts of chemical equilibrium, electrochemistry, acids and bases, and the rate of chemical reactions (Calik and Ayas, 2005). In addition, the other research studies either identified the students' alternative conceptions (Abraham *et. al.*, 1994; Adadan and Savasci, 2012; Azizoglu *et al.*, 2006; Blanco and Prieto, 1997; Calik, 2005; Calik and Ayas, 2005; Devetak *et al.*, 2007; Ebenezer and Erickson, 1996; Fensham and Fensham, 1987; Kalin and Arikil, 2010; Longden *et al.*, 1991; Naah and Sanger, 2013; Smith, 2007; Pinarbasi *et al.*, 2006; Pinarbasi and Canpolat, 2003; Prieto *et al.*, 1989; Smith and Metz, 1996; Smith and Nakhleh, 2011) or they tried to address students' alternative conceptions of solution chemistry by designing the particular instructional approaches (Calik *et al.*, 2007 a, b, 2009, 2010; Kabapınar *et al.*, 2004; Mulford and Robinson, 2002; She, 2004; Uzuntiryaki and Geban, 2005). However, different from the previous studies, the current study used 'the multi-representational instruction' to encourage conceptual change in pre-service chemistry teachers' understanding of solution chemistry.

Majority of the previous studies which identified students' conceptions about solution chemistry focused on dissolving phenomena (Abraham and Williamson, 1994; Calik, 2005; Calik *et al*., 2007b; Calik *et al*., 2007a; Devetak *et al.*, 2007; Fensham and Fensham, 1987;

Kalin and Arikil, 2010; Longden *et al.*, 1991; Naah and Sanger, 2013; Smith, 2007; Prieto *et al.*, 1989; She, 2004; Smith and Nakhleh, 2011; Uzuntiryaki and Geban, 2005). Few studies focused on identifying students' conception of the other aspects of solution chemistry such as colligative properties of solutions (Pinarbasi *et al.*, 2009), solubility (Ebenezer and Erickson, 1996; Kabapınar *et al.*, 2004), concentration of solutions (Devetak *et al*, 2007; Pinarbasi and Canpolat, 2003), factors affecting the rate of dissolving (Blanco and Prieto, 1997; Calik *et al*., 2009; Fensham and Fensham, 1987). Only a few studies included multiple aspects of solution chemistry while examining students' understandings of solution chemistry (Adadan and Savasci, 2012; Calik *et al*., 2010; Pinarbasi *et al*., 2006). These few studies used multiple-choice diagnostic tests to identify the students' alternative conceptions and, only the selected students were interviewed. This study differed from the others in terms of interviewing all the pre-service chemistry teachers in the sample to gain extensive and detailed information about students' conceptions.

In addition, pre-service chemistry teachers were selected as the participants of the current study. Only two previous studies involved pre-service teachers as the participants for solution chemistry research (Pinarbasi *et al.*, 2009; Calik *et al.*, 2007a). However, including pre-service chemistry teachers as the participants is very important for two reasons; (1) like other students; pre-service chemistry teachers also have alternative conceptions, so identifying these conceptions helps pre-service chemistry teachers to be aware of them, and (2) encourage pre-service teachers to design effective instructions for their own students.

2. LITERATURE REVIEW

This chapter reviews the related literature that informed the current study including five main sections namely constructivism, conceptual change learning, the nature of students' alternative conceptions, students' alternative conceptions about solution chemistry and multi-representational (MR) learning. The subsequent section provides an overview of constructivism.

2.1. Constructivism

Tell me, I'll forget
Show me, I'll remember
Involve me, I'll understand (A Chinese proverb)

As stated in the above quotation, telling a piece of knowledge is hardly ever successful for learning. Learning is more than just memorizing the facts. Constructivist learning theory explains how the learning occurs. It changed the view of learner from passively receiving the information to actively engaging in constructing meaning (Driver, 1995). Posner, Strike, Hewson, and Gertzog (1982) stated that "learning is not simply the acquisition of a set of correct responses, a verbal repertoire or a set of behavior…learning is a rational activity" (p. 212). Research into student conceptions revealed that meaningful learning occurs only when learners code, process and construct their understandings based on their previous experiences (Jia, 2010; Scott, Asoko, Driver, and Emberton, 1994). In other words, learners construct their cognitive structures initiatively, generate meanings and make connections with their old and new knowledge during the learning process. According to Sewell (2002), constructivist learning theory maintains that learning is not the result of teaching rather it is the result of what students do with the new information they are presented with. Therefore, constructivist learning theory focuses on students' prior knowledge, because learners make sense of new situations in terms of their existing understandings (Naylor and Keogh, 1999).

Learning science includes both *individual* and *social constructivist* views which will be mentioned in the following sections.

2.1.1. Individual Constructivism

Individual constructivist view of learning mainly inspired from Piaget's works. Piaget (1937) said "Intelligence organizes the world by organizing itself" (p. 311). According to Piaget (1937), social interaction is also a part of the learning process, but he focused more on constructing knowledge within one's own schemas which were described as *cognitive schemes*. According to Piaget, constructing meaning depends on the individuals' current knowledge schemes, and there are two ways for learners in order to accept the new information. One is *assimilation* and the other one is *accommodation*. If new schemes do fit into the old schemes, *assimilation* would take place. If new schemes do not fit into the old schemes *disequilibrium* would occur. When learners are dissatisfied with their current understanding, they will modify the old information so that it fits into the new knowledge. Piaget called this as *accommodation* (Driver, 1994). Posner *et al. (1982)* claimed that learning occurs when accommodation is achieved, so teachers should recognize students' pre-existing knowledge and design their instructions to challenge them (Tytler, 2002).

2.1.2. Social Constructivism

Social constructivist view of learning is based on Vygotsky's works. According to Vygotsky, knowledge is created by means of social interaction. Individuals themselves do not discover knowledge, but cultures or groups construct knowledge by interacting within their members (Baviskar, Hartle, and Whitney, 2009). Vygotsky (1978) explained the importance of social interaction as the following:

> We must look not only at the individual and his/her interaction with the external physical world, but also at the immediate social world in which the child is located and the nature of the interactions that take place within it (p.86).

Through social interaction, individuals challenge their level of understanding and seek assistance to get to the next level (Powell, 2009). In social interaction, *language* plays an important role as a tool that creates the possibility of thought, organizes the thinking processes (Vygotsky, 1978).

Vygotsky (1978) also claimed that a child could solve problems at the higher level than his/her actual developmental level via an adult guidance. He called this situation as the *zone of proximal development* (ZPD). Vygotsky (1978) defined ZPD as:

> This difference between twelve and eight (level), or between nine and eight (level), is what we call *the zone of proximal development.* It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers (p.86).

Thus, social constructivism states that students are able to construct their meaning and learn a subject higher than their current developmental stage with an expert assistance.

To sum up, both individual and social constructivist perspectives agree that learning is not the transmission of knowledge to learners but instead it is the construction by the learners. Both of them give importance to social interaction in the learning process, but individual constructivists focus more on constructing knowledge with one’s own schemas. They emphasize that it is the individual who constructs knowledge based on his or her personal experience.

The next section will summarize the related literature on conceptual change learning which derived from the constructivist view of learning

2.2. Conceptual Change Learning in Science Education

Conceptual change research derived from research into students’ alternative conceptions and individual constructivist approach. Posner *et al.* (1982) claimed that “learning is best viewed as a process of conceptual change” (p. 212). If conceptual change is important for learning, what is conceptual change? Duit and Treagust (2003) defined conceptual change as a “learning in such domains where the pre-instructional conceptual structures of the learners have to be fundamentally restructured in order to allow understanding of the intended knowledge, that is, the acquisition of science concepts" (p.673). At the following sections conceptual change model, which was developed and supported by both cognitive developmental scientists (Chi, 1994; di Sessa, 1993) and science education researchers (Posner, Strike, and Hewson, 1982; Vosniadou, 1994) will be described.

A well- known conceptual change model in science education was developed by Posner *et al*. (1982) and expanded by Hewson (1992). They tried to explain how concepts change under the impact of new ideas or new information. Posner *et al.* (1982) used the terms *accommodation,* and *assimilation* to explain conceptual change which was originally offered by Piaget. Accommodation used for large-scale conceptual changes and assimilation for the kind of learning which does not require a major conceptual modification. Posner *et al*. (1982) stated that if a student enriches his/her existing concept with the new concept, it would be called as assimilation, but if a student's current concept conflicts with the new concept, the student would replace and reorganize his/her central concepts and, it would be called as accommodation.

Posner *et al*. (1982) claimed that conceptual change was based on two components: (1) conditions of *accommodation*, and (2) the features of *conceptual ecology*. If these components are achieved, students will find it reasonable to undertake a major reorganization of their current concepts or to replace one set of central concepts with another. Posner *et al*. (1982) described four conditions to achieve accommodation. Firstly, there should be *dissatisfaction* with existing conceptions. This is the precondition for conceptual change. Students should be aware of the fact that their beliefs or ideas are not adequate in order to solve the problem at hand. Secondly, a new concept must be *intelligable*. Students should understand what it means and able to explain it with their own words. *Intelligable* conception requires not only knowing the symbols and the meaning of words but also constructing and identifying a coherent representation of what a passage or theory says. It should be internally represented by the student. However, this condition still might not be adequate in order to achieve conceptual change. Thirdly, a new concept must be *plausible*. A new concept should be reasonable, and it should be able to solve the problems generated by its predecessors. In this condition, learners' existing concept contradicts with the new concept, and the learners *exchange* or *reorganize* their prior concept with the scientifically accepted one. Lastly, a new concept must be *fruitful*. It should have the potential to be extended to open up new areas of inquiry, and to have technological or explanatory power (Posner *et al.*, 1982). According to Posner and Strike (1982), another component that influences the conceptual change is *conceptual ecology*. It is a conceptual context in which the conceptual change occurs, and the concepts are understood and given meaning. Conceptual ecology consists of *anomalies*, *analogies and metaphors*, *epistemological commitments*, *metaphysical beliefs and concepts*, and *other knowledge*.

Hewson (1992) disregarded the *weak restructuring* (assimilation) as a conceptual change and emphasized that only the *strong restructuring* (accommodation) can be called as conceptual change. Hewson (1992) explained the conceptual change theory in terms of the meaning of change. There are three meanings of change, *extinction, exchange,* and *extension*. *Extinction* means complete disappearance of the existing concept. *Extension* means enrichment of the existing concept (assimilation) and, *exchange* means lowering the status of the existing concept by elevating the status of the new concept. Conceptual change means *exchange* rather than the other meanings of change. The status of the existing concept becomes lower if the new concept has the power to solve the problems at hand, and the new concept gains higher status in the learners' cognitive structure. Hewson (1992) explained the factors that determines the status of concepts as the following: "the learner's conceptual ecology plays a critical role in determining the status of a conception because, amongst other things, it provides the criteria in terms of which he or she decides whether a given condition is (or isn't) met" (p. 9).

Vosniadou (2003) emphasized that students' explanations about the science are not the collection of unrelated pieces of knowledge, but they are the coherent explanatory frameworks that conceptualize the physical world. Vosniadou (2003) defined the conceptual change as "the outcome of a complex cognitive as well as social process thereby which an initial *framework theory* is restructured" (p. 2). Vosniadou (2002) argued that students' theories are different from scientists' theories, because students' theories lack the systematicity, abstractness, and social/institutional nature existing in scientists' theories.

Vosniadou and Brewer (1992) mentioned that the *framework theories* are the explanatory systems in the students' mind which consist of the ontological and epistemological presuppositions (Vosniadou, 1994). The framework theories include the *entrenched presuppositions* and the *specific theories*. The entrenched presuppositions embedded in the framework theories establish a basis for students' alternative conceptions. The specific theories are the domain specific assumptions which consist of a set of interrelated propositions or beliefs of individuals about the reality. The specific theories describe the properties and behavior of physical objects by students' everyday experiences. Vosniadou (1994) distinguished specific theories from framework theory such that "a distinction has been drawn between *specific theories* that describe the internal structure of a given conceptual domain and a *framework theory* that provides the fundamental ontological and epistemological presuppositions that constrain the knowledge acquisition process in the domain" (p. 63).

Vosniadou (1994) claimed that both specific and framework theories constitute mental models which are the representations of physical world. The students' mental models may change through either *enrichment* or *revision. Enrichment* occurs adding the new information to the existing conceptual structures. However, *revision* requires changes in individuals' beliefs or presuppositions or changes in the relational structure of a theory. Conceptual change can be achieved if the revision takes place. Revision may occur at the level of the specific theory or at the level of the framework theory. However, revision of a specific theory is easier than framework theory, because framework theory includes systematic explanations which are supported by everyday experience. Since revisions require gradual restructuring, conceptual change should be a slow and gradual process (Vosniadou, 2003).

During the revision of existing conceptions, however, alternative conceptions might be created. After the instruction, students may have conflicting and inconsistent pieces of information that contradicts with their everyday experiences. They tend to synthesize this information with their existing beliefs or presuppositions based on interpretations of everyday experiences. In this process, *synthetic models* or alternative conceptions are created (Vosniadou, 1999). Vosniadou (2003) claimed that if students are unaware of their beliefs' and presuppositions' theoretical status, they see no reason to change them since they provide good explanations of their everyday experiences. Alternative conceptions are usually generated because of students' inadequate attempts to change their *entrenched presuppositions*. Thus, Vosniadou (2002) stated:"conceptual change involves not only change in specific beliefs and presuppositions but also the development of meta conceptual awareness and the construction of explanatory frameworks with greater systematicity, coherence, and explanatory power" (p.388).

Chi (2002) brought a different view about conceptual change from cognitive perspective. According to Chi (2008), "conceptual change requires categorical shift. Such a shift necessitates that the learner is aware that the shift is needed and that the correct category is available" (pp.79-80). Chi stated that knowledge is a set of interrelated propositions, or "mental model". Meaning is situated in an organized manner, so mental models can be used to generate explanations, make predictions and answer questions. Mental models can be correct, or they can be organized incorrectly. Chi (2008) stated that there might be no need for the conceptual change to correct the mental model. Then, what kind of learning process can be applied to repair the flawed (scientifically incorrect) mental model? Chi suggested two processes: "*assimilation*" and *"revision".* If the new knowledge is compatible with the existing one, it is simply embedded into the existing mental model, and this process is called "*assimilation*". Assimilation alone cannot repair mental models, but they can enrich them. If a student's flawed belief contradicts with the textbook statement, and the student revises it, it is called as "*revision*". When the students change their mental representations' structure, it is called as *"accommodation*". It can occur by ordinary learning process, there might not be needed a radical conceptual change to happen (Chi and Roscoe, 2002). Chi *et al.* (1994) claimed that to achieve conceptual change, a concept should be reassigned from one category to another. Some of the conceptual changes would be more difficult than others, if a change involves ontological re-categorization. Ontological categories involve three categories: ''*matter*'', ''*processes*'' and ''*mental*'' states. People's views about the entities in the world should be included in one of these ontological categories. If people learn a new concept, these categories would help them understand the nature of the concept. A concept in a given category includes all the features of that category. *Lateral categories* do not have any hierarchical relationship one to another, they do not share a category even at the highest levels.

They exists on different or distinct hierarchies or “trees”, they are called “ontologically distinct”. Many scientific concepts belong to the category of *process*. When students place scientific concepts which should belong to the *process* category into their *matter* category, alternative conceptions occur. If these alternative concepts’ ontological status shifts from matter category to the process category, learning would occur, and it happens suddenly (Chi and Roscoe, 2002).

Another cognitive scientist, di Sessa (1993) argued that knowledge is in pieces, rather than in the framework theory as Vosniadou claimed. Di Sessa (1993) stated that the pieces are certain primitive schema and are called as p-prims (phenomenological principles). P-prims interpret physical reality and play an important role in explaining physical phenomena. Conceptual change occurs through the reorganization of p-prims or changing the structure of p-prims; thus, it does not take so much time, it happens quickly.

To sum up, both cognitive scientists and science education researchers agree that students’ alternative conceptions are the key elements for the conceptual change to occur. Students construct their knowledge based on their daily experiences. Conceptual change is required for meaningful learning, because alternative conceptions influence students’ formal learning. However, alternative conceptions are resistant to change. Vosniadou (1994) agree with Chi that alternative conceptions occur when scientifically incorrect ontological presuppositions were assigned to the scientific concepts. In other words, alternative conceptions occur because students assign science concepts to ontologically different category. However, Vosniadou (1994) disagree with Chi (2008) that conceptual change does not mean just the reassignment of a concept from one category to another, because it does not explain why such change is difficult to occur or why some reassignments are difficult while others are not. Thus, concepts should be organized in the framework theory rather than existing independently as di Sessa (1993) stated. In addition, the cognitive developmental scientists and science education researchers disagree for the time passed for the conceptual change. While Vosniadou (2003) and Posner *et al.* (1982) stated that conceptual change is gradual, Chi (2008) and di Sessa (1993) argued that conceptual change is radical and sudden.

This study supports the view that conceptual change process is gradual and slow and investigates the conceptual change from Vosniadou's perspective. The nature of alternative conceptions will be explained in detail in the subsequent section.

2.3. The Nature of Alternative Conceptions

There is a strong consensus that students come to class by possessing many ideas, and these ideas help them make sense of the world in which they live. They are prevalent among many students of different ages, abilities, genders, and cultures (Novak and Gowin, 1994). Students construct such ideas before, during, and after the school science instruction. These ideas may come from students' experiences, parents, teachers and, peers, events, places, textbooks, commercial products, and language (Nakhleh, 1992; Novak and Gowin, 1994; Sewell, 2002). However, students' conceptions about the phenomena may not correspond well with the scientific knowledge. In addition, students' conceptions may not change with the school instruction, since they are resistant to change. These conceptions are called by different researchers as preconceptions, misconceptions, alternative frameworks, synthetic models, and children's ideas (Vosniadou and Brewer, 1992). However, the term alternative conception is now preferred by many researchers to the others because of two reasons;

> It [alternative conception] refers to experience-based explanations constructed by a learner to make a range of natural phenomena and objects intelligible (and), it … confers intellectual respect on the learner who holds those ideas; because it implies that alternative conceptions are contextually valid and rational and can lead to even more fruitful conceptions (i.e. scientific conceptions) (Wandersee, Mintzes, and Novak, 1994, p.178).

Science education research studies emphasize the importance of students' alternative conceptions, because "it will either be a bridge to new learning or a barrier" (Sewell, 2002, p.26). Thus, the question of what the features of students' alternative conceptions were arose in the researchers' mind. Driver, Guesne, and Tiberghien (1985) pointed out the general features of children's conceptions by reviewing the studies on alternative conceptions. According to Driver *et al.* (1985), students' conceptions show the following characteristics: (1) *Perceptually dominated thinking*; students base their reasoning only on observable features in a problem situation. (2) *Limited focus*; students consider only limited aspects of physical situations. They tend to focus on the absolute properties or changing features of objects rather than the interaction between elements of a system. (3) *Focus on change rather than steady-state situations*; students tend to focus on transient states of a system rather than on equilibrium states. (4) *Linear causal reasoning*; when children explain changes, their reasoning tends to follow a linear causal sequence rather than the symmetry in interactions between systems. (5) *Undifferentiated concepts*; students' explanations are more inclusive and global than those of scientists. Students can not differentiate the meanings of the concepts, and they use the concepts as if they are the same thing without being aware of it. (6) *Context dependency*; students often mention different ideas to interpret situations which a scientist would explain in the same way. (7) *Some predominant conceptions*; student ideas about one area influence their ideas about other areas.

In order to prevent the students' alternative conceptions to be a barrier to learning and exchange them with scientific explanations, conceptual change can be effective classroom tool (Novak and Gowin, 1994). However, students' alternative conceptions should be identified first. Students' alternative conceptions about solution chemistry will be mentioned in the following section.

2.4. Students' Alternative Conceptions about Solution Chemistry

Many studies have been carried out in order to explore students' understanding about solution chemistry (Adadan and Savasci, 2006; Blanco and Prieto, 1997; Devetak *et al.*, 2007; Ebenezer and Erickson, 1996; Longden *et al.*, 1991; Naah and Sanger, 2013; Prieto *et al.*, 1989; She, 2004; Smith and Metz, 1996; Smith and Nakhleh, 2011). Why did students' alternative conceptions of solution chemistry take attention of many researchers? Because, understanding the solution chemistry is important for understanding the concepts of chemical equilibrium, electrochemistry, acids and bases, and the rate of chemical reactions (Calik and Ayas, 2005). However, students have difficulties understanding the solution chemistry since solutions involve deep understanding of the concepts such as particulate theory of matter, volume, weight, density, physical and chemical change (Uzuntiryaki and Geban, 2005).

In the following sections, four different aspects of the solution chemistry will be discussed. These aspects are the nature of solutions and dissolving, the types of solutions according to the solubility of a solute, concentration of solutions, and colligative properties of solutions.

2.4.1. The Nature of Solutions and Dissolving

Research studies showed that students at various grade levels use the terms 'disappearing', 'melting', and 'mixing' to refer to the phenomenon of 'dissolving' (Adadan and Savasci, 2012; Blanco and Prieto, 1997; Ebenezer and Erickson, 1996; Fensham and Fensham, 1987; Kabapınar *et al.*, 2004; Pinarbasi *et al.*, 2006; Prieto *et al.*, 1989; Uzuntiryaki and Geban, 2005). For example, in order to explain the 'disappearance' of the solute, some students claimed that solute evaporates and turns to gas, and others believed that solute melts when it is added to the solvent (Abraham and Williamson, 1994; Abraham *et al.*, 1992; Ebenezer and Erickson, 1996; Fensham and Fensham, 1987; Kabapınar *et al.*, 2004; Prieto *et al.*, 1989; Pinarbasi *et al.*, 2006). Students also believed that whenever two or more substances are mixed, a solution is obtained without considering if they are soluble or not (Pinarbasi *et al.*, 2006; Uzuntiryaki and Geban, 2005). Other students believed that a chemical change occurs during dissolving process such that when solute is added to the solvent, it reacts with the solvent and a new substance is formed (Abraham and Williamson, 1994; Abraham *et al.*, 1992; Adadan and Savasci, 2012; Ebenezer and Erickson, 1996; Pinarbasi *et al.*, 2006; Prieto *et al.*, 1989; Uzuntiryaki and Geban, 2005; Taber and Garcia-Franco, 2010).

