INVESTIGATING PRESERVICE CHEMISTRY TEACHERS' EYE MOVEMENTS WHILE WORKING WITH MACROSCOPIC, SYMBOLIC AND SUBMICROSCOPIC LEVEL OF REPRESENTATIONS FOR CHEMICAL EQUILIBRIUM

by

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Integrated B.S. and M.S. Program in Teaching Chemistry, Boğaziçi University, 2013

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Secondary School Science and Mathematics Education
Boğaziçi University
2019

ACKNOWLEDGEMENTS

First of all, I would like to thank my thesis supervisor Assoc. Prof. Sevil Akaygun for her endless support, patience and motivation. She advocated her time to read the drafts of my thesis and helped me in all the time of research. I could not complete this process without her help. I hope we continue working together in the future.

Beside my supervisor, I would also like to thank my thesis committee members Assoc. Prof. Oktay Demircan and Assoc. Prof. Funda Savaşçı Açıkalın for spending their time and making their valuable feedbacks and insightful comments on this study.

I am grateful to Prof. Gülcan Erçetin who guided me about eye tracking technology. Also, my sincere thanks go to Dr. Filiz Rızaoğlu who helped me to learn the properties of eye tracker and the data collection steps. Without her support I could not cope with the difficulties while I was collecting the data. I also would like to thank Assoc. Prof. Fatma Aslan-Tutak for her emotional support and endless understanding.

My special thanks go to my friend Nurseda Tarsan who helped me in the analysis part of this study. I definitely thank to my best friend Zeynep Demir who supported me in data coding.

My biggest thanks go to my parents for their unconditional love, trust and support. Without their encouragement from the beginning of my life, I would not pursuit my goals. I am so lucky to be their daughter.

Finally, my deepest gratitude goes to my husband Mustafa Kemal for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without him.

ABSTRACT

INVESTIGATING PRESERVICE CHEMISTRY TEACHERS' EYE MOVEMENTS WHILE WORKING WITH MACROSCOPIC, SYMBOLIC AND SUBMICROSCOPIC LEVEL OF REPRESENTATIONS FOR CHEMICAL EQUILIBRIUM

The aim of current study is to analyze the eye movements of preservice chemistry teachers according to their experience in multiple representations. In this respect a CEV, which visualizes the chemical equilibrium at three representational levels simultaneously, was demonstrated and then a screen test was applied about it. Preservice chemistry teachers were divided into two groups: the first group (called PCT1, N=18) got trained about multiple representations before the study, whereas the other group (called PCT0, N=22) did not. In order to achieve the aim of this study mixed method design was conducted. The mean scores of CEV Pretest and Posttest were analyzed with Wilcoxon Signed-Rank Test and it revealed that CEV is effective on improving the preservice chemistry teachers? ability of representing the chemical equilibrium at the macroscopic and submicroscopic level ($p < .001$). Chi-Square Test for Independence was used to investigate the relation between the mostly referred representation level on the screen and the experience in multiple representations and no statistically significance ($p = .534$) was found. Additionally, Mann Whitney U Test was applied to examine the correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades on the screen. The result of analysis indicated that PCT1 made more transitions between the symbolic and submicroscopic representations ($p < .05$). Lastly, Chi-Square Test for Independence demonstrated that the preservice chemistry teachers' saccades among the representational levels and their verbal explanations were aligned ($p > .05$).

ÖZET

KİMYA ÖĞRETMEN ADAYLARININ KİMYASAL DENGE KONUSUNDA MAKROSKOBİK, SEMBOLİK VE MİKROSKOBİK SEVİYEDEKİ GÖRSELLERLE ÇALIŞIRKEN GÖZ HAREKETLERİNİN İNCELENMESİ