Students sometimes use the term 'particle' to refer to 'molecules', 'ions' or 'atoms' (Devetak *et al.*, 2007; Kabapinar *et al*., 2004). Some students believe that the solute particles' 'shape', 'weight' and the solute's 'density' are the determining factors for dissolving. They think that if solute particles are big, heavy or dense, they will precipitate at the bottom of the solution, and they will not dissolve (Abraham *et al.*, 1992; Calik *et al.*, 2009; Ebenezer and Erickson, 1996; Prieto *et al.*, 1989; Uzuntiryaki and Geban, 2005). Thus, the solute should be broken into tiny bits, when it is added to the solvent (Ebenezer and Erickson, 1996; Fensham and Fensham, 1987; Prieto *et al.*, 1989). Students also believe that these tiny bits of solute particles fill the air spaces of the solvent while dissolving occurs. According to these students, if solute molecules do not find sufficient space in the dissolving medium, solute will not dissolve (Ebenezer and Erickson, 1996; Fensham and Fensham, 1987; Prieto *et al.,* 1989). In addition, students think that solute plays an active role, whereas solvent plays a passive role in the dissolving process (Pinarbasi *et al.,* 2006; Prieto *et al.,* 1989; Taber and Garcia-Franco, 2010).

Students also tend to consider the factors that affect the rate of the dissolving (e.g, temperature increase and stirring) as if they are the requirements of the dissolving process. They believe that stirring and increasing the temperature are the pre-requisite for dissolving to occur rather than the factors that affect the rate of the dissolving process. They also believe that the solubility of the solution increase if more solvent is added to the solution (Blanco and Prieto, 1997; Calik *et al.,* 2009; Pinarbasi *et al.,* 2006; Taber and Garcia-Franco, 2010).

In the study of Adadan and Savasci (2012), they surveyed 756 Grade 11 students (age 16–17) using a two-tier diagnostic instrument about solution chemistry. After analyzing the responses of students, they concluded that one of the most difficult questions on the test was the identification of solutions when particle level representations were given. In addition, many research studies showed that students have difficulty with identifying the solutions in different physical states. Students believe that solutes are always solid and added to liquid solvent (especially water), and only the ionic salts could generate solutions. They do not accept the solid-solid, liquid-liquid, gas-gas, and liquid-gas homogenous mixtures as solutions. (Adadan and Savasci, 2012; Calik and Ayas, 2005; Prieto *et al.,*1989; Uzuntiryaki and Geban, 2005).

2.4.2. The Types of Solutions According to the Solubility of a Solute

Some research studies focused on the types of solutions, and they tried to elicit students' understandings of unsaturated, saturated, and supersaturated solutions. They concluded that students tend to misidentify the supersaturated solution as the saturated solution with its precipitate. Students believe that if a solution include precipitation, it should be supersaturated solution (Adadan and Savasci, 2012; Pinarbasi and Canpolat, 2003; Pinarbasi *et al*., 2006).

Students also think that undissolved solute is a component of the solution (Pinarbasi and Canpolat, 2003; Pinarbasi *et al.*, 2006). In addition, students believe that when the saturated solution's solvent (especially water) is evaporated, the solution becomes supersaturated solution (Adadan and Savasci, 2012) or its concentration will increase (Mulford and Robinson, 2002).

2.4.3. Concentration of Solutions

In the study of Dahsah and Coll (2008), science students of grade 10 and 11 think that the most concentrated solution includes the greatest amount of solute, regardless of the amount of solvent. These students also believe that if the solvent of a solution is evaporated, the solution with the greatest volume would be the most concentrated solution. In addition, Devetak *et al.* (2007) investigated the level of 16- year-old students' understanding of the solution concentration at the particulate level. Devetak *et al.* (2009) found that students cannot understand the difference between the solutions with different concentration of the same substance. They also can not draw the solution concentration at the particulate level. Students were not able to provide complete correct answer to the question that requires drawing the submicroscopic representation of diluted and saturated aqueous solutions of molecular crystal.
In the study of Adadan and Savasci (2012), the questions were asked by representing the pictures of the solutions at the particulate level. The answers were analyzed to the question 'how do the sucrose molecules appear after some water is added to the solution? Although 84% of the students said that fewer solute molecules appear in the solution compared to the initial case, 20.5% of these students explained it in terms of the increase in the solubility of the solvent. They misused the term solubility for the dilution or further separation of solute molecules. In addition, 11% of these students claimed that additional water dissolves more solute by decreasing the number of solute molecules per unit volume. Moreover, 32.4% of the students believed that if some of the solution is poured out, the concentration of solute molecules per unit volume would increase.

2.4.4. Colligative Properties of Solutions: Boiling Point Elevation and Freezing Point Depression

Calik (2005) examined the different groups (grade 7 to 10) of students' alternative conceptions of solution chemistry. This study showed that some students do not differentiate the freezing and boiling points of salt solution from pure water, because they believe that all salt particles melt in the solution, and they are similar in appearance. However, other students think that the freezing and boiling point of a salt solution is different from the freezing and boiling point of pure water's. Students from grade 8 to 10 claimed that both freezing and boiling points of a salt solution are higher than pure water's (Calik, 2005). In addition, some of the students tried to explain the differences in boiling/freezing points by comparing the boiling/freezing time of pure substances and homogenous mixtures. Students from grade 8 to 10 believed that even though the freezing of salt solution takes a long time, the boiling of that same solution takes a short time (Calik, 2005). Moreover, in the study of Pinarbasi *et al.* (2009), 52% of prospective chemistry teachers thought that boiling point elevation and freezing point depression occurs because of the interactions between the water and salt particles. In other research studies, students also believed that attraction forces between the solvent and solute molecules lower the vapor pressure, and they prevent solvent molecules from escaping out of the solution (Azizoglu *et al.,* 2006; Pınarbası *et al*., 2006). Therefore, adding a substance to the solvent always increases the boiling point. In the same line, students think that attraction forces also cause the freezing point elevation, since they prevent solvent molecules to freeze and form crystals (Azizoglu *et al.,* 2006; Pınarbası *et al*., 2006).

In the study of Pinarbasi *et al.* (2009), 22% of the students argued that the solution boils/freezes at a temperature between the salt's and the water's boiling/freezing temperature. They think that the boiling temperature of the solution would be above the water's boiling temperature, as salt has a higher boiling point than water. On the other hand, the freezing point of the solution would be below the water's freezing temperature, as salt has a lower freezing point than water. In addition, 35% of the students thought that the addition of alcohol increases the freezing point of water, while another 30% of them argued that alcohol addition does not affect the freezing point. Also, 47% of the students claimed that boiling temperature does not stay constant as some of the heat will be used for the salt. In the same line, 23% of the students thought that freezing temperature also does not stay constant as the water freezes first, and then salt freezes (Pinarbasi *et al.*, 2009).

In order to change students' alternative conceptions of solution chemistry, science educators developed different instructional methods such as ‘conceptual change text’ (Calik *et al.*, 2007a; Uzuntiryaki and Geban, 2005) and ‘using particle model of matter with emphasis on discussions’ (Kabapinar *et al.*, 2004), ‘constructivist-based teaching model’ the four step constructivist teaching (Calik *et al*., 2007b, 2009), and ‘the dual situated learning model’ (She, 2004). Since the previous research studies did not use multiple representations in their instructional designs, alternative conceptions of students about solution chemistry in the present study will be addressed by designing and implementing MR instruction. In addition, literature suggested that MR instruction would be effective in order to achieve conceptual change and deep understanding in chemistry education (Ainsworth, 1999; Gabel, 1999; Johnstone 1991; Kirschner 2002).Thus, teaching through multiple representations will be explained in detail in the subsequent section.

2.5. Multi-Representational Learning

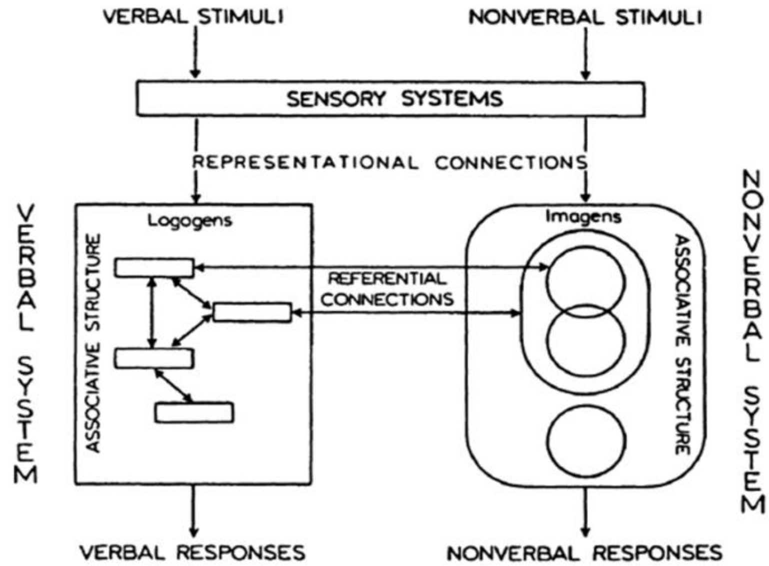
> Perhaps more than other sciences understanding chemistry relies on making sense of the invisible and untouchable. Much of what is chemistry exists at a molecular level and is not accessible to direct perception (Kozma and Russell, 1997, p.949).

As stated above, understanding chemistry depends on understanding it at the molecular level which is not possible to be observed by naked eye or even a microscope. Thus, chemistry concepts are complex to understand for many students. The novice learners observe chemical reactions at the macroscopic level but instructors expect them to explain them at the submicroscopic level (Gabel, 1999). In addition, using symbolic expressions, such as graphs, mathematical symbols, formulas, and reaction equations, molecular structure diagrams to express relationships at the macroscopic and submicroscopic levels make chemistry more complex to understand (Gabel, 1999). However, using multiple representations in the instructional designs can help students to translate information expressed in symbolic representation to another one (Gabel, 1999). Kirschner (2002) stated that representing an explanation in multiple dimensions is better than representing it solely in one dimension. In addition, MR learning not only captures students' interest but also plays an important role for effective learning (Ainsworth, 1999). Therefore, Johnstone (1991) mentioned the importance of three levels of representation for deep understanding in chemistry education: atoms, molecules, ions (*submicroscopic* level), materials themselves or pictures of the materials (*macroscopic* level), and symbols for atoms and formulas for molecules etc. (the *symbolic* level).

MR learning which elicits meaningful learning was supported by several cognitive perspectives: (1) Dual Coding Theory (Paivio, 1986; 1991), (2) Cognitive Load Theory (Sweller and Chandler, 1994), and (3) Cognitive Theory of Multimedia Learning (Mayer, 2001; 2003). Each perspective will be discussed in the following sections.

2.5.1. Dual Coding Theory

The dual-coding theory explains how verbally and pictorially presented knowledge affects students' learning. The dual-coding model assumes two independent systems to retrieve information: the *nonverbal* (imaginary) system and the *verbal* (linguistic) system (D'Agostino *et al*., 1977). Clark and Paivio (1991) stated that *nonverbal* representations include images for shapes (e.g., a chemical model), environmental sounds (e.g., school bell), actions (e.g. drawing lines or pressing keys), skeletal sensations related to emotion (e.g., racing heart), and other objects and events; *verbal* system deals with information involving linguistic units and structures. Sadoski *et al.* (1991) suggested that verbal and non-verbal stimuli in sensory systems continually activate mental representations. These representations are named as *logogens* in the verbal system; and *imagens* in the nonverbal system. They form hierarchical organizations within each system or between the systems (see Figure 2.5.1). For example, eyes, noses, or mouths can be sensed separately but are normally sensed as parts of a face, faces as part of heads, heads as part of bodies, and so on.



Note. From *Mental representations: A dual coding approach* (p. 67) by A. Paivio, 1986. New York: Oxford University Press. Copyright 1986. Reprinted by permission.

Figure 2.1. Dual coding theory. (Sadoski *et al.*, 1991).

Although the verbal and non-verbal systems are functionally independent, they are interconnected to each other such that nonverbal information can be transformed into verbal information, or vice versa (Paivio, 1975). The interdependence of two systems implies that one code can activate the other. For example, an image can be labeled and a word can evoke non-verbal images (D'Agostino *et al*., 1977). Thus, presenting material in a mixed rather than a unitary mode will increase the effect of working memory (Mousavi *et al.*, 1995; Sadoski, 1993). Clark and Paivio (1991) explained it as the following: "Lessons containing concrete information and evoking vivid images will be easier to comprehend and remember than lessons that are abstract and not image arousing" (p.173).

2.5.2. Cognitive Load Theory

Cognitive Load Theory (CLT) uses aspects of human cognitive structure to guide instructional designs (Pollock *et al*., 2002). CLT assumes that working memory has a limited capacity to further process the information and link it to prior knowledge (Cook, 2006). However, the limited capacity of working memory only applies to novel information obtained through sensory memory. There is not any limitation when working memory deals with information retrieved from long-term memory. Long-term memory stores and organizes an immense amount of knowledge in its cognitive *schemata* (Van Merrienboer and Sweller, 2005). Mousavi *et al.* (1995) stated that “schemata has the functions of storing information in long-term memory and of reducing working memory load by permitting people to treat multiple elements of information as a single element” (p. 319).

Cognitive load theory states that most of the instructions are inadequate, because they cause load on working memory by conducting unnecessary cognitive activities (Mousavi *et al*., 1995; Pollock *et al.*, 2002). In order to prevent cognitive load, Sweller and Chandler (1991) suggested the *split-attention effect* as an instructional approach. According to Mousavi *et al.* (1995), split-attention effect occurs when students must split their attention between multiple sources of information. Split-attention effect suggests that students learn better if both pictorial and verbal information is used simultaneously. However, verbal information should be presented in an auditory rather than a visual modality (Mayer and Moreno, 1998). In that way, working memory load will be reduced and effective cognitive capacity will be increased (Mousavi *et al.*, 1995).

2.5.3. Cognitive Theory of Multimedia Learning

Mayer’s (2003) cognitive theory of multimedia learning model is parallel to Dual Coding Theory, since both of the theories assume that combining pictures with words fosters deeper learning. Mayer (2003) stated that the words include printed or spoken text, and the pictures include static graphics (e.g., illustrations, maps, charts, and photos) and dynamic graphics (e.g., animation and video). According to Mayer (2003), it is better to present an explanation in pictures and words than presenting an explanation only with words. In that way, students are able to build two different mental representations a verbal model and a visual model, building connections between them.

Mayer’s (2001) theory of multi-media learning has three primary assumptions: (i) Visual and auditory information processed through separate “channels.” (ii) Each channel has limited capacity to process information. (iii) Processing information in channels is an active cognitive process which constructs mental representations. While pictures and images are registered by visual channel, oral materials are processed by auditory channel. Both of the channels transfer the visual and auditory information to the working memory. Working memory process the selected knowledge actively. However, these channels have a limited capacity (Mayer, 2003).

According to theory of multimedia learning (Mayer *et al.*, 1996; Mayer and Moreno, 1998), active learning occurs through three cognitive processes: (1) *Selecting* relevant words and images for verbal and visual processing. (2) *Organizing* words and images into a coherent verbal and visual model. (3) *Integrating* corresponding components of the verbal and visual models (see Figure 2.5.2).

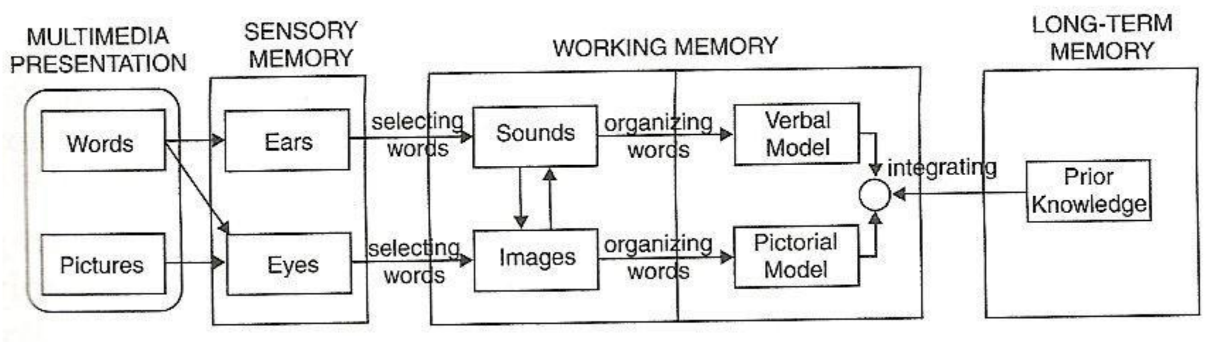


Figure 2.2. Cognitive theory of multimedia learning. (Mayer, 2009)

Mayer and Moreno (1998) suggest that instructors may benefit from these cognitive processes while designing their multimedia representations. In order to foster *selecting* processes, words and pictures should not be too much. To foster *organizing* process, they should include sequential steps. To foster the *integrating* process, they should present words and pictures concurrently in order to use visual and auditory working-memory resources (Mayer and Moreno, 1998).

To sum up, the current study was theoretically based on the five main concepts from the literature namely; constructivism, conceptual change learning, the nature of alternative conceptions, students' alternative conceptions about solution chemistry, and multi-representational learning.

According to constructivist view of learning, learners should actively engage in constructing meaning. While individual constructivists believes that students develop their meanings due to their personal interactions with the outer world, social constructivists states that students develop their meaning when they engage socially in talk and activity about shared tasks. Individual constructivist research studies attach importance to conceptual change learning approach to achieve meaningful learning. Conceptual change learning approach developed by both cognitive developmental scientists (Chi, 1994; di Sessa, 1993) and science education researchers (Posner, Strike, and Hewson, 1982; Vosniadou, 1994). According to Chi (1994), there are three kinds of categories which involve students' concepts. These categories are *matter, process* and *mental* states. A concept should be reassigned from one category to another in order to achieve conceptual change. On the other hand, di Sessa (1993) claims that knowledge is in pieces called as p-prims. Conceptual change would occur if p-prims are reorganized. Both Chi (1994) and di Sessa (1993) believes that conceptual change learning happens quickly and suddenly. According to Posner *et al.* (1982), conceptual change occurs if students replace or reorganize their central concepts. This process is also called as accommodation. Posner *et al.* (1982) described four conditions to achieve accommodation; *dissatisfaction, intelligible, plausible,* and *fruitful*. Hewson (1992) explains conceptual change from the meaning of *exchange* that means lowering the status of the existing concept by elevating the status of the new concept. According to Vosniadou (1994), students' explanations have explanatory frameworks. It should be restructured in order to achieve conceptual change. In addition, both Vosniadou (2003) and Posner *et al.* (1982) claim that conceptual change should be a slow and gradual process.

In order to achieve conceptual change, the students' alternative conceptions should be identified first. Students' alternative conceptions may come from students' experiences, parents, teachers and, peers, events, places, textbooks, commercial products, and language (Nakhleh, 1992; Novak and Gowin, 1994; Sewell, 2002). In the current study, students' alternative conceptions about solution chemistry divided into four aspects namely; (1) the nature of solutions and dissolving , (2) the types of solutions relative to the solubility of a solute, (3) concentration of solutions, and (4) colligative properties of solutions. For each aspects of solution chemistry, students' alternative conceptions identified in order to achieve conceptual change through MR instruction. Using multiple representations in the instructional designs can help students to translate information expressed in one representation to another one. Three levels of representation are important for deep understanding in chemistry education namely; *submicroscopic, macroscopic,* and *symbolic* level. In addition, the MR learning is supported by several cognitive perspectives; (1) Dual Coding Theory (Paivio, 1986; 1991), (2) Cognitive Load Theory (Sweller and Chandler, 1994), and (3) Cognitive Theory of Multimedia Learning (Mayer, 2001; 2003).

3. METHODOLOGY

The current study mainly explored the effectiveness of Multi-Representational (MR) instruction on pre-service chemistry teachers' conceptual understandings of solution chemistry and types of solutions in terms of short-term and long-term learning outcomes. The subsequent aim of the study was to identify the characteristics of individual participants' conceptual understandings of the types of solutions from before beginning the instruction to shortly after completing the instruction to five-months after completion of the instruction. The following research questions guided this research:

(i) How do pre-service chemistry teachers' conceptual understandings of solution chemistry differ from before beginning the MR instruction to immediately after completing the instruction to five-months after completing the instruction?

(ii) How do pre-service chemistry teachers' conceptual understandings of types of solutions differ from before beginning the MR instruction to immediately after completing the instruction to five-months after completing the instruction?

(iii) What kinds of conceptual understandings held by pre-service chemistry teachers about the types of solutions before, immediately after, and five-months after completion of the MR instruction?

Methodology of this chapter includes sub-sections which provide information about the current study. First, the research design of the study will be identified. Second, participants of the study will be introduced, and the context of the study will be described. Third, the framework of MR instruction will be discussed. Fourth, data collection and recording procedures will be described. Fifth, data analysis procedures will be explained.

3.1. Research Design

The research questions and the available resources (course and the number of participants) shaped the design of this study. The current study intended to identify the change in participants' conceptual understandings of the solution chemistry and the durability of their scientific understandings constructed during the instructional phase. In this respect, the study identified the participants' conceptual understandings of solution chemistry before, immediately after, and five-months after the MR instruction. Thus, this study was a mixed method study combined with quantitative and qualitative research methods (Creswell and Clark, 2007).

Quantitative part of the study has a one-group quasi-experimental design with pre, post, and delayed post-interview (Cook and Campbell, 1979). Qualitative part of the study involved verbal data (e.g., interviews, collection of student artifacts, field notes) and descriptive data analysis procedures.

This study consisted of more than two comparable assessment measures; thus, it seems to be a longitudinal study. However, White and Arzi (2005) suggested that a longitudinal study takes at least a 1-year period of time. Because the current study lasted eight months from the beginning to the end, it might not be considered as a true longitudinal study.

3.2. Participants of the Study

This study was conducted with third-year pre-service chemistry teachers at a State University in Istanbul in the fall of 2010. To be accepted to this university, the participants have to pass the National State Examination. All of the participants had taken and passed General Chemistry I and II, Qualitative Analysis of Chemistry, and Introduction to Practical Chemistry courses.

The pre-service chemistry teachers who took "Secondary School Science Laboratory Applications" course at the time of the study were the participants. The course aimed to encourage participants to develop, apply and evaluate the science experiments designed for the secondary school science curriculum. The class meetings were held twice a week, and the participants totally spent five class hours per week.

Initially 15 pre-service teachers agreed to participate in the study. Yet, one of the participants dropped the course so that her pre-interview data were not included in the study. Then, the study consisted of a total of 14 participants: 10 female and four male. Their GPA level was classified in three categories: (1) below 2.0 points (two participants), (2) between 2.0 and 2.5 points (seven participants), and (3) above 2.5 points (five participants). Their ages changed between 21 and 25, being 22 on average.

At the beginning of the course, participants were involved in Particulate Nature of Matter intervention (PNM). Activities of PNM emphasized five different aspects of the particle theory of matter; (1) “matter is made up of particles”, (2) “particles are in continuous motion in all three states of matter”, (3) “nothing exists between the particles of matter”, (4) “the distance between particles of solids, liquids and gases”, and (5) “electrostatic interaction occurs between the particles of matter”.

The instruction implemented in this study was carried out by a science teacher educator. Her undergraduate and graduate major was in chemistry education. She had four years of experience in teacher education at the university, and she has been teaching "Secondary School Science Laboratory Applications" course for four years. The course was aimed to create MR learning environment that pre-service chemistry teachers could gain first-hand experience with such instructional approach and develop scientific understandings of the relevant topic such as solution chemistry.

3.3. The Framework of the Instruction

This section includes the description of “MR instruction” involving the topic of solution chemistry. The instruction lasted twenty class periods. The instructional pedagogies used in the intervention were: inquiry, discussion, MR instruction, and journal writing.

3.3.1. Inquiry

In the current study, inquiry-based activities were emphasized while designing the instruction. Instructional activities in the current study were planned and conducted according to guided inquiry and structured inquiry. Some of the activities (activity one, three and four, see Table 3.1) were based on *structured* (*level two*) *inquiry* (Eick *et al.*, 2005). During the instructions, participants were introduced with a demonstration that models a scientific phenomenon or targeted principle in action through a focusing question. In the structured inquiry, participants conducted the given method, recorded and manipulated their data, formulated their explanations by making connections between observable phenomenon and the underlying scientific principles, and they presented them to the class (Eick *et al.*, 2005). Participants followed a cycle of Predict-Discuss-Explain-Observe-Discuss-Explain (P-D-E-O-D-E) approach. It is a modification of the P-O-E approach which was used by White and Gunstone (1992). The P-D-E-O-D-E approach was suggested initially by Savander-Ranne and Kolari (2003) and used in many research studies (Costu, 2008; Costu *et al.*, 2012; Savander-Ranne and Kolari, 2003). The main difference of P-D-E-O-D-E from P-O-E is emphasizing discussions after each step. During the P-D-E-O-D-E approach, participants first predicted what will happen in a situation, and wrote down why they think it happens so. Second, they discussed their predictions with their group members. Third, participants reached an agreement about the solution of the research question within the group and then shared and discussed it with the whole class. Fourth, they observed and recorded what they observed. Fifth, they compared their predictions to their observations and discussed it within their groups. Sixth, participants explained their contradictions between their predictions and observations. They found out the reasons behind such a conflict and resolved them. The activities two, five and six (see Table 3.1 below) were based on *guided (level 3) inquiry* (Bell *et al.*, 2005). In these activities, the participants were provided with a research question, but they were expected to find their own methods and solutions in order to find an answer to the research question (Bell *et al.*, 2005).

Participants performed totally six different activities about the different aspects of solution chemistry (see Table 3.1). Participants were actively participated and cooperatively worked in groups. The participants were divided into four groups, and each group composed of three or four participants. Participants completed activities as a group, but they wrote their explanations to their activity sheets individually. Before doing the activity participants were expected to write down their prediction about the result of the experiment. Then, participants observed the particular phenomena. Observations helped them to compare what they predicted and what happened naturally. If there were conflicts between their predictions and observations, participants became eager to learn more about the subject. Following the observations, participants were asked to explain their reasoning about the phenomena so that participants organized their mental schema about the subject.

Table 3.1 describes the activities along with the types of instructional practices and intended learning goals as stated above in the MR instruction (also see Appendix A).

Throughout the MR instruction, individual constructivist view and social constructivist views were adopted. According to constructivist view of learning, meaningful learning occurs only when learners code, process, and construct their understandings based on their previous experiences (Jia, 2010; Scott *et al*., 1994). Thus, the instruction should include activities and some triggering questions. These activities and questions make participants to think and motivate (Tytler, 2002), lead them to new levels of conceptual understanding (Vygotsky, 1978), and guide them from their own meanings to socially agreed definitions, concepts, and theories (Driver, 1995). In the same line, Fosnot and Perry (2005) claimed that instructions should be designed "to allow learners to raise their own questions, generate their own hypothesis and models as possibilities, test them out for viability, and defend and discuss them in communities of discourse and practice" (p.34). Thus, the instruction in the current study, valued participants' previous knowledge and asked them to make predictions before the experiments, allow the participants to test their explanations through observations, explain, and discuss their reasoning.

Table 3.1. The instructional strategies implemented in the MR instruction.

Activities	**Instructional Strategies**
Activity 1	
The nature of dissolving	Observing the phenomenon Explaining it with respect to the particle theory of matter Drawing pictorial representations at the molecular level Comparing pictorial particle representations with the animation shown Journal writing
Activity 2	
Factors affecting solubility of solids	Comparing and contrasting the given pair of terms (soluble vs. solubility and solubility vs. dissolving) Designing an experiment to find out the solubility of a salt at different temperatures Providing data table and plotting the data on the graph Writing down a conclusion based on the data Explaining the conclusion at the submicroscopic level Journal writing
Activity 3	
Factors affecting solubility of gases	Observing the effect of pressure on solubility of gases Explaining it with respect to the particle theory of matter Designing an experiment to observe the effect of temperature on dissolving of gases Writing down the observations, and explaining the phenomenon at the submicroscopic level Journal writing
Activity 4	
Types of solutions	Comparing and contrasting the given pair of terms Preparing a saturated solution Predicting what would happen to the saturated solution of sodium chloride, if you evaporate the half of the solution. Explaining the situation at the molecular level Drawing pictorial representations of given solutions at the molecular level Journal writing
Activity 5	
Freezing point depression	Predicting how the nature of salt affects the freezing point of water Designing an experiment to find out how the nature of salt affects the freezing point of water Providing data table Writing down a conclusion based on the data Explaining the conclusion at submicroscopic level Journal writing

cont.

Table 3.1. The instructional strategies implemented in the MR instruction cont.

Activities	**Instructional Strategies**
Activity 6	
Boiling point elevation	Predicting the given situation Designing an experiment to find out how the concentration of NaCl affects the boiling point of the water Providing data table Writing down a conclusion based on the data Explaining conclusion at submicroscopic level Journal writing

3.3.2. Multiple Representations

Gabel (1999) believes that using multiple representations during instruction can help students to translate information expressed in symbolic representation to understanding phenomena expressed in another representation. Thus, the current instruction provided participants with MR learning environment. The representations were verbal (discussions, written expressions in the activity sheets) and pictorial (animations that show various phenomena at the submicroscopic level, and participants' drawings of atoms and molecules). In this respect, submicroscopic (pictorial) and verbal representations were in accord with Paivo's dual coding theory which emphasizes the importance of coding knowledge in different channels (pictorial/auditory) to retain and retrieve information (Sadoski and Paivio, 2001). For the submicroscopic level, both the dynamic representations (animations) and the static representations (participants' drawings of the given phenomenon) were used during the instruction. After participants drew their pictorial (submicroscopic) representations, the world-wide web animations at the submicroscopic level were shown about the dissolving of a salt (see Figure 3.1), the representation of a salt solution (see Figure 3.2), and the representation of saturated salt solution with its precipitate (see Figure 3.3).

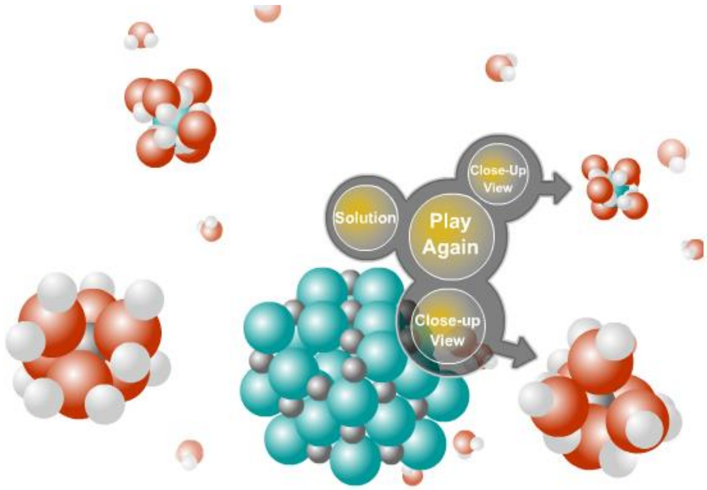
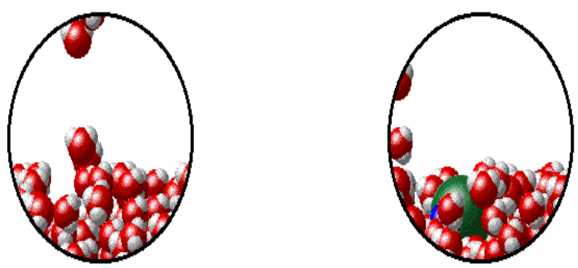


Figure 3.1. Dissolving of a salt. (available at http://www.Chem.iastate.edu/group/Greenove/sections/projectfolder/flashfiles/thermochem/solutionSalt.html)

- there are fewer water molecules in the vapor (i.e., lower vapor pressure) above the NaCl solution than in the vapor above pure water, and
- the boiling point of the NaCl solution will be greater than the boiling point of pure water.



Pure water - microscopic view.
Normal boiling point = 100.0°C.

1.0 M NaCl solution - microscopic view.
Normal boiling point = 101.0°C.
Note that the ionic solid, NaCl, produces Na^+ ions (blue) and Cl^- ions (green) when dissolved in water.

Figure 3.2. Representation of a salt solution. (available at http://www.chem.purdue.edu/gchelp/solutions/colligv2.html).

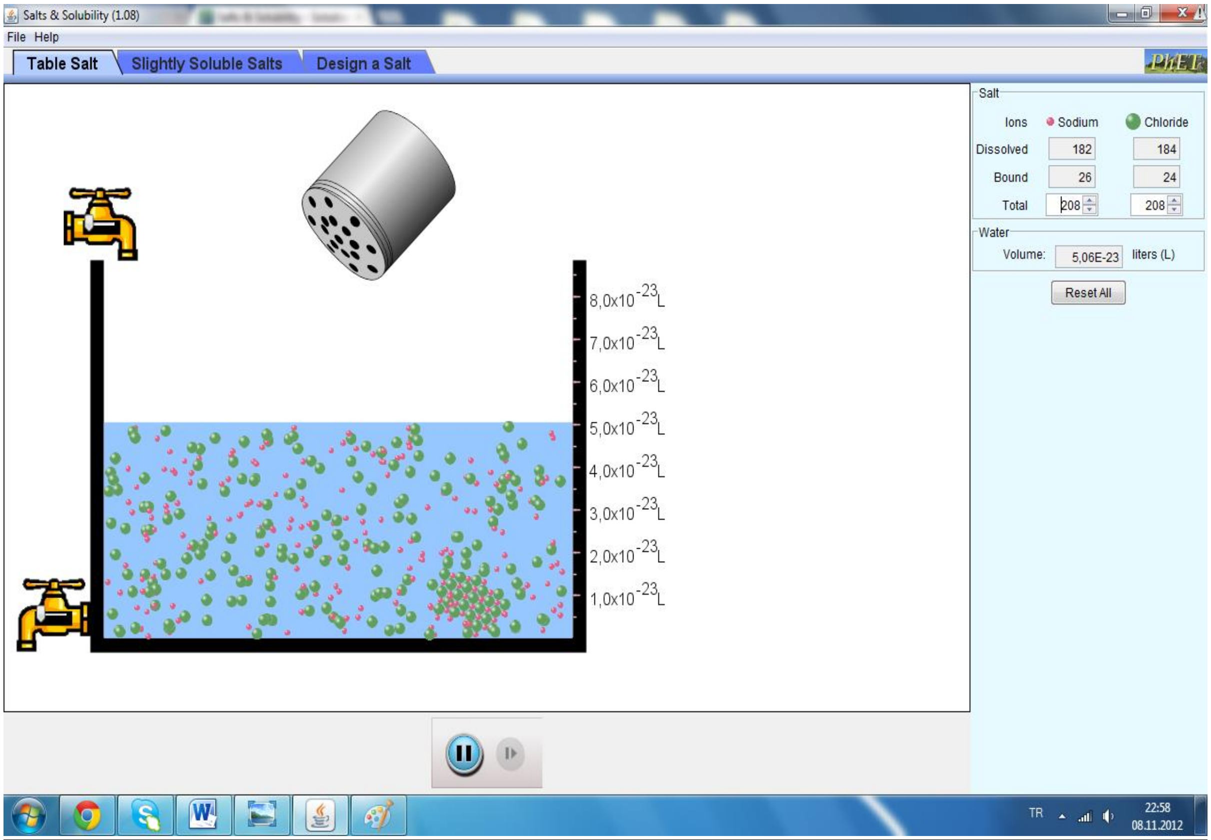


Figure 3.3. Representation of saturated salt solution with its precipitate. (available at http://phet.colorado.edu/en/simulation/soluble-salts)

3.3.3. Discussion

One of the aims of the current study's instruction was to create a learning environment in which the participants exchanged their ideas and discussed the observed phenomenon. Driver (1995) thinks that through discussion, teacher scaffolds learners for the developing of their thinking and the opportunity to reorganize their own ideas. In the same line, Glasersfeld (1995) stated that discussions with classroom members improve learners' ability to defend, provide, justify, and communicate their ideas to the classroom community. Learners' ideas can be accepted, only if they make sense to the community, classroom members.

During the instruction in the current study, participants were encouraged to make both verbal discussions and written expression of their knowledge. Firstly, participants shared their reasoning/theories with their peers within small groups verbally. Then, each group discussed their theories or their drawings with the whole class. The participants sometimes were stopped and asked some questions about their drawings and explanations. Other participants in the class were encouraged to share their agreement or disagreement about the drawings and explanations. Thus, through discussion, the participants explained their justification, identified its weak and strong points, and reorganized them according to others feedback.

3.3.4. Student Artifacts

Participants were provided activity sheets during the instruction. Activity sheets offered participants opportunity to verbally explain the phenomena with respect to particulate theory and pictorially represent the occurrences of macroscopically observed phenomena at the molecular level. In addition, participants wrote their predictions about the phenomena to their activity sheets and compared it with their explanations after observing the phenomena. They also recorded their data, drew graphs, and wrote their procedures to their activity sheets if they were necessary for their observations.

Participants were assigned to write down a journal entry for each activity to compare and contrast how the knowledge that they currently know differ from the knowledge that they used to think. Journal writings aimed to promote participants' metacognitive thinking process, develop participants' writing skills in science, and encouraged them to express their understanding. As Glasersfeld (1995) said: "there is no understanding without reflection, and reflection is an activity participants have to carry out themselves. No one else can do it for them" (p.382).

3.4. Data Collection and Recording Procedures

The data were collected from September 2010 through June 2011. The data sources were interviews, participant artifacts, and field notes. However, the interviews were used as the main data source to be analyzed. Field notes were read in order to remember and describe the instruction. Pre-interview was conducted before the instruction in the first week of October

2010, post-interview was conducted immediately after the solution chemistry instruction in December 2010, and the delayed post-interview was conducted five-months after completion of the instruction in June 2011. The sections below describe each data source.

3.4.1. Student Interviews

The semi-structured interview tasks used in the current study were adapted from the tasks included in the two-tier diagnostic instrument, namely ‘The Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI)’. This diagnostic instrument was developed by Adadan and Savasci (2012). The interview protocol included three conceptual aspects of solution chemistry. The tasks for the two aspects, namely the nature of solutions and dissolving, and the types of solutions relative to the solubility of a solute modified from the NSS-DI instrument, but the tasks for the third aspect, namely the colligative properties of solutions was created for the current study. Tasks included in the interview can be seen in Table 3.2 (see also Appendix B).

All participants who enrolled in the course (fourteen participants) were invited to individual interviews. The reason for conducting the interviews rather than conducting the tests or other written assessments was to collect more insightful and extensive data about participants’ ways of thinking (Patton, 2002).

In the pre, post, and delayed post-interview, participants were asked the same questions. However, the molecular representations of the solutions’ pictures slightly changed in the post and delayed post-interview. The participants’ ideas were investigated in depth by asking further questions such as: “What do you mean by saying this, could you please explain it a bit more? What makes you think like that? What does your drawing represent? Why do you think that happens in this case?” The participants were interviewed individually in the instructor’s office. The length of time for interviews changed with respect to participants’ responses and required further questions. The time lasted between the minimum of twenty minutes and the maximum of an hour. Each interview session was audio recorded with participants’ permissions.

Table 3.2. The content and focus of interview tasks.

Tasks	Description of Context of the Task
1	Given that a beaker is filled with water, students were asked what would happen when salt was added to it with no stirring. Explain the dissolving process at submicroscopic level.
2	Given the four different submicroscopic representations of mixtures, students were asked to identify if each one is a solution or not, explaining their reasoning.
3	Students were asked if there is any difference between solubility and dissolving and to explain their reasoning.
4	Given that a flask is filled with water at room temperature and potassium nitrate salt was added until the water could not dissolve any more salt. Then, half of the water was evaporated and the solution was cooled down until its temperature becomes equal to room temperature. Students were expected to explain what would happen to the solution.
5	Three flasks containing some sugar solution were represented at the submicroscopic level; students were asked to identify the concentration of each of them and to explain their reasoning.
6	Given that some liquid is added to automobile's radiator in cold winter days, students were expected to explain why such a liquid added into automobile radiator and the reasoning behind it at the submicroscopic level.
7	Given that oceans do not freeze but lakes do freeze in cold winter days, students were expected to explain why such a phenomenon happens and to explain it at submicroscopic level.
8	Three flasks containing different solutions at different concentrations were given. Students were asked to identify the solution which boils at the highest temperature and to explain their reasoning at the submicroscopic level.

3.4.2. Student Artifacts

For each activity, the participants were provided activity sheets (see Appendix D) so that participants were able to record their predictions, observations, and explanations, drawings of phenomena at the molecular level, comparisons of their drawings with the animation, and the designs of the experiments in written form for activities done in the classroom. The activity sheets have the questions such as: "What happens? What is your prediction? Does your conclusion support your prediction? What conclusions can you draw?" Each participant handed in their activity sheets at the end of instruction, and they were used as an additional data source for the research.

At the end of each activity, journal writings were assigned to the participants in order to identify the issues that they did not understand or they confused. Participants were expected to write them at home, and bring them to the class in the following lesson. The instructor read them as soon as the participants handed them in, and they discussed the common conceptual issues in the following class. They were expected to be written no more than one page in length. The participants provided response to the following prompt: "How does the knowledge that you currently know differ from the knowledge that you used to think?" The total number of each student' journal writing about solution chemistry was six at the end of the instruction.

3.4.3. Field Notes

The field notes were taken during each lesson in order to remember and describe the events that occurred during the instruction, when needed. The notes included the activities done in the classroom, the instructor's method used in the classroom, and some important discussions and the responses of the participants to the questions. In addition, the topics which were hard to understand, spent more time, and discussed more were recorded in the field notes.

3.4.4. Researcher's Role

During the MR instruction, the researcher participated in the classroom and attended all the lessons. The researcher observed the participants' activities in each group, listened to the participants' discussions and took the field notes.

In the interviews, both the researcher and the course instructor met with the participant in the instructor's office. In a few case, the researcher conducted interviews alone, when the instructor was absent. The questions were mainly asked by the professor to the participants. However, the instructor sometimes stopped and asked the researcher whether she had any further questions to ask. If the researcher had the questions, she asked them to the participant. In addition, the researcher followed the questions that the instructor asked to the participant from the interview protocol in order to detect any missing questions. If there were any question which was not asked, the researcher asked them to the participant.

All the interviews were recorded and transcribed entirely. Both the researcher and the instructor read the transcripts and listened to the interview records individually. They gave points to the participants' responses seperately. If there were differences in their data coding, both the researcher and the instructor met and reread the participants' responses again in order to reach an agreement.

3.5. Data Analysis

The audio-recorded pre, post, and delayed post-interviews were entirely transcribed, and the figures that the participants drew as part of their responses were collected during the interviews so that the researcher were able to easily read, code, and organize the data. The transcripts were both read and listened before starting the data analysis.