Bu çalışmanın amacı, kimya öğretmen adaylarının çoklu gösterim (makroskobik, sembolik ve tanecik düzey) deneyimlerine göre göz hareketlerinin incelenmesidir. Bu bağlamda kimyasal dengeyi (KD) eş zamanlı olarak üç gösterim seviyesinde sunan bir dinamik görsel izletilmiş ve ardından bu görselle ilgili ekran testi uygulanmıştır. Kimya öğretmen adayları, bu çalışmada iki gruba ayrılmıştır: Birinci grup (KÖA1, N=18) çoklu gösterim konusunda çalışmadan önce eğitim almışken; ikinci grup ise (KÖA0, N=22) bu konuda eğitim almamıştır. Bu çalışmada amaca ulaşabilmek için karma yöntem tercih edilmiştir. Sesli düşünme protokolü ile nitel veri; KD ön-testi, KD son-testi ve göz izleme uygulaması ile nicel veri toplanmıştır. KD ön-testi ve KD son-testinin ortalamaları Wilcoxon Signed-Rank Testi ile karşılaştırılmıştır. Analiz sonuçları kimyasal denge görsellemesinin kimya öğretmen adaylarının kimyasal denge konusunda makroskobik ve tanecik düzeyde görselleme yeteneğini geliştirdiğini göstermiştir ($p < .001$). Çoklu gösterim konusunda tecrübeli olma ve ekranda en çok ziyaret edilen gösterim arasında anlamlı bir ilişki bulunmamıştır ($p = .534$). Fakat çoklu gösterim konusunda tecrübeli öğretmen adaylarının sembolik ve mikroskobik gösterim arasında daha çok geçiş yaptığı saptanmıştır. Son olarak kimya öğretmen adaylarının ekran sorularını cevaplarken gösterimler arasındaki göz hareketleri ile sözlü açıklamaları birbirine uyumlu bulunmuştur.

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df	Degrees of freedom
f	Frequency
M	Mean
N	Number of participants
p	Significance
r	Effect size
Z	The number of standard deviations from the mean
κ	Cohen's kappa

LIST OF ACRONYMS/ABBREVIATIONS

AOI	Area of Interest
CEV	Chemical Equilibrium Visualization
MP	Transition between macroscopic level of representation and submicroscopic level of representation
MS	Transition between macroscopic level of representation and symbolic level of representation
PCT0	Preservice chemistry teachers who did not have an experience about multiple representation
PCT1	Preservice chemistry teachers who had an experience about multiple representation
PS	Transition between symbolic level of representation and submicroscopic level of representation
Sig.	Significance
Std. Dev.	Standard Deviation

1. INTRODUCTION

In chemistry, three levels of representations are commonly used to present the chemical phenomena (Johnstone, 1982). These levels include macroscopic, submicroscopic and symbolic representations (Figure 1.1). The macroscopic level is the representation of chemical phenomena at the observable level such as color change, change in physical state, appearance of matter, bubbles and the release of a gas. The submicroscopic level mainly focuses on the particles of matter. Electrons, molecules, ions and atoms that are represented at this level are too small to be observed by naked eye. Submicroscopic representations are used to explain the macroscopic phenomena. For instance, submicroscopic explanations are used to explain why bubbles are observed when a fizzy drink is opened. Symbolic level includes signs and symbols to represent particles and their behaviors such as chemical equations, ball and stick models, structural formulae and computer models. According to Taber (2013), symbolic level is a bridge between macroscopic and submicroscopic level because symbols are used to explain both observable concepts and particles. Although each level of representation provides different information about a particular phenomenon, such representations are directly related to each other and could be used interchangeably.

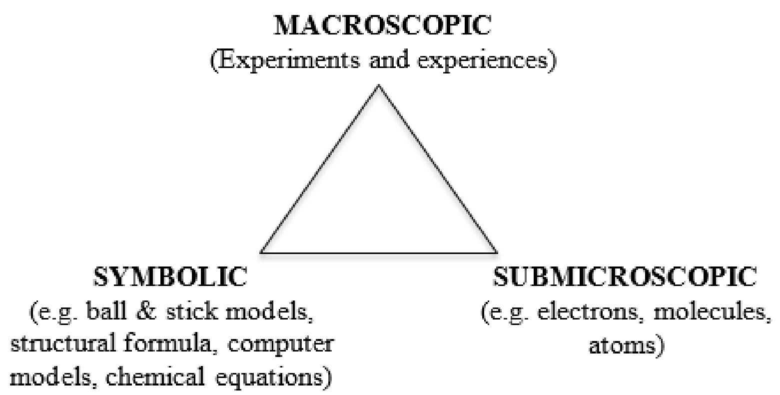


Figure 1.1. Three representational levels in chemistry (Johnstone, 1982).