3.5.1. Quantitative Analysis

Participants' responses to each task on the interviews were divided into units, and their responses to each unit were compared to scientific criteria (see Table 3.3). The numeric point of one (1) was given to each unit's scientific explanations and the point of zero (0) was given to all other responses. Participants' names were replaced with numerical pseudonyms such as 'Participant 3', which represented the participant number. Since the number of conceptual units that existed within each task was different, relative weights of the tasks varied across the tasks. The points for each task were added up for each participant and their total scores were calculated for the pre, post, and delayed post-interview. The numeric points of each participant were recorded on a coding sheet for the pre, post, and delayed post-interview (see Table 3.4) in order to determine the effect of the instruction on participants' conceptual understandings in the short-term and the long-term.

In response to the research question 1, non-parametric statistics were conducted for the numeric data (Siegel and Castellan, 1988). The Wilcoxon-signed ranks test was utilized to compare the participants' scores for solution chemistry and to understand whether the changes were statistically significant or not. The test first takes the total scores from the pre, post, and delayed post-interview as a pair and takes absolute values of these differences and ranks them, and then a Z score and significance level were calculated from these values (Gibbons, 1993).

Table 3.3. Scientific criteria.

Task	Criteria
The nature of solutions and dissolving	Solutions are homogenous mixtures and have the same properties at everywhere of the solution. Dissolving is a process and can occur without stirring, it is not a prerequisite for dissolving. However, stirring or shaking speeds the process because it brings more free water molecules to the surface of the solid and sweeps the hydrated ions away. Solutions may exist in different physical states as long as two or more substances generate a homogeneous mixture. The mixtures of solid-solid, gas-gas, solid-liquid, liquid-liquid, gas-liquid may form a solution. (The participants should be able to identify the given solutions at different physical states with respect to their submicroscopic representations and they should be able to identify all the given mixtures if they are solutions or not.) When sodium cloride is put into water, there is a competition between the attraction of sodium ions and chloride ions to each other (due to their opposite charges) and the attraction of sodium and chloride to water molecules.The attraction of sodium and chloride ions to water is based on the polar nature of the water molecule (ion-dipole forces). The oxygen atom in water is electron-rich, giving it a partial negative charge, the hydrogen atoms, in contrast, are electron-poor, giving them a partial positive charge. As a result, the positively charged sodium ions are strongly attracted to the oxygen side of the water molecule (which has a partial negative charge), and the negatively charged chloride ions are attracted to the hydrogen side of the water molecule (which has a partial positive charge). Thus, the attraction between the separated ions and the water molecules overcomes the attraction of sodium and chloride ions to each other, and the sodium chloride dissolves in the water and it dissociates into its ions as sodium and chloride ions. These partially charged atoms surround the cations and pry them away from the crystal lattice. At the same time, water molecules form hydrogen bonds to anions at the crystal surface and begin to attract the anions away from their cation partners. Each sodium and chloride ions are surrounded by six water molecules. In addition, since water molecules are moving constantly, and the salt-water mixture becomes homogenous.
The types of solutions relative to the solubility of a solute	*Unsaturated solution* *Verbal:* A solution containing less than the equilibrium amount of solute is defined as an unsaturated solution. If you add additional solute to an unsaturated solution, it will dissolve. If a solid crystal of the solute is placed in the unsaturated solution it will decrease in size as it dissolves. The rate at which particles leave the crystal is significantly greater than the rate at which solute particles stick to the crystal. There would be free moving water molecules which are not sticked to salt ions. However, because of the water molecules constant move, the salt ions will be placed among water molecules homogenously. *Visual:* When sugar molecule’s submicroscopic three pictures are shown in sugar-water solution and asked to identify the unsaturated, supersaturated and saturated solution, the sugar molecules which has the least amount in the solution should be identified as unsaturated solution. The sugar molecules in the solution is homogenously distributed among the water molecules and there is not any precipitation at the bottom.

cont.

Table 3.3. Scientific criteria cont.

Task	Criteria
The types of solutions relative to the solubility of a solute	*Saturated solution* *Verbal:* A solution in which the dissolved solute is in dynamic equilibrium with the solid (undissolved) solute is called as a saturated solution. If additional solute is added to a saturated solution, it will not dissolve, since the concentration of solid solute in a saturated solution has reached its greatest value and no more can dissolve. When salt is added to water, water molecules rapidly solvate sodium cations and chloride anions, resulting in a noticeable decrease in the amount of solid sodium chloride in the water. Over time, however, the concentration of dissolved sodium chloride in the solution increases. This dissolved sodium chloride can then begin to recrystallize as solid sodium chloride. Initially the rate of dissolution far exceeds the rate of recrystallization, but as the concentration of dissolved sodium chloride increases, the rate of recrystallization also increases. Eventually the rates of dissolution and recrystallization become equal, and the dynamic equilibrium has been reached. *Visual:* Students should explain that there are sugar molecules at the bottom of the solution which could not be dissolved, however the solution includes the sugar molecules greater in amount than unsaturated solution but less in amount than the supersaturated solution. In addition, students should explain that the precipitate is in equilibrium with salt ions. It means that salt molecules of precipitate break down to its ions, salt ions in the solution form solid salt molecules and goes down as precipitate. Those processes occur at the same time. If the students mark the supersaturated as a saturated solution, there would be no point, even if he/she marks the unsaturated solution correctly.
The types of solutions relative to the solubility of a solute	*Supersaturated Solution* *Verbal:* A solution which contains more than the equilibrium amount of solute called as supersaturated solution. If it is left undisturbed, it does not include precipitate at the bottom. However, such solutions are unstable and if it is cooled quickly the excess solute normally precipitates out of the solution. If a solid crystal of the solute is placed in the supersaturated solution, solid crystals will increase in size and there would be precipitate at the bottom of the solution. The rate at which particles leave the crystal is significantly lower than the rate at which solute particles stick to the crystal. Solute particles will continue to precipitate until a saturated solution is achieved. A supersaturated solution can be prepared by carefully cooling a saturated solution so that crystallization (precipitation) does not occur. In addition, its appearance seems the same as the saturated solution at macroscopic level. *Visual:* The amount of dissolved sugar molecules in supersaturated solution is more, when compared to unsaturated and saturated sugar solutions' submicroscopic representations. There should not be any sugar precipitate at the bottom of the solution. The sugar molecules should be distributed homogenously, but they are closer to each other compared to saturated and unsaturated solutions.

cont.

Table 3.3. Scientific criteria cont.

Task	Criteria
Colligative Properties	The colligative properties depend on the number of particles dissolved in a solvent rather than the type of those particles.
Freezing Point Depression	The freezing point depression depends on the number of particles dissolved in a solvent rather than the type of those particles. When a solute (in the current case, anti-freezing liquid or an ionic salt) homogeneously mixes with water, the particles of solute (ions or molecules) electrostatically interact with the molecules of water. This interaction affects the energy and orientation of water molecules, because the particles of solute are relatively large compared to the molecules of water. These large particles disrupt the formation of hydrogen bonds among water molecules, preventing the formation of solid crystal structure at 0°C. That is, the resulting solution (an aqueous antifreeze solution or an aqueous salt solution) is more disordered than the pure water would be. This requires the removal of more energy from the solution, which slows down the motion of particles of solution. Therefore, the freezing temperature of water decreases below 0°C.
Boiling Point Elevation	The boiling point elevation of water depends on the existence of nonvolatile but dissolved solute particles in water and their number rather than the identity of those particles. When a nonvolatile solute (in the current case, ionic salt) dissolves in water, the ions of soluble salt electrostatically interact with the molecules of water. A solution consists of intermolecular interactions both among water molecules in which hydrogen bonds exist as well as ion-dipole interactions between the ions of a salt and the water molecules. These ion-dipole interactions are stronger than hydrogen bonds. Therefore, when water molecules are escaping from a salt solution, they not only need to overcome the electrostatic forces existing between water molecules, but also the ion-water interactions in the solution. This requires more energy than for the escape of water molecules from pure water. The boiling point is therefore elevated from the boiling point of pure water.

The following null hypotheses were tested for the participants.

1. There is no median difference between the participants' pre-interview scores and their post-interview scores.

H0: M pre = M post.

2. There is no median difference between the participants' post-interview scores and their delayed post-interview scores.

H0: M post = M delayed-post.

3. There is no median difference between the participants' pre-interview scores and their delayed post-interview scores.

H0: M pre = M delayed-post.

Table 3.4. Coding sheet that shows conceptual units of solution chemistry tasks on the pre, post, and the delayed post-interviews.

Conceptual Units	**PRE**	**POST**	**DELAYED POST-INTERVIEW**
Dissolution			
1.1. Homogeneous mixture			
1.2. Dissociation into ions			
1.3. Electrostatic Interaction			
1.4. Being aware of solutions at different physical states			
1.5. identifying the physical state of given mixtures			
1.6. identifying the given mixture if they are mixtures or not			
Types of Solutions (Verbal-Macro)			
2.1. Saturated solution			
2.2. Super Saturated solution			
2.3. Saturated solution with its precipitation			
2.4. Unsaturated solution			
Types of Solutions (Visual-Submicroscopic)			
3.1. Saturated solution			
3.2. Super Saturated solution			
3.3. Saturated solution with its precipitate			
3.4. Unsaturated solution			
Colligative Properties (Freezing point depression)			
4.1. Being aware of FPD			
4.2. Its relationship with concentration			
4.3. Explaining the FPD at the submicroscopic level			
Colligative Properties (Boiling point elevation)			
5.1. Being aware of BPE			
5.2. Its relationship with molar ion concentration			
5.3. Explaining the BPE at the submicroscopic level			

3.5.2. Qualitative Analysis

The interviews were analyzed by listening, reading, and coding the audio-recordings and the transcripts of interviews to identify the participants' conceptual understandings of the *types of solutions*. In the data analysis, the procedures of the constant comparative method which views the processes of data collection, coding, and analysis as a simultaneous process were used (Glaser, 1965; Glaser and Strauss, 1967). Initially, the participants' responses were compared to the scientific criteria about the *types of solutions* (see Table 3.3). Then, their responses were coded as scientific, alternative conceptions, or no response. In addition, the codes emerged from the data corresponding to students scientific and nonscientific (alternative) responses for each type of solution can be seen in Table 3.5, 3.6, 3.7.

Table 3.5. Meaning of the codes for unsaturated solutions.

Code	Meaning
SciAmount_1	A solution containing less than the equilibrium amount of solute. (Unsaturated-verbal).
SciAmount_2	The solute molecules which has the least amount in the solution should be identified as a unsaturated solution
SciHomo_1	The solute particles should be placed among water molecules homogenously.
SciHomo_2	Based on the visual representations, the sugar molecules in the solution are homogenously distributed among the water molecules and there is not any precipitation at the bottom.
AltDist_2	If the distance between the solute molecules are less and the concentration of solute molecules are high, it means there is little dissolving happened. This kind of solutions called as an unsaturated solution.
AltAmount_2	When three particular representations of sugar solutions are shown, and asked to identify the unsaturated, supersaturated, and saturated solution, the sugar molecules which has the least amount in the solution identified as a saturated solution not as an unsaturated solution.

Table 3.6. Meaning of the codes for saturated solutions.

Code	Meaning
SciEqui_1	Students should explain that the precipitate is in equilibrium with dissolved sugar particles in the solution. It means that sugar particles of precipitate break down into small particles, and dissolved sugar particles in the solution form solid sugar particles and goes down as precipitate. Those processes occur at the same time.
SciAdd_1	If additional solute is added to a saturated solution, it will not dissolve, since the concentration of solid solute in a saturated solution has reached its greatest value, and no more can dissolve.
SciAmount_2	Students should explain that there are solute molecules at the bottom of the solution which could not be dissolved, however the solution includes the solute molecules greater in amount than the unsaturated solution but less in amount than the supersaturated solution.
AltSuper_2	In the visual representations of unsaturated, saturated, and supersaturated solutions, students identify saturated solution as being a supersaturated solution.

The number of scientific and the alternative conceptions of participants for each type of solution were identified on the pre, post, and delayed post-interview in order to establish the criteria for the conceptual understanding categories of each type of solution. The type of conceptual understanding criteria identified for each type of solution can be seen in Table 3.8, 3.9, 3.10.

Table 3.7. Meaning of the codes for supersaturated solutions.

Code	Meaning
SciAmount_1	A solution which contains more than the amount of dissolved solute called as a supersaturated solution.
SciAmount_2	The amount of dissolved solute particles is more molecules in supersaturated solution when compared to the particulate representations of unsaturated and saturated solutions. The solute particles should be distributed homogenously, but they are closer to each other compared to saturated and unsaturated solutions.
SciPpt_1	If it is left undisturbed, it does not include precipitate at the bottom.
SciPpt_2	There should not be any sugar precipitate at the bottom of the solution.
SciUnstable_1	Supersaturated solutions are unstable and if it is cooled quickly the excess solute normally precipitates out of the solution.
SciCrys_1	If a solid crystal of the solute is placed in the supersaturated solution, solid crystals will increase in size and there would be precipitate at the bottom of the solution. The rate at which particles leave the crystal is significantly lower than the rate at which solute particles stick to the crystal. Solute particles will continue to precipitate until a saturated solution is achieved.
AltPpt_1	If the supersaturated solution is cooled down to the room temperature slowly, it will precipitate. The supersaturated solutions can only exist at high temperatures (above the room temperature). It is a temporary situation.
AltPpt_2	A supersaturated solution includes precipitate at the bottom of the solution.
AltCrys_1	If we add a few crystal of its salt to the supersaturated solution, only the added crystal will precipitate, the concentration of the solution would not change.
AltConc_1	If we add a few crystal of its solute to the supersaturated solution, only the added crystal will precipitate. The concentration of the solution would be greater, since we add solute to the solution, the amount of the precipitate in the solution would be higher, and it will increase the concentration.
AltStir_1	If we stir the supersaturated solution, it will stay the same, it will not precipitate, because we would prevent the salt particles become together.
AltDist_2	The greater the distance between solute particles, the greater the dissolving occurs. This kind of solutions called as a supersaturated solution.

The types of conceptual understanding categories were identified as scientific understanding, scientific understanding with alternative fragments, alternative understanding with scientific fragments, and alternative fragments (Trundle *et al.*, 2002; 2006). If the participants' responses included all the aspects of scientific explanation determined in the criteria without any alternative conception, it was categorized as a scientific understanding. The participants' responses sometimes included both some scientific explanations and some alternative conceptions. In this situation, the number of the type of explanation shaped the criteria. If the scientific explanations were more than the alternative explanations, it was categorized as scientific with alternative fragments. However, if the alternative explanations were more than the scientific explanations, it was categorized as an alternative understanding with scientific fragments. Lastly, if the students' responses did not include any aspects of scientific explanation but included some alternative conceptions, it was categorized as alternative fragments.

Table 3.8. Types of conceptual understanding criteria for unsaturated solutions.

<table>
<tr><th>Categories of Conceptual Understandings</th><th>Criteria - Unsaturated Solution</th></tr>
<tr><td>Scientific Understanding</td><td>Must include all of the following scientific conceptual understanding criteria:
<table>
<tr><td>Verbal</td><td>Visual</td></tr>
<tr><td>(1) A solution containing less than the equilibrium amount of solute. If you add additional solute to an unsaturated solution, it will dissolve.</td><td>(1) The solute molecules which has the least amount in the solution should be identified as unsaturated solution.</td></tr>
<tr><td>(2) The solute should be placed among the solvent homogenously.</td><td>(2) The solute molecules in the solution is homogenously distributed among the solvent molecules and there is not any precipitation at the bottom.</td></tr>
</table></td></tr>
<tr><td>Scientific understanding with alternative fragments</td><td>If the participant explains the unsaturated solution scientifically (scientific understanding), but did not identify its visual representation correctly (alternative conception), it will be categorized as scientific with alternative fragments.</td></tr>
<tr><td>Alternative fragments</td><td>Include a subset of the conceptual understandings that are in conflict with scientific aspects of the unsaturated solution with no fragments of scientific understanding. The alternative conceptions emerged from the data follow:

If the distance between the solute molecules are less and the concentration of solute molecules are high, it means there is little dissolving happened. This kind of solutions called as an unsaturated solution.

When sugar molecule’s submicroscopic three pictures are shown in sugar-water solution and asked to identify the unsaturated, supersaturated and saturated solution, the sugar molecules which has the least amount in the solution identified as saturated solution not as unsaturated solution.</td></tr>
</table>

Table 3.9. Types of conceptual understanding criteria for saturated solutions.

<table>
<tr><th>Categories of Conceptual Understandings</th><th colspan="2">Criteria-Saturated Solution</th></tr>
<tr><td rowspan="4">Scientific Understanding</td><td colspan="2">Must include all of the following scientific conceptual understanding criteria:</td></tr>
<tr><td>Verbal</td><td>Visual</td></tr>
<tr><td>(1) A solution in which the dissolved solute is in dynamic equilibrium with the solid (undissolved) solute is called as a saturated solution.</td><td>(1) Students should explain that the precipitate is in equilibrium with dissolved solute particles in the solution. It means that solute particles of precipitate break down into small particles, and dissolved solute particles in the solution form solid solute particles and goes down as precipitate. Those processes occur at the same time.</td></tr>
<tr><td>(2) If additional solute is added to a saturated solution, it will not dissolve, since the concentration of solid solute in a saturated solution has reached its greatest value, and no more can dissolve.</td><td>(2) Students should explain that there are solute particles at the bottom of the solution which could not be dissolved, however the solution includes the solute particles greater in amount than unsaturated solution but less in amount than the supersaturated solution.</td></tr>
<tr><td>Scientific understanding with alternative fragments</td><td colspan="2">Must include scientific understanding criteria of ‘if additional solute is added to a saturated solution, it will not dissolve, since the concentration of solid solute in a saturated solution has reached its greatest value and no more can dissolve’ with one alternative conception. The alternative conception emerged from the data follow:

In the visual representations of unsaturated, saturated, and supersaturated solutions, students identify saturated solution as being a supersaturated solution.</td></tr>
</table>

While determining the participants’ conceptual understanding categories, both verbal and pictorial responses were taken into consideration. They should be consistent with each other in order to be accepted as a scientific explanation. In addition, participants’ responses to the different tasks concerning the types of solutions also needed to be consistent with each other. After the participants’ conceptual understanding categories for each type of solution in all the three interviews were determined, the frequency of participants’ conceptual understanding categories was calculated. In this respect, the category change of participants was able to be observed after the MR instruction.

Table 3.10. Types of conceptual understanding criteria for supersaturated solutions.

<table>
<tr><th>Categories of Conceptual Understandings</th><th colspan="2">Criteria-Supersaturated Solutions</th></tr>
<tr><td rowspan="6">Scientific Understanding</td><td colspan="2">Must include at least four of the following scientific conceptual understanding criteria:</td></tr>
<tr><td>Verbal</td><td>Visual</td></tr>
<tr><td>(1) A solution which contains more than the amount of dissolved solute called as a supersaturated solution.</td><td>(1) The amount of dissolved solute in supersaturated solution is more, when compared to the particulate representations of unsaturated and saturated solutions. The solute particles should be distributed homogenously, but they are closer to each other compared to saturated and unsaturated solutions.</td></tr>
<tr><td>(2) If it is left undisturbed, it does not include precipitate at the bottom.</td><td>(2) There should not be any solute precipitate at the bottom of the solution.</td></tr>
<tr><td>(3) Super saturated solutions are un-stable and if it is cooled quickly the excess solute normally precipitates out of the solution.</td><td></td></tr>
<tr><td>(4) If a solid crystal of the solute is placed in the supersaturated solution, solid crystals will increase in size and there would be precipitate at the bottom of the solution. The rate at which particles leave the crystal is significantly lower than the rate at which solute particles stick to the crystal. Solute particles will continue to precipitate until a saturated solution is achieved.</td><td></td></tr>
<tr><td>Scientific understanding with alternative fragments</td><td colspan="2">Must include scientific understanding criteria of ‘A solution which contains more than the equilibrium amount of solute’, and includes a subset of the other three aspects of supersaturated solution with at one to four two alternative criteria (see alternative fragments).</td></tr>
<tr><td>Alternative understanding with scientific fragments</td><td colspan="2">Must only include scientific understanding criteria of ‘A solution which contains more than the equilibrium amount of solute’, and includes a subset of the alternative conception criteria indicated in alternative fragments section.</td></tr>
</table>

cont.

Table 3.10. Types of conceptual understanding criteria for supersaturated solutions cont.

Categories of Conceptual Understandings	**Criteria-Supersaturated Solutions**
Alternative fragments	Include at least one conceptual understanding that is in conflict with scientific aspects of the saturated solution with no fragments of scientific understanding. The alternative conceptions emerged from the data follow: If the supersaturated solution is cooled down to the room temperature slowly, it will precipitate. The supersaturated solutions can only exist at high temperatures (above the room temperature). A supersaturated solution includes precipitate at the bottom of the solution. If we add a few crystal of its solute to the supersaturated solution, only the added crystal will precipitate, the concentration of the solution would not change. If we add a few crystal of its solute to the supersaturated solution, only the added crystal will precipitate. The concentration of the solution would be greater, since we add solute to the solution, the amount of the precipitate in the solution would be higher and it will increase the concentration. Even if we left the supersaturated solution undisturbed, it will precipitate. It is a temporary situation. If we stir the supersaturated solution, it will stay the same, it will not precipitate, because we would prevent the solute particles become together. The greater the distance between soluteparticles, the greater the dissolving occurs. This kind of solutions called as a supersaturated solution.

3.6. Validity and Reliability Issues

The validity issues were mentioned in terms of prolonged engagement and instrumentation and testing, and the reliability issue was mentioned in terms of inter-rater reliability in the subsequent sections.

3.6.1. Validity Issues

To establish prolonged engagement, the researcher was present in all the class meetings. The instruction lasted twenty class periods and every class periods were three hours in length. The researcher took field notes, observed the instruction, talked to the participants, discussed the phenomena and observed the experiments done by the groups in order to spend sufficient time with the participants. In addition, the researcher was present in all the interviews. In this respect, the researcher was able to build trust, and understand the participants' meaning better in the interviews. The participants were able to gain familiarity with the researcher, and express their responses comfortably in the interviews.

In order to prevent the instrumentation threat to the validity of the study, similar questions and visual representations were asked on all of the three interviews in the current study, since Creswell (2003) stated that the scores of the study might be affected if the instrument changes on the pre, post, or delayed post-interviews. However, the visual representations, algorithmic numbers, and the sequence of the questions were changed a little for the post and delayed post-interviews in order to prevent testing threat to validity. Gay *et al*. (2006) defines testing threat as the improved performance on the post-interview. Since the participants had already asked the same questions on the pre-interview, participants might had familiarity with the questions on the post and delayed post-interview.

3.6.2. Inter Rater Reliability

The researcher and the course instructor individually scored the data, and then they met and compared the scores that they assigned for each dimension in order to check the agreement for the participants' scores and the types of conceptual understandings of the solution chemistry. All of the participants' responses on the pre and post-interview were analyzed by both researcher and the instructor, and their scores were compared. In addition, the participants' responses on the delayed post-interview were just analyzed by the researcher. On the pre-interview, the agreement between the scores assigned by the two scorers for each dimension of solution chemistry was calculated at 96%. Similarly, on the post-interview, the agreement between the scores assigned by the two scorers for each dimension of solution chemistry was calculated at 98.5%.

4. RESULTS

In this section, the findings are organized around research questions. The first research question investigated the change in pre-service chemistry teachers' conceptual understandings of solution chemistry from pre to post-interview to delayed post-interview. The second research question investigated the change in pre-service chemistry teachers' conceptual understandings of types of solutions from pre to post-interview to delayed post-interview. The third research question involved identifying the characteristics of conceptual understandings held by pre-service chemistry teachers about the types of solutions from pre to post-interview to delayed post-interview. In order to answer the research questions, the interviews were conducted with the participants before, after, and five-months after the multi-representational instruction and the findings from the data will be presented in detail in the following sub-sections.

4.1. Findings Related to the Research Question 1

Research Question 1: *How do pre-service chemistry teachers' conceptual understandings of solution chemistry differ from before beginning the multi-representational instruction to immediately after completing the instruction to five-months after completing the instruction?*

Table 4.1 presents the mean scores of participants on the pre, post, and delayed post-interview. The mean of the participants' scores on the pre-interview was found to be M=8.1 (SD=1.8). The mean of the post-interview scores was found to be M=15.6 (SD=2.2). The mean of the delayed post-interview scores was found to be M=15.0 (SD=1.8). The participants achieved higher in the post and delayed post-interviews compared to the pre-interview. The possible highest total score could be 19, if the participant provided scientific responses for all the tasks included in the interview protocol. The participants scores increased sharply from pre to post-interview and stayed quite similar in the delayed post-interview (see Table 4.1).

Table 4.1. The descriptive statistics of the total scores of interviews.

	Mean	N	Std. Deviation	Highest score	Lowest score
Pre-Interview	8.1	14	1.8	12	5
Post-Interview	15.6	14	2.2	19	12
Delayed Post-Interview	15.0	14	1.8	19	12

While analyzing the data in SPSS, the Wilcoxon-signed ranks test was utilized to statistically compare the participants' total scores from pre to post-interview, from post to delayed post-interview, and from pre to delayed post-interview. The following sections summarize the statistical results of such comparisons.

4.1.1. Comparison of Pre and Post-Interview Scores of Solution Chemistry

Research Question 1a: *How do pre-service chemistry teachers' conceptual understandings of solution chemistry differ from before beginning the multi-representational instruction to immediately after completing the instruction?*

Null Hypothesis 1: *There is no median difference between the participants' pre-interview scores and their post-interview scores (H_0: M pre = M post).*

When the participants' pre and post-interview scores were compared, the Wilcoxon-signed ranks test statistics resulted in statistically significant difference ($z= -3.301$, $p<0.05$; see Table 4.2). Because the calculated p value was lower than the critical value of 0.05, the null hypothesis was rejected. Therefore, it is concluded that there was a significant median difference in the participants' conceptual understandings of solution chemistry from the pre-interview to the post-interview conducted immediately after the multi-representational instruction. In other words, it can be said that the multi-representational instruction was effective from pre to post-interview.

Table 4.2. Results of the Wilcoxon-signed ranks test on students' pre and post-interview scores.

	N	Mean Rank	Sum of Ranks	Z	p (2-tailed)
Negative Ranks *	0	0.00	0.00	-3.301	0.001
Positive Ranks**	14	7.50	105.00		
Ties***	0				
Total	14				

* Negative Ranks indicate that post- interview score is less than pre- interview score.
** Positive Ranks indicate that post- interview score is greater than pre- interview score.
*** Ties indicate that post- interview score is equal to pre-interview score.

4.1.2. Comparison of Post and Delayed Post-Interview Scores of Solution Chemistry

Research Question 1b: *How do pre-service chemistry teachers' conceptual understandings of solution chemistry differ from immediately after completing the multi-representational instruction to five-months after completing the multi-representational instruction?*

Null Hypothesis 2: *There is no median difference between the participants' post-interview scores and their delayed post-interview scores (H_0: M post = M delayed post).*

When the participants' post and delayed post-interview scores were compared, the Wilcoxon-signed ranks test statistics did not result in statistically significant difference (z= -1.027, p>0.05; see Table 4.3). Because the calculated p value was higher than the critical value of 0.05, the null hypothesis was accepted. Therefore, it was concluded that there was not a significant median difference in the participants' conceptual understandings of solution chemistry from the post-interview to the delayed post-interview after the multi-representational instruction. The participants score's stayed quite similar from the post-interview to the delayed-post interview. It can also be concluded that the effect of the multi-representational instruction lasted in the long term period.

Table 4.3. Results of the Wilcoxon-signed ranks test on students' post, and delayed post-interview scores.

	N	Mean Rank	Sum of Ranks	Z	p (2-tailed)
Negative Ranks*	7	7.43	52.00	-1.027	0.304
Positive Ranks**	5	5.20	26.00		
Ties***	2				
Total	14				

* Negative Ranks indicate that delayed post- interview score is less than post- interview score.
** Positive Ranks indicate that delayed post-interview score is greater than post- interview score.
*** Ties indicate that delayed post-interview score is equal to post- interview score.

4.1.3. Comparison of Pre and Delayed Post-Interview Scores of Solution Chemistry

Research Question 1c: *How do pre-service chemistry teachers' conceptual understandings of solution chemistry differ from before beginning the multi-representational instruction to five-months after completing the instruction?*

Null Hypothesis 3: *There is no median difference between the participants' pre-interview scores and their delayed post-interview scores (H0: M pre = M delayed post).*

When the participants' pre and delayed post-interview scores were compared, the Wilcoxon-signed ranks test statistics resulted in statistically significant difference (z=-3.308, p<0.05; see Table 4.4). Because the calculated p value was lower than the critical value of 0.05, the null hypothesis was rejected. Therefore, it was concluded that there was a significant median difference in the participants' conceptual understandings of solution chemistry from the pre-interview to the delayed post-interview after the multi-representational instruction. It can also be concluded that the multi-representational instruction was effective and this effect lasted in the long term period.

Table 4.4. Results of the Wilcoxon-signed ranks test on participants' pre and delayed post-interview scores.

	N	Mean Rank	Sum of Ranks	Z	p (2-tailed)
Negative Ranks*	0	0.00	0.00	-3.308	0.001
Positive Ranks**	14	7.50	105.00		
Ties***	0				
Total	14				

* Negative Ranks indicate that delayed post- interview score is less than pre- interview score.
** Positive Ranks indicate that delayed post- interview score is greater than pre- interview score.
*** Ties indicate that delayed post- interview score is equal to pre- interview score.

4.2. Findings Related to Research Question 2

Research Question 2: *How do pre-service chemistry teachers' conceptual understandings of types of solutions differ from before beginning the multi-representational instruction to immediately after completing the instruction to five-months after completing the instruction?*

Table 4.5 presents the mean scores of participants on the pre, post, and delayed post-interview. The mean of the participants' scores on the pre-interview was found to be M=3.1 (SD=0.6). The mean of the post-interview scores was found to be M=4.9 (SD=1.3). The mean of the delayed post-interview scores was found to be M=5.1 (SD=1.2). The participants achieved higher in the post and delayed post-interviews compared to the pre-interview. The possible highest total score could be 6, if the participant provided scientific responses for all the types of solutions tasks included in the interview protocol. The participants scores increased sharply from pre to post-interview and stayed quite similar in the delayed post-interview (see Table 4.5).

The Wilcoxon-signed ranks test was utilized to statistically compare the participants' total scores for the types of solutions aspect from pre to post-interview, from post to delayed post-interview, and from pre to delayed post-interview. The following sections summarize the statistical results of such comparisons.

Table 4.5. The descriptive statistics of the total scores of interviews.

	Mean	N	Std. Deviation	Highest score	Lowest score
Pre-Interview	3.1	14	0.6	5	2
Post-Interview	4.9	14	1.3	6	3
Delayed Post-Interview	5.1	14	1.2	6	3

4.2.1. Comparison of Pre and Post-Interview Scores of Types of Solutions

Research Question 2a: *How do pre-service chemistry teachers' conceptual understandings of types of solutions differ from before beginning the multi-representational instruction to immediately after completing the instruction?*

Null Hypothesis 4: *There is no median difference between the participants' pre-interview scores and their post-interview scores (H_0: M pre = M post).*

When the participants' pre and post-interview scores were compared, the Wilcoxon-signed ranks test statistics resulted in statistically significant difference (z= -2.844, $p<0.05$; see Table 4.6). Because the calculated p value was lower than the critical value of 0.05, the null hypothesis was rejected. Therefore, it is concluded that there was a significant median difference in the participants' conceptual understandings of types of solutions from the pre-interview to the post-interview conducted immediately after the multi-representational instruction.

Table 4.6. Results of the Wilcoxon-signed ranks test on students' pre and post-interview scores.

	N	Mean Rank	Sum of Ranks	Z	p (2-tailed)
Negative Ranks *	0	0.00	0.00	-2.844	0.004
Positive Ranks**	10	5.50	55.00		
Ties***	4				
Total	14				

* Negative Ranks indicate that post- interview score is less than pre- interview score.
** Positive Ranks indicate that post- interview score is greater than pre- interview score.
*** Ties indicate that post- interview score is equal to pre-interview score.

4.2.2. Comparison of Post and Delayed Post-Interview Scores of Types of Solutions

Research Question 2b: *How do pre-service chemistry teachers' conceptual understandings of types of solutions differ from immediately after completing the multi-representational instruction to five-months after completing the multi-representational instruction?*

Null Hypothesis 5: *There is no median difference between the participants' post-interview scores and their delayed post-interview scores (H_0: M post = M delayed post).*

When the participants' post and delayed post-interview scores were compared, the Wilcoxon-signed ranks test statistics did not result in statistically significant difference ($z = -0.343$, $p > 0.05$; see Table 4.7). Because the calculated p value was higher than the critical value of 0.05, the null hypothesis was accepted. Therefore, it was concluded that there was not a significant median difference in the participants' conceptual understandings of types of solutions from the post-interview to the delayed post-interview after the multi-representational instruction. It can also be concluded that the effect of the multi-representational instruction lasted in the long term period.

Table 4.7. Results of the Wilcoxon-signed ranks test on students' post, delayed post-interview scores.

	N	Mean Rank	Sum of Ranks	Z	p (2-tailed)
Negative Ranks*	3	4.00	12.00	-0.343	0.732
Positive Ranks**	4	4.00	16.00		
Ties***	7				
Total	14				

* Negative Ranks indicate that delayed post- interview score is less than post- interview score.
** Positive Ranks indicate that delayed post-interview score is greater than post- interview score.
*** Ties indicate that delayed post-interview score is equal to post- interview score.

4.2.3. Comparison of Pre and Delayed Post-Interview Scores of Types of Solutions

Research Question 2c: *How do pre-service chemistry teachers' conceptual understandings of types of solutions differ from before beginning the multi-representational instruction to five-months after completing the instruction?*

Null Hypothesis 6: *There is no median difference between the participants' pre-interview scores and their delayed post-interview scores (H_0: M pre = M delayed post).*

When the participants' pre and delayed post-interview scores were compared, the Wilcoxon-signed ranks test statistics resulted in statistically significant difference ($z=-2.992$, $p<0.05$; see Table 4.8). Because the calculated p value was lower than the critical value of 0.05, the null hypothesis was rejected. Therefore, it was concluded that there was a significant median difference in the participants' conceptual understandings of types of solutions from the pre-interview to the delayed post-interview after the multi-representational instruction. It can also be concluded that the multi-representational instruction was effective and this effect lasted in the long term period.

Table 4.8. Results of the Wilcoxon-signed ranks test on participants' pre and delayed post-interview scores.

	N	**Mean Rank**	**Sum of Ranks**	**Z**	**p (2-tailed)**
Negative Ranks*	0	0.00	0.00	-2.992	0.003
Positive Ranks**	11	6.00	66.00		
Ties***	3				
Total	14				

* Negative Ranks indicate that delayed post- interview score is less than pre- interview score.
** Positive Ranks indicate that delayed post- interview score is greater than pre- interview score.
*** Ties indicate that delayed post- interview score is equal to pre- interview score.

4.3. Findings Related to the Research Question 3

Research question 3: *What kinds of conceptual understandings held by pre-service chemistry teachers about the types of solutions before, immediately after, and five-months after completing the multi-representational instruction?*

The frequency percentages of pre-service chemistry teachers' conceptual understanding categories on the pre, post, and delayed post-interviews were presented in order to track the changes in their conceptual understandings of types of solutions. In addition, the examples of participants' understanding of types of solutions before, after, and five-months after the multi-representational instruction were explained in the following sub-sections.

4.3.1. The Pre-Service Chemistry Teachers' Conceptual Understanding of Unsaturated Solutions

Research question 3a: *What kinds of conceptual understandings held by pre-service chemistry teachers about the unsaturated solutions before, immediately after, and five-months after completing the multi-representational instruction?*

The percentages that show the pre-service chemistry teachers' understanding of the unsaturated solutions on the pre, post, and delayed post-interviews can be seen in Table 4.9. Majority of the participants' conceptual understandings about unsaturated solutions were classified as scientific on the pre, post, and delayed post-interview (92.8%, 85.7%, and 92.8%, respectively). Yet, the percentage of scientific understanding slightly decreased from pre to post-interview and then increased again from post to delayed post-interview (see Table 4.9). In addition, few of the participants' conceptual understandings were classified as scientific understanding with alternative fragments (7.1% on all the three interviews) or alternative fragments on the post-interview (0%, 7.1%, and 0%, respectively).

Table 4.9. Summary of the pre-service chemistry teachers types of conceptual understandings about unsaturated solutions.

Types of Conceptual Understanding	**Unsaturated Solutions**		
	Pre	Post	Delayed
Scientific understanding	13 (92.8%)	12 (85.7%)	13 (92.8%)
Scientific understanding with alternative fragments	1 (7.1%)	1 (7.1%)	1 (7.1%)
Alternative fragments	0 (0%)	1 (7.1%)	0 (0%)
Total	14 (100%)	14 (100%)	14 (100%)

An interview excerpt represents Participant 6's verbal responses on the pre-interview (see Table 4.10). In the transcript, corresponding assigned codes have been inserted in parentheses in italic. In addition, the pictorial representation from the interview was included.

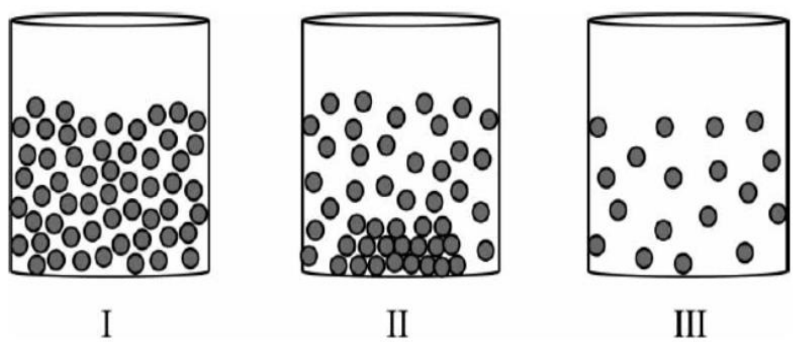


Figure 4.1. The particle level representations of sucrose solutions at different concentrations.

Table 4.10. Interview excerpt about unsaturated solutions on the pre-interview.

Researcher:	…What is a saturated solution? Could you explain what it is, please?
Participant 6:	A solution that dissolves a certain amount of solute in 100 grams of water homogenously (*SciHomo_1*). If a solute is reached a certain amount [that is the maximum amount of solute dissolved in 100 ml of water at the room temperature], it will become a saturated solution.
Researcher:	What happens if we add more water to this solution [saturated solution]?
Participant 6:	It will become an unsaturated solution (*SciAmount_1*).
Researcher:	[see Figure 4.1] Here, there are particle representations of sugar solutions at different concentrations, but in the same temperature and volume of water. The representations include only the sugar particles but not the water particles in order to make the image easier. According to these representations, how do you name each solution?
Participant 6:	The first one is unsaturated solution…Here, the distance between the sugar particles are less. Since the particles are closer to each other, the solute must be dissolved a little (*AltDist_2*).
Researcher:	Could you please explain it again?
Participant 6:	This one should be unsaturated solution (showed representation 1). This one should be dissolved a little (showed representation 2) and I can say that this one also dissolved a little (showed representation 3).

Participant 6 verbally explained that unsaturated solution containing less than the equilibrium amount of solute (SciAmount_1), and she explained that the solute particles places among water molecules homogenously (SciHomo_1). Based on the visual representations, she thought that the less the distance between the solute particles means the less the dissolving happened (AltDist_2). Thus, Participant 6 explained the unsaturated solution scientifically (SciHomo_1, SciAmount_1)**,** but she did not identify its visual representation correctly (AltDist_2); it was categorized as *scientific with alternative fragments.*

The following interview excerpt represents Participant 6's verbal responses on the post-interview (see Table 4.11).

Table 4.11. Interview excerpt about unsaturated solutions on the post-interview.

Researcher:	[see figure 4.1] Here, there are particle representations of sugar solutions at different concentrations, but in the same temperature and volume of water. The representations include only the sugar particles but not the water particles in order to make the image easier. According to these representations, how do you name each solution?
Participant 6:	…Here [representation 2], this is saturated solution with its precipitate.
Researcher:	…Representation 1?
Participant 6:	Supersaturated solution.
Researcher:	Why?
Participant 6:	When I compared 1 and 2...
Researcher:	According to what, did you compare 1 and 2?
Participant 6:	…dissolved molecules...I compared it according to the density of sugar molecules... (see below SciAmount_1and 2) Here, if the representation 2 includes these amounts of dissolved molecules above its precipitate, here [representation 1] there are more molecules. Thus, I call it as supersaturated solution [representation 1]. I say this because... the sugar molecules separated from each other homogenously, and the distance between them is a little (see below SciHomo_1 and 2).
Researcher:	The water molecules were not shown here.
Participant 6:	Hı hı. Only the sugar molecules...because of it I said this supersaturated...
Researcher:	Representation 3?
Participant 6:	Representation 3...I said this unsaturated, when I compared it with the representation 2. If I only looked at the representation of 1 and 3, and if this [representation 1] is a supersaturated solution, then I will call this [representation 3] as a saturated solution. However, when I looked at the representation 2 and compared it with the representation 3, I decided that the representation 3 is an unsaturated solution (SciAmount_1and 2; SciHomo_1 and 2).

Participant 6 verbally explained that unsaturated solution containing less than the equilibrium amount of solute (SciAmount_1), and she explained that the solute particles places among water molecules homogenously (SciHomo_1). Based on the visual representations, she identified an unsaturated solution (SciAmount_2) and referred to the homogenous distribution of solute molecules (SciHomo_2). Since Participant 6's verbal and visual responses included all of the scientific conceptual understanding criteria for an unsaturated solution (SciAmount_1and 2; SciHomo_1 and 2), the Participant 6's conceptual understanding categorized as *scientific understanding* on the post-interview.

The following interview excerpt represents Participant 6's verbal responses on the delayed post-interview (see Table 4.12).

Table 4.12. Interview excerpt about unsaturated solutions on the delayed post-interview.

Researcher:	How do you imagine a saturated solution at macroscopic and submicroscopic level?
Participant 6:	…It is a homogenous solution…All the Na^+ and Cl^- ions are surrounded by water molecules. I mean the water dissolved enough solute that it can dissolve (see below SciAmount_1; SciHomo_1**).**
Researcher:	It will dissolve the maximum amount of NaCl that it can dissolve?
Participant 6:	There would be some free moving water molecules of course…
Researcher:	How do you obtain an unsaturated solution from a saturated solution?
Participant 6:	I can obtain unsaturated solution from saturated solution by adding water (SciAmount_1; SciHomo_1).
Researcher:	[see figure 4.1] Here, there are particle representations of sugar solutions at different concentrations, but in the same temperature and volume of water. The representations include only the sugar particles but not the water particles in order to make the image easier. According to these representations, how do you name each solution?
Participant 6:	This [representation 3] is unsaturated solution (SciAmount_2; SciHomo_2)…

According to Participant 6, if a solution contains less than the equilibrium amount of solute it is called as unsaturated solution (SciAmount_1), and she also verbally explained that the solute particles are homogenously distributed in the solution (SciHomo_1). When the visual representations of solutions were shown, she identified unsaturated solution (SciAmount_2), and the homogenous distribution of solute molecules (SciHomo_2). Since Participant 6's explanations included scientific criteria for unsaturated solutions, her conceptual understanding categorized as scientific understanding on the delayed post-interview. Overall, Participant 6's conceptual understanding category changed from scientific understanding with alternative fragments to scientific understanding after the multi-representational instruction, and remained the same over a five-month period. The Participant 6 was able to identify the unsaturated solution at particulate level on the post and delayed post-interview.