Teaching and learning chemistry is beyond understanding each of these representational levels. Kozma and Russell (1997) emphasized that observable properties, in other words macroscopic representations, are insufficient to understand the underlying principles of a concept because macroscopic representations by itself could not provide the information about the nature of the matter. Additionally, Treagust *et al.* (2003), Kozma (2003) and Gilbert and Treagust (2009) emphasized that developing an understanding of chemistry requires not only understanding of each representational levels but also the relationship between these levels. Constructing connections between the representational levels provide a better understanding of underlying principles of a concept. For instance, students could explain macroscopic representation based on submicroscopic explanations and drawings. Consistently, Sanger (2000) worked on submicroscopic drawings to determine substances' states of matter and highlighted that teaching with drawings at the submicroscopic level helps students to understand the chemical process. Chittleborough and Treagust (2008) worked with first-year university students on interpretation of chemical diagrams. They concluded that correct interpretation of chemical diagrams highly depends on navigating from one level of representation to another. Furthermore, Dori and Hameiri (2003) investigated 10th grade students' difficulties in transformations from one level to the other such as symbolic-submicroscopic transformation and they found that students were less successful in problems that require symbolic-process transformation. Process level which was added by Dori and Hameiri (2003) refers to chemical process in a chemical equation. For example, it focuses on that after students balance the chemical equation, how much they are capable of explaining the essence of the process that the equation described. Problems that require symbolic-submicroscopic transformation were solved less than the problems that required symbolic-macroscopic transformation. It means students are more successful in symbolic-macroscopic transformation rather than other transformations because macroscopic level is sensory level where the substance could be seen, touched and smelled. Students made better explanations that they are more familiar.

1.1. Reasons of Having Difficulties in Navigating Between Different Representational Levels

Submicroscopic entities are not observed with naked eye, thus students have difficulty while transforming representations to this level. Gabel, Samuel and Hunn (1987) worked with preservice science teachers on distinguishing solids, liquids, gases, and chemical and physical changes at the submicroscopic level. The finding of this study indicated that participants could not differentiate submicroscopic representations to decide the macroscopic view. Likewise, Kozma and Russell (1997) stated that students experience significant challenge in representational competence because they are asked to explain observable change in the chemical phenomena by referring imperceptible molecular and atomic representations of the phenomena. Although students are able to represent the phenomena, they could not transfer it to another form. For example, students can observe the process of melting ice cubes through naked eyes. However, they have difficulty in transforming the macroscopic level to submicroscopic and symbolic ones. It is due to the fact that submicroscopic representations could not be experienced, so students could have problems while navigating to or from submicroscopic level (Chandrasegaran *et al.*, 2007). Even though transformation from one level to another is difficult, they are all necessary to understand and enrich the explanations of the chemical concepts. Learning chemistry relies on understanding all levels of representation and being able to navigate between levels to explain a chemical concept.

One of the reasons that students have difficulty while learning science is the discrepancy between school science and students' real-life experiences (Osborne and Freyberg, 1985) In chemistry, with the aid of relation between representation levels students could give explanations of daily life experiences. Wu (2003) examined how high school students relate their daily life experiences to their submicroscopic views of chemistry. She visited a high school's science class and observed the teacher who presented the topic with a real life experience and let students link and explain it with the representation levels of the chemistry. The results of the study revealed the significance of the multiple representations because students' daily life experiences were observable phenomena and they were able to link them with their chemistry knowledge at the submicroscopic level. In other words, they used their chemistry knowledge to explain a daily life experience. For instance, in this research a student could observe that acetone is toxic and explain why it is toxic by writing its symbolic representation and discussing molecular structure of it. Consistently, Gabel (2003) advocated the necessity of this linkage with her claim that the instruction would be made more effective if three levels of chemistry are used to describe everyday phenomena. Additionally, she emphasized that if the students could not link their everyday life to the science, the knowledge would not be retrieved after a time. Concerning this claim in chemistry and the findings of the studies, explaining a daily life experience using three levels of representation both prompts students' conceptual understanding and retrieve the knowledge for a long time.

Additionally, before making connections between macroscopic and submicroscopic representations, Williamson *et al.* (2012) suggest that using real-life example of phenomenon makes the transition easier. Because real-life examples provide macroscopic level experience and students could easily relate it to submicroscopic representations. This perspective is also consistent with Vygotsky's zone of proximal development (Vygotsky, 1978); after a learner interacts with familiar concepts s/he moves to unfamiliar ones. Here, students become familiar with macroscopic representations and then they move to unfamiliar submicroscopic level.

1.2. The Effect of Understanding Representational Levels on Alternative Conceptions

Simultaneous use of three levels of representation diminishes students' alternative conceptions in learning and teaching chemistry (Russell *et al.*, 1997). Alternative conceptions lead students to make peculiar connections between the concepts and to grow an inappropriate perspective in chemistry (Treagust *et al.*, 2003). Misleading everyday language is one of the sources of alternative conceptions. For example, in daily life people could not observe the behaviors of the sugar particles in water or tea, so they think the sugar is changing its phase from solid to liquid and called the process as melting. This view might create an alternative conception in student's mind (Prieto *et al.*, 1989; Ebenezer and Gaskell, 1995; Ebenezer and Erickson, 1996; Goodwin, 2002; Uzuntiryaki and Geban, 2005; Pierri *et al.*, 2008; Çalik *et al.*, 2010; Durmuş and Bayraktar, 2010; Smith and Nakhleh, 2011). The dissolving of sugar in the tea takes place rather than melting. Significantly, colloquial language would create alternative conceptions. One way to prevent alternative conceptions, which are sourced from colloquial language, is to explain each concept with its submicroscopic presentations and allow students to navigate between levels. They could match the representations and with the aid of this approach students could criticize why melting and dissolving are different.