4.3.2. The Pre-Service Chemistry Teachers' Conceptual Understanding of the Characteristics of Saturated Solutions

Research question 3b: *What kinds of conceptual understandings held by pre-service chemistry teachers about the saturated solutions before, immediately after, and five-months after completing the multi-representational instruction?*

The percentages that show the pre-service chemistry teachers' understanding of the saturated solutions on the pre, post, and delayed post-interviews can be seen in Table 4.13. On the pre-interview, participants had only two types of the conceptual understanding categories namely; *scientific understanding* and *scientific understanding with alternative fragments*. The percentages of scientific understanding increased sharply from the pre-interview (14.3%) to the post and delayed-post interview (85.7%). The percentages of scientific understanding with alternative fragments on the pre-interview decreased from 85.7% to 14.3% on the post and delayed-post interview.

Table 4.13. Summary of the pre-service chemistry teachers' types of conceptual understandings about saturated solutions.

Types of Conceptual Understanding	**Saturated Solutions**		
	Pre	Post	Delayed
Scientific understanding	2 (14.3%)	12 (85.7%)	12 (85.7%)
Scientific understanding with alternative fragments	12 (85.7%)	2 (14.3%)	2 (14.3%)
Total	14 (100%)	14 (100%)	14 (100%)

Although all of the participants who belong to *scientific understanding with alternative fragments* explained the saturated solution scientifically, they failed to identify the visual representation of a saturated solution when the particle representations of solutions were shown (see Figure 4.1). They misidentified the saturated solution with its precipitate as a supersaturated solution, because they believed that a supersaturated solution must include precipitate at the bottom of the solution. However, they were able to identify the saturated solution at the particulate level and explained it scientifically on the post and delayed post-interview.

The following interview excerpt represents Participant 11's verbal responses on the pre-interview. In the transcript, corresponding assigned codes have been inserted in parentheses in italic (see Table 4.14).

Table 4.14. Interview excerpt about saturated solutions on the pre-interview.

Researcher:	…Imagine that there is a beaker filled with 100 ml of water. We add potassium nitrate to this beaker until the point where the water cannot dissolve any more potassium nitrate. How do you name this solution?
Participant 11:	There is not any precipitation?
Researcher:	Yes.
Participant 11:	Saturated solution [SciAdd_1]…
Researcher:	Have you ever heard saturated solution with its precipitate?
Participant 11:	There is a precipitate, but there is also dissolved solute in the solution. It is in equilibrium… but the dissolving and precipitation occurs at the same time [SciEqui_1].
Researcher:	[Restating the question, see Figure 4.1] According to these representations, how do you name each solution?
Participant 11:	There is a precipitation here [Representation 2], so it is a supersaturated solution. Here, [Representation 3] it has not become saturated yet, so it is an unsaturated solution [AltSuper_2].
Researcher:	According to what, did you name each solution?
Participant 11:	According to the separation of the dissolved solute molecules… Here [Representation 1], the molecules are dense and they are regularly dissolved. Here [Representation 3], the molecules are rare but they are regularly dissolved again. Here [Representation 2], the molecules densely placed at the bottom, thus I think that there is a precipitate here [AltSuper_2].

Participant 11 identified a verbal explanation of saturated solution which is 'if additional solute is added to a saturated solution, it will not dissolve, since the concentration of solid solute in a saturated solution has reached its greatest value and no more can dissolve' (SciAdd_1), and she explained that the precipitate is in equilibrium with dissolved sugar particles in the solution (SciEqui_1). However, Participant 11 failed to identify the visual representation of saturated solution; she identified saturated solution as a supersaturated solution (AltSuper_2). Thus, the participant 11's conceptual understanding categorized as *scientific understanding with alternative fragments* on the pre-interview.

Other interview excerpt represents Participant 11's verbal responses on the post-interview (see Table 4.15).

Table 4.15. Interview excerpt about saturated solutions on the post-interview.

Researcher:	Imagine that we have a supersaturated solution. If we add a few crystal of its solute to the solution, what will happen to the solution?
Participant 11:	There would be precipitation at the bottom of the solution.
Researcher:	After precipitation, what will you say about the concentration of the solution?
Participant 11:	Its concentration would be low compared to a supersaturated solution. Since the amount of the solute in the solution become less after precipitation.
Researcher:	Okay. How do you imagine that solution at the particulate level?
Participant 11:	…At the particular level…Dissolving and precipitation occurs at the same time…Water molecules surround solute ions, and then leave it give to the solution again … (SciEqui_1)
Researcher:	Okay. Imagine again that we have a beaker which is filled with 100 ml water. We add potassium nitrate to this beaker until the point where the water cannot dissolve any more potassium nitrate. How do you name this solution?
Participant 11:	Is there any precipitation in the solution?
Researcher:	The solution is at the point where it cannot dissolve any more salt, that is to say, we see minimum amount of precipitate.
Participant 11:	It would be a saturated solution at the point where the precipitate just begins. If there is precipitate at the bottom of the solution, it will be a saturated solution with its precipitate. (SciAdd_1)
Researcher:	Okay. How do we keep the solution as saturated? What should or should not I do to maintain the solution as saturated?

cont.

Table 4.15. Interview excerpt about saturated solutions on the post-interview cont.

Participant 11:	If we decrease the temperature, the dissolved solute will precipitate. But, if we increase the temperature, the solution will be able to dissolve more solute…
Researcher:	…[Restating the question, see Figure 4.1] According to these representations, how do you name each solution?
Participant 11:	Supersaturated [showed representation1], Saturated with its precipitate [showed representation 2], and Unsaturated [showed representation 3].
Researcher:	How did you differentiate a saturated and a supersaturated solution at the macroscopic and microscopic level?
Participant 11:	When I looked at these representations, I considered the spaces between particles. It [showed representation 2] should be a saturated solution above the solution, because there is precipitate at the bottom of the solution. When I compared these two [representation 1 and 2], there [representation 1] should be more particles in order to be a supersaturated solution. Then, this [representation 2] should be a saturated solution with its precipitate, and this [representation 3] should be an unsaturated solution. I considered the amount of dissolved particles and compared them to each other while identifying these solutions. (SciAmount_2)

Participant 11 verbally explained that the precipitate is in equilibrium with dissolved sugar particles in the saturated solution (SciEqu_1), and explained that additional solute will not be dissolved in the saturated solution (SciAdd_1). Based on the visual representations, she identified the visual representation of saturated solution (SciAmount_2). Since Participant 11 included all of the scientific conceptual understanding criteria (SciEqu_1, SciAdd_1, and SciAmount_2) on the post-interview, her conceptual understanding was categorized as a *scientific understanding.*

The following interview excerpt represents Participant 11's verbal responses on the delayed post-interview (see Table 4.16).

Table 4.16. Interview excerpt about saturated solutions on the delayed post-interview.

Researcher:	Imagine again that we have a beaker which is filled with 100 ml water. We add potassium nitrate to this beaker until the point where the water cannot dissolve any more potassium nitrate. How do you name this solution?
Participant 11:	Saturated solution.
Researcher:	Okay. How do you imagine that saturated solution at the macroscopic and the submicroscopic level?
Participant 11:	At the macroscopic level, I imagine that there is no precipitate, but if we add a few crystals it will precipitate. (SciAdd_1) At the submicroscopic level, I imagine that particles interact with each other; let's say salt solution, the water molecules will surround the salt ions. There would be no free water molecules in the solution, each of them will interact with the salt ions. If I add a few of salt to the solution, the interaction will be disturbed and there would begin precipitation, because there will not be any water molecules which will surround the salt ions. Then, there would be precipitation at the bottom but the precipitate will not stay there all the time. It will interact with other water molecules, and it will go to the solution; and other dissolved salt ions will precipitate at the same time. This change happens all the time. (SciEqui_1)
Researcher:	…[Restating the question, see Figure 4.1] According to these representations, how do you name each solution?
Participant 11:	Supersaturated [showed representation1], Saturated with its precipitate [showed representation 2], Unsaturated [showed representation 3].
Researcher:	...How did you decide on this classification?
Participant 11:	When I looked at this [representation 2] and this [representation 3], this one [representation 2] has more dissolved sugar molecules (SciAmount_2). It [representation 2] shows that the sugar dissolves that amount at this temperature. Here, there [representation 1] are more dissolved sugar molecules compared to representation 2, thus it should be supersaturated solution. If we disturb the supersaturated solution, it will precipitate. There is precipitate at the bottom of the solution [representation 2], the dissolved sugar molecules above the precipitate are greater than this solution [representation 3]. Thus, it [representation 3] needs more molecules to be saturated.
Researcher:	You say that it can dissolve more sugar molecules.
Participant 11:	Yes.

Participant 11 verbally explained that the precipitate is in equilibrium with dissolved sugar particles in the solution (SciEqui_1), and she explained that additional solute will not be dissolved in the saturated solution (SciAdd_1). Based on the visual representations, she explained that the saturated solution includes the solute molecules greater in amount than the unsaturated solution but less in amount than the supersaturated solution (SciAmount_2). Since participant 11 included all of the scientific conceptual understanding criteria (SciEqui_1, SciAdd_1, and SciAmount_2) on the delayed post-interview, her conceptual understanding was categorized as a *scientific understanding.* Her conceptual understanding was also *scientific* on the post-interview. In addition, her conceptual understanding category changed from *scientific understanding with alternative fragments* to *scientific understanding* stayed the same after multi-representational instruction.

4.3.3. The Pre-Service Chemistry Teachers' Conceptual Understanding of the Characteristics of Supersaturated Solutions

Research question 2c: *What kinds of conceptual understandings held by pre-service chemistry teachers about the supersaturated solutions before, immediately after, and five-months after completing the multi-representational instruction?*

The percentages that show the pre-service chemistry teachers' understanding of the supersaturated solutions in the pre, post, and delayed post-interviews can be seen in Table 4.17. In the pre-interview, no student held a scientific understanding, however its percentage increased on the post (50%) and delayed post-interview (57.1%). In addition, the percentage of alternative fragments decreased sharply from pre (50%) to post-interview (7.1%), and no one was categorized as having an understanding of alternative fragments on the delayed post-interview.

In general, findings of the study revealed that the number of alternative conceptions about supersaturated solutions were greater than the alternative conceptions about the other types of solutions (see Table 4.9, 4.13, 4.17). At the beginning of the multi-representational instruction, the majority of the participants believed that supersaturated solutions include precipitate at the bottom of the solution, and these solutions can only be at high temperatures. The types of alternative conceptions about supersaturated solutions and their percentages on the pre, post, and delayed post-interview can be seen in Table 4.21.

Table 4.17. Summary of the pre-service chemistry teachers' types of conceptual understandings about supersaturated solutions.

Types of Conceptual Understanding	**Supersaturated Solutions**		
	Pre	Post	Delayed
Scientific Understanding	0 (0%)	7 (50%)	8 (57.1%)
Scientific understanding with alternative fragments	1 (7.2%)	4 (28.6%)	2 (14.3%)
Alternative understanding with scientific fragments	6 (42.8%)	2 (14.3%)	4 (28.6%)
Alternative fragments	7 (50%)	1 (7.1%)	0 (0%)
Total	14 (100%)	14 (100%)	14 (100%)

An interview excerpt represents Participant 1's verbal responses on the pre-interview (see Table 4.18). In the transcript, corresponding assigned codes have been inserted in parentheses in italic.

Table 4.18. Interview excerpt about supersaturated solutions on the pre-interview.

Researcher:	What is a supersaturated solution? Could you explain, please?
Participant 1:	… If the temperature is changed, the solute dissolves more than the amount that it can dissolve at the room temperature…It is that kind of solution (SciAmount_1).
Researcher:	Imagine that we have 100 ml of saturated potassium nitrate solution at room temperature. We heat and evaporate it until it becomes 50 ml, and then we cool it down. What type of solution is this?
Participant 1:	This is a supersaturated solution.
Researcher:	How do we observe the supersaturated solution at the macroscopic level?
Participant 1:	…When the solution becomes 50 ml, the amount of the solvent will become half, but it cannot dissolve all of the solute. Then, the precipitate will appear (AltPpt_1).
Researcher:	That means…a supersaturated solution has precipitate?
Participant 1:	Yes, there would be precipitation.
Researcher:	…Okay, Imagine again that we have a supersaturated solution. If we add a few crystal of its salt to the solution at the room temperature, what do you think that will happen?

cont.

Table 4.18. Interview excerpt about supersaturated solutions on the pre-interview cont.

Participant 1:	It will precipitate at the bottom…The concentration will not change (AltCrys_1).
Researcher:	… [Restating the question, see Figure 4.1] According to these representations, how do you name each solution?
Participant 1:	The first one is saturated [representation 1]...the second one is supersaturated [representation 2]…the third one is unsaturated [representation 3].
Researcher:	Okay. According to what, did you name each one?
Participant 1:	I started with the third one [representation 3], it is an unsaturated one. When I compared it with the first one [representation 1], the first one [representation 1] is more dense. It is a saturated solution. When I compared it [representation 1] with the second one, it is also dense but there is a precipitate at the bottom (AltPpt_2). Thus, it is a supersaturated solution.

Participant 1 verbally explained that supersaturated solution contains more than the amount of dissolved solute (SciAmount_1) and explained that if the supersaturated solution is cooled down slowly, it will precipitate (AltPpt_1). In addition, he explained that if a few crystal of salt is added to the supersaturated solution, only the added crystal will precipitate (AltCrys_1). Based on the visual representations, participant 1 explained that a supersaturated solution includes precipitate at the bottom of the solution (AltPpt_2). Since Participant 1 included the scientific understanding (SciAmount_1), and included a subset of the alternative conception (AltPpt_1, AltCrys_1, AltPpt_2), his conceptual understanding was categorized as an *alternative understanding with scientific fragments.*

Other interview excerpt represents Participant 1’s verbal responses on the post-interview (see Table 4.19).

Table 4.19. Interview excerpt about supersaturated solutions on the post-interview.

Researcher:	How do you prepare a supersaturated solution?
Participant 1:	Supersaturated solution... It is the solution which dissolved greater amount than it can dissolve (*SciAmount_1*). Here, the solution will dissolve greater

cont.

Table 4.19. Interview excerpt about supersaturated solutions on the post-interview cont.

Participant 1:	amount of solute if the temperature increases. If we decrease the temperature slowly to the room temperature, the dissolved solute ions will not precipitate. They stay in the solution, and it is called as a supersaturated solution.
Researcher:	Okay. If we put this supersaturated solution to water bath at 0^{o} C or cool down to room temperature, leaving undisturbed, could you explain please what will happen in each case?
Participant 1	If we put it into cold water bath, there would be precipitate, since we disturbed the equilibrium and decreased the temperature (*SciUnstable_1*). The water molecules will lose its kinetic energy and they cannot surround the ions in the solution. Then, the ions will come together and begin to precipitate.
Researcher:	How much do they precipitate?
Participant 1	It will precipitate until the level which it can dissolve at normal conditions. If we can decrease the temperature to the 0^{0} C, there may be more precipitate.
Researcher:	Okay. What will happen if we cool it down slowly or leave it undisturbed to the room temperature?
Participant 1	If we cool it down slowly, there would not be any precipitate. It will protect its energy level. It will not allow the ions to precipitate... (*SciPpt_1*).
Researcher:	Okay. How do you imagine saturated and supersaturated solutions at the macroscopic and the submicroscopic level?
Participant 1	There is no difference at the macroscopic level. Both of them will be viewed the same. However, there would be lesser ions in the saturated solution compared to a supersaturated solution. The number of free water molecules will decrease, and the concentration will be greater in the supersaturated solution (*SciAmount_2*).
Researcher:	… [Restating the question, see Figure 4.1] According to these representations, how do you name each solution?
Participant 1	This [representation 1] is supersaturated, this [representation 2] is saturated with its precipitate, and this [representation 3] is unsaturated solution.
Researcher:	How did you decide on your classification?
Participant 1	I looked at the amount of dissolved sugar molecules. Here [representation 1] there are more dissolved sugar molecules homogenously compare to this [representation 2]. Here [representation 1], there are more sugar molecules, thus I say that it is supersaturated (*SciAmount_2*)...Here, there [representation 3] are less dissolved molecules than it can dissolve.

Participant 1 explained that supersaturated solution contains more than the amount of dissolved solute (SciAmount_1), it is unstable and it precipitates if it is disturbed (SciUnstable_1), if it is left undisturbed, it does not include precipitate at the bottom (SciPpt_1), the amount of dissolved solute particles is more in the visual representation of supersaturated solution compared to other types of solutions (SciAmount_2). Since participant 1 included four scientific conceptual understandings criteria (SciAmount_1, SciUnstable_1, SciPpt_1, and SciAmount_2) with no alternative conception, his conceptual understanding categorized as a *scientific understanding* on the post-interview.

The following interview excerpt represents Participant 1's verbal responses on the delayed post-interview (4.20).

Table 4.20. Interview excerpt about supersaturated solutions on the delayed post-interview.

Researcher:	How do you prepare a supersaturated solution?
Participant 1:	We dissolve greater amount of solute than it can dissolve by increasing the temperature (SciAmount_1).
Researcher:	How does the increasing temperature help dissolving more solute?
Participant 1:	...When we heat the solution, the molecules gain energy. Thus, the water molecules' capacity to dissolve more sugar molecules increases.
Researcher:	What are the differences between a supersaturated and a saturated solution at the macroscopic and the microscopic level?
Participant 1:	There is no difference in their appearance at the macroscopic level...We will observe them like water... At the microscopic level, a supersaturated solution will include more sugar molecules but less free water molecules compared to a saturated solution (SciAmount_2).
Researcher:	Okay. If we put this supersaturated solution to water bath at 0^{o} C, could you please explain what will happen?
Participant 1:	The dissolved sugar molecules will precipitate (SciUnstable_1).
Researcher:	Why?
Participant 1:	Because there was equilibrium and molecules were stable. However, if the temperature changes, this equilibrium will be disturbed. The extra dissolved sugar molecules will precipitate at the room temperature. There would be solid molecules at the bottom of the solution.
Researcher:	Okay. How much do they precipitate?
Participant 1:	The extra amount of sugar molecules, which is more than the solution can dissolve at the room temperature, will precipitate.
Researcher:	If we left the supersaturated solution undisturbed or cool down slowly, what will happen?
Participant 1:	There would be nothing...It will stay the same (SciPpt_1).
Researcher:	Okay. If we add a few crystal of its solute, what will happen?

cont.

Table 4.20. Interview excerpt about supersaturated solutions on the delayed post-interview cont.

Participant 1:	We will disturb the equilibrium again. The extra dissolved solute molecules will want to join these solid salt and they will altogether precipitate to the bottom. The extra amount of sugar molecules which is more than the solution can dissolve at the room temperature will precipitate (SciCrys_1).
Researcher:	… [Restating the question, see Figure 4.1] According to these representations, how do you name each solution?
Participant 1:	The third one is unsaturated solution.
Researcher:	Why?
Participant 1:	I compared it with representation 2. Representation 2 has precipitate at the bottom, and there is a saturated solution above the precipitate. Since it dissolved enough solute that it can dissolve and the extra solute is at the bottom. Then, I call this [representation 2] as a saturated solution. When I look at representation 3, there are less dissolved molecules compared to representation 2. Thus, it can dissolve more. Representation 3 is unsaturated. Representation 1 is supersaturated solution, since the dissolved solute molecules are denser than representation 2 (SciAmount_2).

Participant 1 explained that supersaturated solution contains more than the amount of dissolved solute (SciAmount_1), it is unstable and it precipitates if it is disturbed (SciUnstable_1), if it is left undisturbed, it does not include precipitate at the bottom (SciPpt_1), if a solid crystal of the solute is placed in the supersaturated solution, it will precipitate at the bottom of the solution (SciCrys_1), the amount of dissolved solute particles is more in the visual representation of supersaturated solution compared to other types of solutions (SciAmount_2). Since participant 1 included five scientific conceptual understandings criteria (SciAmount_1, SciUnstable_1, SciPpt_1, SciCrys_1 and SciAmount_2) with no alternative fragments, his conceptual understanding categorized as a *scientific understanding* on the delayed post-interview. His conceptual understanding was also *scientific understanding* on the post-interview.

Table 4.21. Participants' alternative conceptions about supersaturated solutions.

	Alternative Conceptions	**Percentage of students with alternative conception**		
		Pre	Post	Delayed Post-Interview
1	A supersaturated solution includes precipitate at the bottom of the solution.	12 (85.7%)	2 (14.3%)	1 (7.1%)
2	If we add a few crystal of its salt to the supersaturated solution, only the added crystal will precipitate, the concentration of the solution would not change.	9 (64.3%)	2 (14.3%)	1 (7.1%)
3	Even if we left the supersaturated solution undisturbed, it will precipitate. It is a temporary situation.	1 (7.1%)	2 (14.3%)	0 (0%)
4	If the supersaturated solution is cooled down to the room temperature slowly, it will precipitate. The supersaturated solutions can only exist at high temperatures (above the room temperature).	3 (21.4%)	5 (35.7%)	5 (35.7%)
5	If we add a few crystal of its salt to the supersaturated solution, the concentration of the solution would be greater, since we add salt to the solution, the amount of the precipitate in the solution would be higher and it will increase the concentration.	1 (7.1%)	0 (0%)	0 (0%)
6	If we stir the supersaturated solution, it will stay the same, it will not precipitate, because we would prevent the salt particles become together.	0 (0%)	1 (7.1%)	0 (0%)
7	The greater the distance between solute particles, the greater the dissolving occurs. This kind of solutions called as a supersaturated solution.	1 (7.1%)	0 (0%)	0 (0%)

To sum up, the results of the quantitative analysis showed that after the multi-representational instruction the participants' scores about solution chemistry increased from pre-interview to the post and delayed post-interview. The statistical analysis showed that there was a significant median difference in the participants' conceptual understandings from the pre-interview to the post-interview; however there was not any significant median difference from the post-interview to the delayed post-interview. It showed that multi-representational instruction was effective and it lasted in a long term period. In addition, the participants' kinds of conceptual understanding about *types of solutions* analyzed qualitatively. The results showed that a majority of participants' conceptual understandings about *unsaturated* solutions were classified as scientific on all the three interviews. For the *saturated* solutions, the percentage of participants who held scientific understanding about saturated solutions sharply increased from the pre-interview to the post and delayed-post interview. For the *supersaturated* solutions, none of the participants held a scientific understanding on the pre-interview, however the percentage participants who held scientific understanding about supersaturated solutions increased on the post and delayed post-interview. In general, it can be concluded that multi-representational instruction was effective in terms of developing and retaining the participants' scientific understanding of solution chemistry.

5. DISCUSSION AND CONCLUSION

The current research study had two main purposes. The first one was to explore the effectiveness of Multi-Representational (MR) instruction on pre-service chemistry teachers' conceptual understandings of solution chemistry. The second one was to describe pre-service chemistry teachers' conceptual understandings about the types of solutions relative to the solubility of a solute before, immediately after, and five-months after they completed the MR instruction. In this section, the results of the research questions will be discussed and then the limitations of the current research study, recommendations and implications for further research will be mentioned.

Conclusion 1: The pre-service chemistry teachers' scores about solution chemistry and the types of solutions sharply increased after the MR instruction. The results showed that there was a statistically significant change in the participants' scores both from pre to post-interview and from pre to delayed post-interview.

Before starting the MR instruction, the participants' conceptual understanding scores about solution chemistry were low, and the participants' conceptions about solution chemistry and the types of solutions were found mainly non-scientific in the pre-interview. Consistent with the previous studies, the pre-service chemistry teachers' scores about solution chemistry were found statistically significant from pre to post-interview and statistically insignificant from post to delayed post-interview five-months after the instruction (Calik *et al*., 2007a, 2009; Calik *et al*., 2007b; She, 2004; Uzuntiryaki and Geban, 2005). However, these studies used different instructional methods such as: 'conceptual change text' (Calik and Coll, 2007; Uzuntiryaki and Geban, 2005), 'constructivist-based teaching model' the four step constructivist teaching (Calik *et al*., 2007b, 2009), and 'the dual situated learning model' (She, 2004). Different from these instructional methods, the current study used the MR instruction, and it can be concluded that the MR instruction was also effective to improve pre-service chemistry teachers' conceptual understandings about solution chemistry.

As previous studies suggested, the MR instruction is effective in order to achieve conceptual change and deep understanding in chemistry education (Ainsworth, 1999; Gabel, 1999; Johnstone 1991; Kirschner 2002). Since chemical phenomena happen at the submicroscopic level, it is impossible to observe it by naked eye or even by a microscope (Gabel, 1999). In the current study, the participants found it difficult to explain the phenomena at the submicroscopic level, and they generally failed to imagine and answer the questions at the submicroscopic level before the MR instruction on the pre-interview. However, after receiving the MR instruction, students were able to translate information expressed in one representation to another one (Gabel, 1999). As dual coding theory and cognitive theory of multimedia learning suggested (Mayer, 2003; Sadoski *et al.*, 1991), verbal (discussions, written expressions in the activity sheets) and nonverbal (animations that show various phenomena at the submicroscopic level, and students' drawings of atoms and molecules) stimuli used in the instruction were integrated into learners' existing explanatory framework both verbally and pictorially. In that way, participants were able to build two different mental representations (a verbal model and a visual model), and they have built connections between them (Mayer, 2001).

The MR instruction also involved inquiry-based activities. While doing the inquiry-based activities, the participants were provided with a focusing question, performed the activity, recorded and manipulated their data, formulated their explanations by making connections between observable phenomenon and the underlying scientific principles, and they presented them to the class (Eick *et al*., 2005). They also followed a cycle of Predict-Discuss-Explain-Observe-Discuss-Explain (P-D-E-O-D-E) approach (Savander-Ranne and Kolari, 2003). In this respect, participants were able to aware of their pre-existing knowledge; test it with the observable phenomenon, and discussed its weak and strong points. Perhaps, these activities helped participants to achieve conceptual change. First of all, it is important for participants to be aware of their pre-existing knowledge. According to conceptual change perspective, pre-existing knowledge of learners plays a critical role in building the new concepts, and it is required to be restructured in learners' framework theory in order to achieve conceptual change (Duit and Treagust, 2003; Vosniadou, 2003). Secondly, participants tested their pre-existing knowledge with the observed phenomena and were able to identify its weak points during the instruction. In this case, *disequilibrium* might be happened. According to Posner *et al. (1982)*, disequilibrium is the pre-condition to achieve conceptual change. Since participants were dissatisfied with their current understanding, they needed to modify the old information so that it fits into the new knowledge (Posner *et al*., 1982).

After each activity, participants were also asked to write journal entries in order to compare and contrast how the knowledge that they currently know differ from the knowledge that they used to think. After the instructor read these journal writings, she started new discussion in the class concerning the participants' conceptual issues with particular solution chemistry concepts. According to Vosniadou (2003), the conceptual change is the outcome of a complex cognitive and social process and the initial *framework theory* needs to be restructured. Perhaps, journal writings and class discussions helped the participants to have this complex cognitive and social process and they were able to restructure their initial framework theories through these processes.

Conclusion 2: There was not any significant change in the pre-service chemistry teachers' conceptual understandings about solution chemistry and the types of solutions from post to delayed post-interview. It can be concluded that MR instruction was effective and helped them to maintain their conceptual understandings over a five-month period.

Participants' conceptual understandings about solution chemistry improved as they engaged in the MR instruction, and their understandings remained similar five months after the MR instruction. In order to maintain these scientific conceptions over a five-month period, there should be required *revision* in the participants' explanatory framework (Vosniadou, 1994). According to Vosniadou (1994), *revision* requires changes in individuals' beliefs or presuppositions or changes in the relational structure of a theory. The conceptual change can be achieved if the revision takes place (Vosniadou, 1994). Perhaps, the MR instruction helped participants achieving conceptual change and deep understanding (Ainsworth, 1999; Gabel, 1999; Johnstone, 1991; Kirschner, 2002). In the MR instruction, discussions, activities and questions made participants to think and motivate (Tytler, 2002), lead them to new levels of conceptual understanding (Vygotsky, 1978), and guided them from their own meanings to socially agreed definitions, concepts, and theories (Driver, 1995). According to social constructivist view of learning, students develop their meaning when they engage socially in talk and activity about shared tasks. As Driver (1995) said, through discussions, the participants were able to develop their thinking and had the opportunity to reorganize their own ideas in order to establish scientific understanding. Thus, the participants in the current study might had restructured their conceptual understandings and based them on to their framework theory which helped them to remember and reason the concept in the long term period (Vosniadou, 1994).

Conclusion 3: The pre-service chemistry teachers' conceptual understandings about unsaturated solutions were mainly scientific on the pre-interview. However, the percentages of their scientific understandings slightly decreased from pre to post-interview and increased again from post to delayed post-interview.

In general, the participants did not have any conceptual problem in terms of understanding unsaturated solutions on the pre-interviews. They both explained it scientifically and identified it correctly at the particulate level. However, only two students' understanding category changed from scientific to alternative on the post-interview and changed again from alternative to scientific on the delayed post-interview. Participant 9 (P9) and Participant 14 (P14) failed to identify the unsaturated solution at the submicroscopic level on the post-interview, although they identified it correctly on the pre and delayed post-interview. They both hesitated identifying the unsaturated solution as an unsaturated or a saturated solution. They said on the post-interview that they would not be able to decide whether the given visual representation was an unsaturated or a saturated one, since they did not know the amount of solute dissolved in the solution. However, they could have decided the concentration of an unsaturated solution by looking at the concentration of a saturated solution with its precipitate given as a reference in the visual representations (see Figure 5.1). The reason why they both had identified it correctly on the pre and delayed post-interview but not on the post-interview might have stemmed from the conceptual change in their understanding of a supersaturated solution on these interviews. Since Vosniadou (2003) and Chi (2008) stated that knowledge is a set of interrelated propositions, or “mental model” and meaning is situated in an organized manner, the conceptual change occurred in the participants mental model about supersaturated solutions might have affected their conceptual understandings about unsaturated solutions immediately after the MR instruction. This change will be mentioned in the following paragraph.

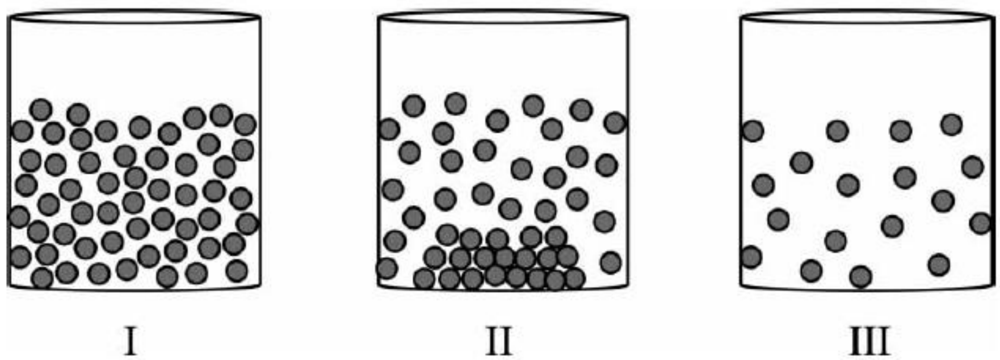


Figure 5.1. The particle level representations of sucrose solutions at different concentrations.

The participants were provided with the particle level representations of sucrose solutions at different concentrations, but in the same temperature and volume of water on the interviews (see Figure 5.1). Students were expected to identify the type of solution in each beaker. On the pre-interview, most of them identified the representation II as the supersaturated solution, since it involved precipitate. They identified the representation I as a saturated, and representation III as an unsaturated solution. However, on the post-interview, they changed their identification for a supersaturated solution from representation II to representation I. They became aware of the fact that a supersaturated solution did not include precipitate after the MR instruction. Then, they identified representation II as a saturated solution with its precipitate but failed to identify the representation III as an unsaturated solution. They all said that they would not be able to decide whether the representation III was an unsaturated or a saturated solution, since they did not know the amount of solute dissolved in the solution. On the pre-interview, after they selected the representation II as the supersaturated solution, they were left with the two representations and the two labels (saturated and unsaturated) which was easy to match them. However, on the post-interview, after they identified the supersaturated solution and the saturated solution with its precipitate, they were left with one representation and the two labels (saturated or unsaturated). In that point, they hesitated to decide between the two labels. On the delayed post-interview, they identified the representation III as unsaturated as they initially did on the pre-interview.

Conclusion 4: The pre-service chemistry teachers' conceptual understandings about saturated solutions did not include any alternative conceptions. They all explained it scientifically; however they failed to identify it at the particulate level on the pre-interview. The percentages of participants' understanding increased from pre to post-interview because they become able to identify the particular representations correctly after the MR instruction.

In the previous study of Adadan and Savasci (2012), they concluded that one of the most difficult questions on their test was the identification of solutions at the particle level. In addition, Devetak *et al.* (2009) found that students cannot understand the difference between the solutions with different concentration of the same substance. They also can not draw the solution concentration at the particulate level. Students were not able to provide complete correct answer to the question that required drawing the submicroscopic representation of diluted and saturated aqueous solutions of molecular crystal.

In the current study, most of the participants also had difficulty in identifying the saturated solutions at the particulate level on the pre-interview. However, during the MR instruction, the following activities were completed about saturated solutions: viewing animations which showed representation of saturated salt solution with its precipitate at the submicroscopic level, preparing a saturated solution, explaining the situation at the molecular level and drawing the atoms or molecules of saturated solution. These activities probably helped participants to imagine the saturated solutions at the particulate level, and most of the participants become able to identify the visual representations of saturated solutions correctly on the post and delayed post-interviews.

Conclusion 5: The number of participants' alternative conceptions about supersaturated solutions was the highest compared to the other types of solutions (unsaturated and saturated solutions). The participants' conceptual understanding was all alternative on the pre-interview; however the percentages of their scientific understandings increased from pre to post and delayed post- interview.

Literature indicated that students tend to misidentify the supersaturated solution as the saturated solution with its precipitate, because they believe that supersaturated solutions include precipitate at the bottom of the solution (Adadan and Savasci, 2012; Pinarbasi and Canpolat, 2003; Pinarbasi *et al.*, 2006). Consistent with the past literature, majority of the students on the pre-interview explained that supersaturated solutions included precipitate and identified the visual representation of saturated solution with its precipitate as a supersaturated solution. However, most of them (71.4%) changed this view and were able to explain it scientifically on the post and delayed post-interview.

One of the reasons that caused this alternative conception might be related to the participants' everyday experiences of the dissolving of sucrose in tea. If excessive amount of sucrose is placed in tea, there would be precipitate at the bottom. For the participants, it might have implied oversaturation (Adadan and Savasci, 2012). According to Vosniadou (2003), these everyday experiences of students provide good explanations, thus students see no reason to change them. However, if students become aware of their beliefs' and presuppositions' theoretical status, they can change these alternative conceptions (Vosniadou, 2003). Thus, the MR instruction in the current study aimed to make participants become aware of their alternative conceptions, recognize the incompatibility between their scientific and nonscientific conceptions, and became dissatisfied with their existing nonscientific conceptions which is the pre-condition for conceptual change learning (Posner *et al.*, 1982).

Another reason for this alternative conception might stem from the participants' lack of experience with the supersaturated solutions at submicroscopic levels (Adadan and Savasci, 2012). In addition, Devetak *et al.* (2009) states that instructions include mostly the algorithmic aspects of concentration of solutions rather than visual representations and explanations of supersaturated solutions at the submicroscopic level. Thus, it becomes difficult for students to imagine the supersaturated solutions at the submicroscopic level. Educators should emphasize not only solving the algorithmic questions about supersaturated solutions, but also they should give importance to the visual representations and animations of supersaturated solutions in their instructions. In the current study, the MR instruction included animations, activities and drawings for the types of solutions at the submicroscopic level. During the instruction, the participants prepared a supersaturated solution, explained the given situations at the molecular level, drew the pictorial representations of given solutions at the molecular level and wrote a journal at the end of the lesson. In this respect, the participants were able to observe the supersaturated solution both at the macroscopic and submicroscopic level, and discussed the given situations both orally and textually. Thus, they were able to develop and reorganize their thinking in order to establish a scientific understanding about supersaturated solutions (Vosniadou, 2003).

5.1. Limitations of the Study

The main limitation of this research study was the sample size. Fourteen pre-service chemistry teachers participated in the current study. They were not selected randomly; all of the participants were the pre-service chemistry teachers who took "Secondary School Science Laboratory Applications" course at the same university. Therefore, the results of the study cannot be generalized to all pre-service chemistry teachers. It can be valid only for this sample. In addition, the majority of the participants were at their third or fourth years at the university, the participants who were at lower or higher grade levels may have resulted in different results.

5.2. Recommendations for Further Research

In the following paragraphs, some recommendations will be discussed for the further research studies. A large number of participants, time spent between post and delayed-post interviews, including more aspects of solution chemistry for the qualitative analysis, and developing more animations for the further research studies will be suggested.

In the further studies, it would be better to involve a large number of participants with random selection from different grade levels. In that respect, generalizing the results with those participants would be more meaningful. In addition, participants from different universities or schools can change the results of this study, thus further studies should be done with different participants.

Another recommendation for the further studies might be about the time passed between the post and delayed post-interviews. In the current study, there were five-month period between the post and delayed post-interview because the semester would end, and the participants would not be available later. However, this period might be longer in order to conduct a longitudinal study in the further studies.

In the current study, all of the aspects of solution chemistry analyzed quantitatively, but only the types of solutions aspect analyzed qualitatively. In the further studies, however, all of the aspects which include dissolving, identifying the solutions' physical states and colligative properties might also be analyzed qualitatively in order to describe the effects of MR instruction on the pre-service chemistry teachers' conceptual understandings about each aspect of solution chemistry.

Finally, animations were very important tools used in the instruction of the current study, since it helped the participants to imagine the macroscopically observed phenomena (experiments) at the particulate level. However, only the animations which were available online were used in this study, they were not developed by the researcher. Thus, there were a limited number of available online animations to be used for each activity; it may have affected the results. In the further studies, animations or dynamic models which are developed by researchers for each particular activity included in the MR instruction could be more useful.

5.3. Implications

This section discusses the implications of the findings of the current study for instruction and educational research. The benefits of inquiry based activities, MR instruction, journal writings and mixed method research study used in the current study will be mentioned in the following paragraphs.

In the MR instruction, the representations were verbal (discussions, written expressions in the activity sheets) and pictorial (animations that show various phenomena at the submicroscopic level, and participants' drawings of atoms and molecules). These multiple modes of representations may have made the conceptual change possible for the participants' alternative conceptions about solution chemistry. As dual coding theory and cognitive theory of multimedia learning suggested (Mayer, 2003; Sadoski *et al.*, 1991), verbal and non-verbal stimuli might continually activated mental representations of the participants. In that way, participants were able to build two different mental representations; a verbal model and a visual model, and built connections between them. In this respect, instructors should use animations, particulate representations, ask their students to draw visual representations of particles. Therefore, instructors would be able to identify students' mental models of the phenomena, see their progress during the instruction, and they would be more successful in terms of promoting conceptual change in their classrooms.

During the MR instruction, inquiry based activities were conducted. Participants predicted what will happen in a given situation, observed the situation through a focusing question, recorded and manipulated their data, compared their predictions to their observations, discussed it within their groups, and explained their contradictions between their predictions and observations. Thus, participants were able to aware of their existing knowledge, understand its' strong and weak points when they compared it with the observed phenomena. If the observed phenomena conflicts with their existing concepts, they might need to change their conceptions with the new ones. While participants were conducting the experiments, observing the phenomena, finding the answers to their questions, and comparing the new information with their existing knowledge, they were able to re-organize their ideas in their framework theories. Therefore, the instructors should involve students in inquiry-based activities in order to achieve conceptual change in their instructions.

Another aspect of the MR instruction was discussions. Participants made both small group discussions and whole-class discussions during the instruction. They were able to question their own ideas, compare them with others' ideas, develop their thinking and had the opportunity to reorganize their own ideas in order to establish scientific understanding through discussions (Driver, 1995; Duit and Treagust, 2003). While participants are restructuring their conceptual understandings, they might combine those ideas into their explanatory framework.
The other aspect of the MR instruction was journal writings. Participants were assigned to write down a journal entry for each activity to compare and contrast how the knowledge that they currently know differ from the knowledge that they used to think. It encouraged them to express their understandings. After reading journal writings of each participant, the instructor was able to gain insight into the participants' conceptual understandings and addressed the issues that students experienced about particular concepts during the instruction. Therefore, the instructors should include journal writings while designing their instructions.

The current study was a mixed method study combined with quantitative and qualitative research methods (Creswell and Clark, 2007). Quantitative part of the study was a one-group quasi-experimental design with pre, post, and delayed post-interview (Cook and Campbell, 1979). Qualitative part of the study involved verbal data (e.g., interviews, collection of student artifacts, field notes) and descriptive data analysis procedures. In the quantitative part, the general picture of participants' conceptual understandings about solution chemistry was determined. In the qualitative part, participants' conceptual understanding categories about types of solutions were examined in detail. Thus, this mixed method study gave additional perspectives and insights that are beyond the scope of any single technique. Quantitative studies allow analysis in numerical dimension whereas qualitative analysis allow for an in-depth understanding of phenomenon. Both quantitative and qualitative methods have some strength but more benefits are realised when they are brought together.

APPENDIX A: DESCRIPTION OF INSTRUCTIONAL INTERVENTIONS

The First Lesson

At the beginning of the lesson, the students watched an animation about dissolving sugar molecules in the water. Then, they were asked about how the dissolving occurs. They discussed the intermolecular forces and molecular bonds of molecules in the solution. They drew the pictorial representations of the sugar solution at the molecular level in their activity sheets. Then, they watched the animation again and compared their drawings with the animation shown. Another discussion was about the amount of solute and solvent in the solid-solid, solid-liquid and gas-gas solutions.

Then, the students completed an activity sheet about the factors affecting solubility of solids. In that sheet they are expected to compare and contrast the given terms such as soluble versus solubility and design an experiment that shows the increasing the solubility of KNO_3 as the temperature was increased. After they discussed how to design their experiment in the class with the teacher, each group took different amount of the salt and added to 5 mL water. They first heated the salt solution until all the salt was dissolved in the water bath and cooled the solution until the salt was precipitated. At the time they observed the precipitation of salt; they recorded the temperature in their sheets and compared their data with other groups. Then they drew the graph of solubility of the salt vs. the temperature in their activity sheets. They wrote and discussed their conclusion based on their data. They also explained their conclusion at the particulate level and wrote journal at the end of the lesson.

The Second Lesson

The students talked about what they did in the previous lesson. They discussed why the solubility increases with the increasing temperature in the salt solution. They also talked about the entropy change when the temperature increased. Then, they did an experiment about factors affecting the solubility of gases. The students took 5 mL of coke to the syringe without having any bubbles in it. Then they pulled the arm of the syringe to the 20 ml. They wrote down what they observed and explained it with respect to the particle theory of matter. After discussing it in the class, they concluded that as pressure decreases, CO_2 particles which dissolved in the water turned into gas and left the solution. On the other hand, as the pressure increases, some of the gas particles dissolve and bubbles decreases. In the other part of the activity sheet students were expected to design an experiment which shows the effect of temperature on the dissolution of gases. They put same amount of coke to two identical beakers then, they put one of them to the ice bath and the other one to the hot water bath. They observed that bubbles are less in the beaker in ice bath than the bubbles in the beaker in hot water bath. Then, the teacher asked them to explain what they observed with respect to particle theory. At the end of the lesson, the teacher showed an animation about dissolving NaCl from preparatorychemistry.com. They wrote a journal about the lesson.