Additionally, learning different levels of representations forms as a basis in the chemistry education supports learning further topics like chemical equilibrium. Niaz (1995) aimed to teach dynamic nature of the equilibrium which is about the movements of particles to support students' achievement in quantitative problems. Regarding the results of the study, conceptual understanding is obtained with multiple representations and it increases students' achievement in computational problems.

2. REVIEW OF LITERATURE

2.1. Using Dynamic Visualization in Learning Chemistry

The triangle of representational levels and the transformation among them are important for learning chemistry and conceptualizing the topics, however it is not easy to learn. Researchers have investigated new instructional methods to improve students' representational competence and overcome their alternative conceptions. Dynamic visuals, a series of pictures that move through the actions, have been integrated into the learning environment. Dynamic visuals could be animations, simulations, videos and virtual laboratories and they could present either one representation level or a combination of the levels of representation. Williamson and Abraham (1995), Burke *et al.* (1998), Sanger *et al.* (2000), Ardac and Akaygun (2004), Adadan *et al.* (2009) and Stieff (2011) found out that students who received the instruction with a dynamic visual at the submicroscopic level comprehend the chemistry concepts better than who did not.

The reason of why a dynamic visualization enhances students' learning has been investigated. Williamson and Abraham (1995) and Yezierski and Birk (2006) stated that students who were treated with static visuals could able to create a mental model, however, they failure to understand the dynamic behavior of the particles. On the other hand, Suits and Sanger (2013) stated that dynamic visuals allow the students to observe how the particles interact, so they develop a better mental model and conceptual understanding. In addition, Adadan *et al.* (2009) treated high school students with a dynamic visualization about the particulate nature of matter and indicated that a dynamic visualization made students more likely to believe in the dynamic nature of matter. Dynamic nature of matter is an unseen process and it could be visualized better with the dynamic visualizations.

It was also investigated whether a dynamic visualization, which combines both macroscopic and submicroscopic representations, provides better understanding of chemistry. Velázquez-Marcano *et al.* (2004) in their study on the effectiveness of a video that demonstrates the experiment in the laboratory and a particulate level animation of this experiment worked with 171 college students. The result of the study indicated that using only submicroscopic visual was not sufficient for students to imagine the macroscopic view and vice versa. However, the integration of the submicroscopic and macroscopic visuals enhances their conceptual understanding and they could generate a better dynamic model of the process. Similarly, Kelly *et al.* (2004) investigated whether the effect of integration the particular level animation into a can-crushing demonstration and concluded that high school students who watched the animation with the demonstration had better conceptual understanding of atmospheric pressure. Akaygun and Jones (2013) developed and tested a simulation that demonstrates both macroscopic and submicroscopic view of liquid-vapor equilibrium and concluded that college students achieved a better conceptual understanding with the aid of this simulation. The integration of macroscopic and submicroscopic representations enhances students' conceptual understanding rather than by oneself.

Dynamic visuals that combine all levels of representations allow students to correlate the level so they improve their conceptual understanding and create a better dynamic mental model. Russell *et al.* (1997) studied with 295 college students about the chemical equilibrium topic and provided a computer split-screen design that shows simultaneously the video of the real experiment, particulate level animation of this experiment, symbolic representations and the graph. The authors concluded that students had ability to link the representations and showed better understanding of nature of the chemical equilibrium. In this respect, in this study a dynamic visualization that integrates three levels of representation is used to investigate its effectiveness in learning chemical equilibrium.

2.2. Understanding the Nature of Chemical Equilibrium

Chemical equilibrium has a significant impact on life not only biologically but also environmentally. All living things maintain their lives due to the equilibrium on the universe. Chemistry, as a science, deals with the nature and properties of such equilibria. Students generally learn the chemical equilibrium topic at high school and it is mainly aimed to teach the nature of the dynamic equilibrium and its reflection to the real life. Barke *et al.* (2012) highlighted that chemistry has a strong connection with everyday life and students' interests could be aroused about their immediate living environment and this interest could be discussed referring chemistry topics. For instance, in this sense, high school students have already been aware of that hemoglobin in the blood interacts with oxygen and it is delivered to the cells and tissues. In chemistry courses while student have been learning the reaction $Hb\ (aq) + 4O_2\ (g) \rightleftharpoons Hb(O_2)_4\ (aq)$, where "Hb" stands for hemoglobin, chemical equilibrium topic helps them to explain how the amount of oxygen gas in the air affects our body. Concerning the importance of chemistry education, chemical equilibrium makes sense the procedures from the everyday life.