The Third Lesson

The students talked about what they did in the previous lesson firstly. They summarized that solubility of gases decreases with increasing temperature and decreasing pressure. Then, they completed an activity sheet about types of solutions. In the first part, they compared and contrasted the given terms: concentrated solution vs. saturated solution and diluted solution vs. concentrated solution. Then, they discussed how to classify a solution as concentrated or dilute. In the other part of the activity sheet, they compared and contrasted saturated solution vs. percent concentration. They were asked the questions: “How do you imagine salt and sugar solutions in submicroscopic level?” and “How do you classify solutions as saturated, supersaturated and dilute?” After they discussed it in the class, they concluded that supersaturated solutions are in equilibrium. If people disturb it by heating and stirring much, they will end up with precipitation in the solution.

The Fourth Lesson

At the beginning of the lesson, the students were asked the questions such as: “How do you prepare saturated or diluted salt solutions”, “How do you imagine a saturated solution?” “Why does the solubility of sugar and salt solutions different at room temperature?” After discussing them, they continued to work on the types of solutions activity sheet. The students weighed the salt from last week’s experiment to check out evaporation. They compared their predictions with their results. Then, they were asked questions such as: “What were your predictions and what so you end up after weighing it?” “If you add 25 g sodium thiosulfate to the 2.5 mL water, what do you expect to observe? Can you dissolve all of it? Do you end up with a solution or not?” After they discussed them, they decided to do this experiment in the next lesson.

The Fifth Lesson

The students went on writing their “types of solutions” activity sheet. They prepared a supersaturated solution. They added 25g NaS_2O_3 in 2.5 mL water as written in their sheets. They put their test tubes on a hot water bath. After they dissolved the solid completely, they waited a while and observed no precipitation. Then, they wrote what they observed on their sheets. The teacher added one crystal of the solid to this solution when it was cooled to room temperature. They observed precipitation. Then they were asked: “what do you think about its concentration? What type of solution is that?” They were also expected to predict what would happen to the saturated solution of sodium chloride, if they evaporate half of the solution. Then they were asked to explain the situation at the molecular level and draw pictorial representations of given solutions at the molecular level. After discussing it, they wrote their journal.

Another sheet called “Colligative Properties- Freezing Point Depression” was given to the students. In the first part of the sheet, there was a question: “How does the nature of salt affect the freezing point of water? Write your predictions.” In the second part, it was expected students to design an experiment to observe how the nature of salts affects the freezing point of water. There were given three types of solid, sucrose, NaCl and $CaCl_2$, and their molecular weight to design an experiment to observe their freezing point. Each group selected one solid and prepared a 0, 3 M solution with 40 mL water. In the next lesson, each group would have all of the three types of solution and observe the freezing point depression.

The Sixth Lesson

They talked about what they have learnt in the previous lesson. Then they went on doing activities in the “Colligative properties- freezing point depression activity sheet”. Each group put some solution which they prepared in the previous lesson in their test tubes. While the tubes were in the cold water bath (included ice, water and salt), they observed and recorded its freezing point. They concluded:” The more ions in water, the less freezing point of the solution. Ions block the crystals to come together to go to the solid state.” Then, they discussed the effect of concentration on freezing point depression at the submicroscopic level. After they were asked how they would design an experiment in order to observe the effect of concentration on the freezing point, they suggested designing an experiment which they observe the different concentrations of the same substance.

Then the teacher gave another activity sheet called “Colligative Properties- Boiling Point Elevation”. In the first part, they answered the question “How does the concentration of NaCl affect the boiling point of the water?” In the second part, they were expected to design an experiment to observe how the concentration of NaCl affects the boiling point of water. They took three different concentrations of salt solutions, observed their boiling points and recorded them. Then, they discussed the results. They concluded: “Water molecule has interaction with both ions and the other water molecules, so to break this interaction needs more energy and increases the boiling point”.

APPENDIX B: INTERVIEW PROTOCOL

GÖRÜŞME TUTANAĞI

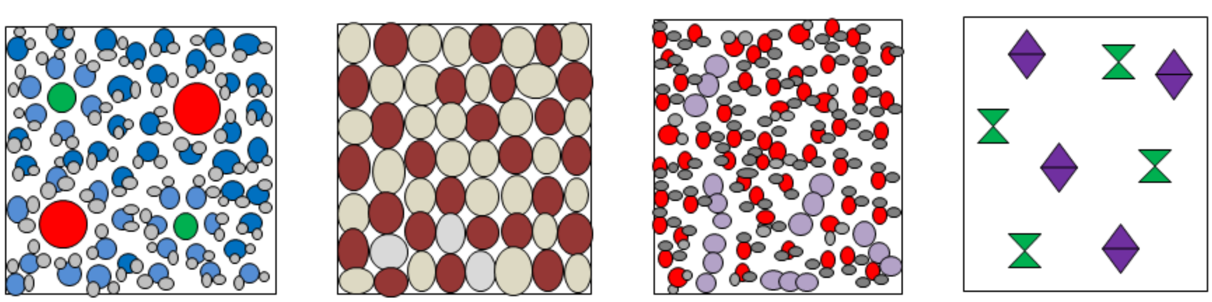
ÇÖZELTİLERİN DOĞASI VE ÇÖZÜNÜRLÜK

BÖLÜM 1 - Çözünme

Çözünme nedir? Örnek vererek açıklar mısın? Çözünme olayı moleküler seviyede nasıl gerçekleşmektedir? Açıklayabilir misin? Şayet 2. soru anlaşılmamışsa ya da yeterli cevap gelmiyorsa; su ile tuz arasında gözlemleyemediğimiz moleküler seviyede neler oluyor da çözünme gerçekleşiyor? Erime nedir? Çözünme ile erime arasında fark var mıdır? Evetse, çözünme ile erime arasında ne gibi farklılıklar vardır? Örnek vererek açıklar mısın? Bir beherde bulunan oda sıcaklığındaki (25 ºC) 100 mL suya 15 g tuz (NaCl) ekleniyor. Beher, eklenen tuz karıştırılmadan bir gün süreyle bekletiliyor. Bu süre içerisinde tuza ne olacağını düşünüyorsunuz? (*Not: 25 ºC' de tuzun [NaCl] çözünürlüğü 36 g/100 mL su*)
Neden? Cevabını açıklayabilir misin?

BÖLÜM 2 – Submikro Seviyede Çözeltilerin Belirlenmesi

Çözelti nedir? Tanımlayabilir misin? Örnek verebilir misin? Çözeltilerin en önemli özellikleri nelerdir? Karışımlardan farkı nedir? Aşağıda atomik/moleküler düzeyde gösterilen karışımlardan hangisi ya da hangileri çözeltidir? (*Not: Şekildeki her bir daire atom, iyon veya molekülü göstermektedir*.) Cevabını açıklar mısın?



I **II** **III** **IV**

BÖLÜM 3 – Çözelti Çeşitleri (Sözel)

Oda sıcaklığındaki (25 ºC) 100 mL suya, daha fazla çözünmeyecek kadar potasyum nitrat (KNO_3) tuzu karıştırılarak ekleniyor. Daha sonra çözeltideki suyun hacmi 50 mL' ye düşene kadar buharlaştırılıyor ve çözelti oda sıcaklığına gelene kadar soğutuluyor. Elde edilen çözelti için ne söylenebilir? Neden sence bu …….? Cevabını açıklayabilir misin? Daha sonra ayrı ayrı aşağıdaki sorular sorulur.

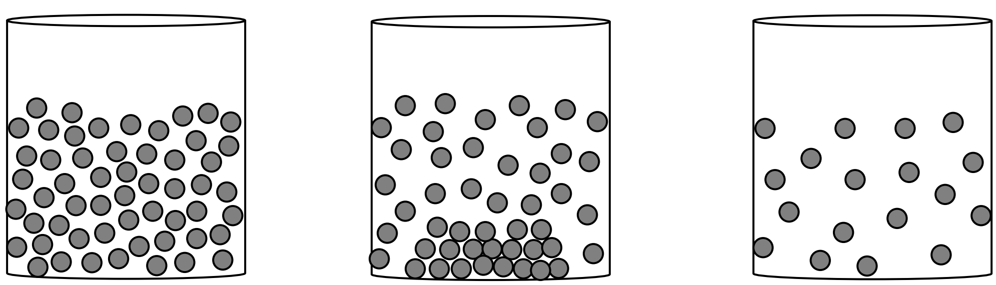
Katısı ile dengede olan çözelti nedir? Açıklayabilir misin?

Aşırı doymuş çözelti nedir? Açıklayabilir misin?

Aşırı doymuş çözelti ile katısıyla dengede olan doymuş çözelti arasında fark var mıdır? Açıklayabilir misin?

Doymuş çözelti nedir? Açıklayabilir misin?

BÖLÜM 4 –Çözelti Çeşitleri (Görsel)



I II III

Yukarıdaki şekilde, I, II ve III kaplarında bulunan farklı derişimlerdeki şeker çözeltilerinin moleküler seviyedeki gösterimleri verilmiştir. Her bir çözeltinin derişimi hakkında ne söylenebilir? (*Not: Şekildeki koyu renkli daireler şeker moleküllerini göstermektedir. Şekli basitleştirmek için su molekülleri gösterilmemiştir*.)

Cevabını açıklayabilir misin?

Katısı ile dengede olan çözelti nedir? Açıklayabilir misin?

Aşırı doymuş çözelti nedir? Açıklayabilir misin?

Aşırı doymuş çözelti ile katısıyla dengede olan doymuş çözelti arasında fark var mıdır? Açıklayabilir misin?

Doymuş çözelti nedir? Açıklayabilir misin?

Bir tuzun oda sıcaklığındaki (25 ºC) aşırı doymuş çözeltisine çok az miktarda aynı tuzdan atıldığında, çözeltinin derişimi hakkında ne söylenebilir?

Neden ……?

Cevabını açıklayabilir misin?

BÖLÜM 5 – Donma Noktası Düşmesi

Soğuk kış günlerinde, içinde su bulunan araba radyatörlerine suda çözünebilen sıvılar eklenir. Bu sıvıların donma noktası suyun donma noktasından düşük, kaynama noktası ise suyun kaynama noktasından oldukça yüksektir. Bu sıvıların konulmasının sebebi sence ne olabilir? Bu maddeler suyun donma noktasını nasıl düşürür? Açıklayabilir misin? Şayet öğrenci yükseltir diyorsa nasıl yükseltir? olarak sorulur soru. Şayet öğrenci moleküler seviyede açıklamıyorsa, soruyu tekrar sorarız, moleküler seviyede ne oluyor da eklenen bu sıvılar suyun donma noktasını düşürüyor (yükseltiyor – öğrenci yükseltir demişsse).

“Bolu'da ... etkili olan kar yağışıyla birlikte düşen hava sıcaklıkları Abant Gölü’nü dondurdu.”

9 Ocak 2009 tarihli gazete haberi

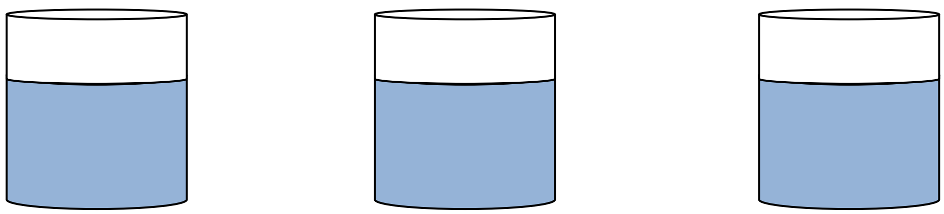
Kışın göllerin donduğuna dair haberleri sıkça okuyor olmamıza rağmen, denizler nadiren donmaktadır (kutup bölgeleri hariç). Denizlerin donmamasının sebebini nasıl açıklayabilirsin?

Bir sonraki soru: Şayet öğrenci moleküler seviyede açıklamıyorsa, soruyu tekrar sorarız, moleküler seviyede ne oluyor da tuz suyun donma noktasını düşürüyor (yükseltiyor – öğrenci yükseltir demişse).

BÖLÜM 6 – Kaynama Noktası Yükselmesi

Aşağıda molar derişimleri ve hacimleri verilen çözeltilerden hangisi en yüksek sıcaklıkta kaynar? (*Not: Aşağıda verilen maddelerin hepsi suda tamamen çözünür*.)

0.2 M, NaCl 0.2 M, Na_3PO_4 0.4 M, $C_6H_{12}O_6$ (Şeker)



Cevabını açıklayabilir misin? Neden?
Moleküler seviyede ne oluyor ki, eklenilen tuz, suyun kaynama sıcaklığını yükseltiyor?

Oda sıcaklığındaki (25°C) 100 mL su ve 2 M, 100 mL $CaCl_2$ (Kalsiyum Klorür) çözeltisi özdeş ısıtıcılarla eşit hızda ısıtılmaya başlanırsa, su ve kalsiyum klorür çözeltisinin kaynama süresi ile ilgili ne söylenebilir? Neden? Cevabını açıklayabilir misin? Moleküler seviyede ne oluyor ki, eklenilen tuz, suyun kaynama sıcaklığını yükseltiyor?

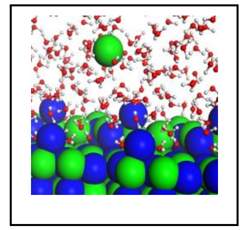
Su (H_2O) 2 M, $CaCl_2$

APPENDIX C: STUDENT ACTIVITY SHEETS

ÖĞRENCİ AKTİVİTE KAĞITLARI

Name --

Date--



Activity 1: The Nature of Dissolving

Put two pieces of ice cubes into the water placed in a beaker. Observe what happens to the ice cubes over time. Explain the phenomenon with respect to *the particle theory of matter.*

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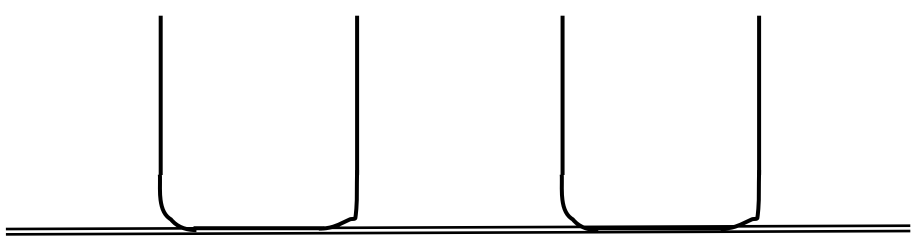
Draw two pictures that represent what happens to the ice cubes at the submicroscopic level just after and a day after the ice cubes were dropped into the water.



Just after A day after

You will be provided with a beaker consists of some water. Put some table salt in water without stirring, and observe what happens to the table salt in water? Describe/Explain the phenomenon in detail with respect to *the particle theory of matter*.

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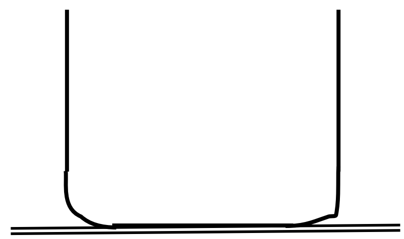
Draw a picture that represents the dissolution of the table salt in water at the molecular level.



Compare your drawing with the animation that show what happens to the table salt in water.

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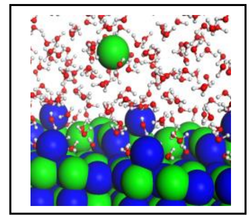

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Activity 2: Factors Affecting Solubility of Solids

Compare and contrast the given pair of terms.

Soluble vs. solubility

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Solubility vs. dissolving

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How does the solubility of KNO_3 change with increasing temperature? Design an experiment to find out the solubility of KNO_3 at different temperatures.

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Provide a data table, and construct a solubility curve for KNO_3 by plotting your data on graph paper.

Write down your conclusion based on your data.

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Explain your conclusion at the submicroscopic level.

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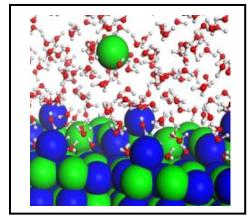

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Activity 3: Factors Affecting Solubility of Gases

1) You will be provided a syringe filled with 10 ml of a carbonated drink without any space. Pull the plunger of the syringe to the point of 50 ml (see Figure B), and observe what happens. Then, push the plunger of the syringe to its initial point (see Figure A)

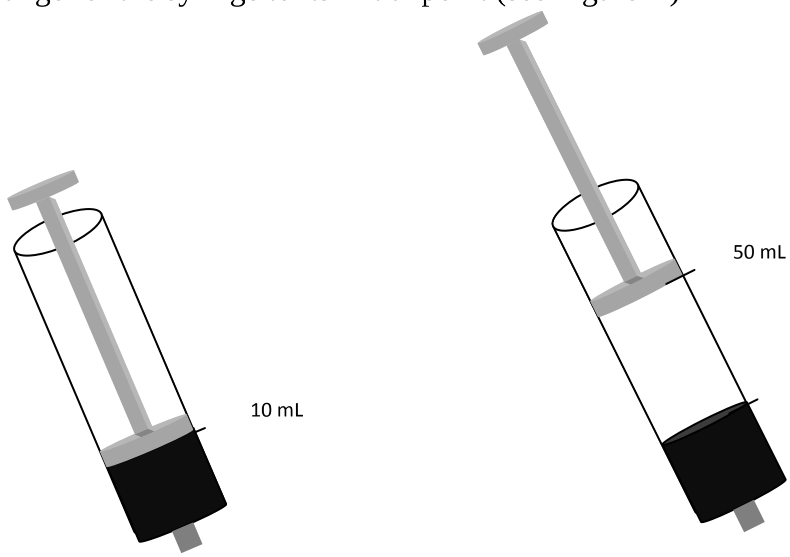

Figure A Figure B

Write down your observations.

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Explain your observations with respect to *the particle theory of matter*.

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2) How does the temperature affect dissolution of gases? Design an experiment to observe the effect of temperature on dissolution of gases.

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Write down your observations, and explain the phenomenon at the submicroscopic level.

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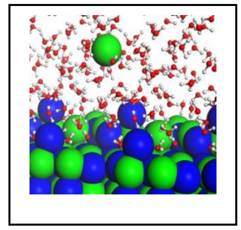

Activity 4: Types of Solutions

Compare and contrast the given pair of terms.

Diluted vs. Concentrated solution:

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Saturated vs. Concentrated solution:

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Saturated solution vs. Percent Concentration:

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Prepare a saturated solution of sodium chloride by using 100 ml of water at room temperature. Predict what would happen to the solution, if you evaporate the half of the NaCl solution.

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Write down your observations during the evaporation of the half of the NaCl solution.

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Explain what happens at the molecular level during and after the evaporation of the half of the NaCl solution. PLEASE provide evidence while explaining the phenomenon.

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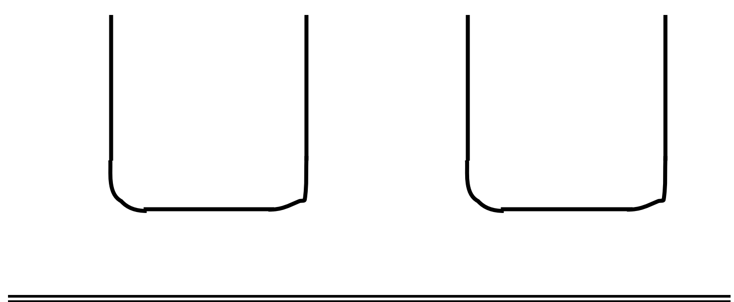
Draw two particle models that represent what happens to the saturated NaCl solution before and after evaporation of half of the solution.



Before evaporation After evaporation

Dissolve 25 g of Sodium thiosulfate, $Na_2S_2O_3$ in 2.5 ml of water. Gently heat the test tube in a *warm* water bath until all of the $Na_2S_2O_3$ is dissolved. Allow the solution to cool to the room temperature. Write down your observations during this process.

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What type of solution is that?

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Add one crystal of sodium thiosulfate to the solution you just cooled down to the room temperature. What happened to the solution? Write down your observations.

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What would you think about the concentration of the $Na_2S_2O_3$ solution after the addition of one crystal?

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What type of solution is that? Why?

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Journal

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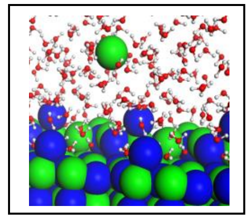

Activity 5: Colligative Properties – Freezing Point Depression

How does the nature of salt affect the freezing point of water? What is your prediction?

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Design an experiment to observe how the nature of salt affects the freezing point of water. [Materials to be used: Sucrose ($C_{12}H_{22}O_{11}$= 342.3 g/mol); Sodium chloride (NaCl = 58.5 g/mol); Calcium chloride ($CaCl_2$ = 111 g/mol)]

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Provide a data table

Do you observe any pattern in your data? Explain.

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Draw a conclusion based on your data. Does your conclusion support your prediction? Explain.

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Explain the phenomenon that you observed at the submicroscopic level.

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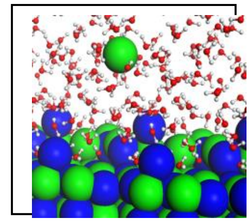

Activity 6: Colligative Properties – Boiling Point Elevation

How does the concentration of NaCl affect the boiling point (b.p.) of the water? What is your prediction?

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Design an experiment to observe how the concentration of NaCl affects the b. p. of the water. [Sodium chloride ($NaCl$ = 58.5 g/mol)]

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Provide a data table

Do you observe any pattern in your data? Explain.

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Draw a conclusion based on your data. Does your conclusion support your prediction? Explain.

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Explain the phenomenon that you observed at the submicroscopic level.

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