Learning the concept of chemical equilibrium is important for students because it is the prerequisite concept for learning and understanding other chemistry topics such as the topic of redox (Allsop and George, 1984), acid and base (Banerjee, 1991; Camacho and Good, 1989) and solubility (Buell and Bradley, 1972). Chemical equilibrium underlies all of these difficult topics and misunderstanding of principles of chemical equilibrium makes them difficult to learn (Quilez-Pardo and Solaz-Portoles, 1995).

2.2.1. The Reasons of Why Chemical Equilibrium Topic Is a Challenge

Studies have revealed that chemical equilibrium is one of the most challenging concepts among chemistry topics for both teachers and students (Finley *et al.*, 1982; Hackling and Garnett, 1985; Quilez-Pardo and Solaz-Portoles, 1995). The difficulty brings a series of misunderstanding and misconceptions with itself. Researchers have investigated why both students and teachers have such comprehension problems. One of the reasons is that the topic is abstract (Wheeler and Kass, 1978; Ben-Zvi, *et al.*, 1987; Huddle and Pillay, 1996; Piquette and Heikkinen, 2005; Chiu *et al.*, 2002). Instead of visualizing the chemical equilibrium process as breaking and forming bonds, students think the process as adding the reactants and forming the products. They visualize the macroscopic level and imagine the process as well. Chiu *et al.* (2002)

worked on the students' mental models of chemical equilibrium and they concluded that students understand the concept as static rather than a dynamic phenomenon. It is sourced from inability to observe the particles and their dynamic movement. In other words, students could observe reaction of reactants and their products rather than breaking and formatting the bonds.

Additionally, the words in everyday language are used in this topic but they have different meanings (Bergquist and Heikkien, 1990). 'Equilibrium' and 'chemical equilibrium' words have different meanings and associations in students because students relate 'equilibrium' to physical and everyday life balance and 'chemical equilibrium' to chemistry (Gussarsky and Gorodetsky, 1990). Equilibrium is an interdisciplinary word that is used not only in chemistry but also in physics. Despite providing familiarity in learning the topic, it has different meanings in each discipline. Whilst equilibrium is static in physics, it is dynamic in chemistry (Gussarsky and Gorodetsky, 1990). Consistently, Maskill and Cachapuz (1989) found out that equilibrium is an interfering concept that could block learning by referring the meaning of 'static balance'. Such word associations could complicate the chemical equilibrium concept and create misconceptions.

The language of chemistry is mainly based on particulate nature of matter. Nakhleh (1992) stated that many students from all age groups have difficulty to understand the particulate nature of matter and view the matter as static; therefore students could not conceptualize many chemical concepts like dissolving process and equilibrium. Akaygun and Jones (2014) analyzed students' pictorial and written explanations in the topic physical and chemical equilibria to find out their mental models and emphasized that conceptual understanding of particulate nature of matter and dynamic molecular process promote learners to create better mental models. Students who could not develop conceptual understand of the particulate nature of matter could consider the topic too abstract. Based on Piaget's theory of intellectual development high school students are at the formal reasoning stage in which they consider abstract concepts but their cognitive level development may not be same during this process. Students' learning of chemical equilibrium is associated with their cognitive level in formal operational stage and before teaching the principle of chemical equilibrium students' cognitive level could be assessed (Wheeler and Kass, 1978). If the students are at the early or late concrete levels, they can have difficulty to reason what is happening at the level that they cannot observe.

Phase of the matter in the chemical equilibrium also affects students' learning. Camacho and Good (1989) investigated problem-solving behaviors of novices and experts in chemical equilibrium problems and they found out that the number of subjects who are successful at gas-phase problems are greater than the number of subjects who are successful at solution-equilibrium problems. The reason is based on that particles in solution equilibrium are more abstract considering representation and conceptualization of cations and anions than the molecules in the gaseous state. It points that the topic 'chemical equilibrium' becomes more difficult to conceptualize if it is used in ionic equilibrium. Therefore, in the present study ionic equilibrium was selected as a focus and related visuals were used to visualize the process of equilibrium.

Additionally, although students understand the dynamic nature of equilibrium, they can continue to face with difficulties in the topic due to the lack of prior knowledge in algebraic problems and expressions. Piquette and Heikkien (2005) stated that students could not differentiate K (the equilibrium constant expression) and Q (reaction quotient) and calculate them because of their inadequate mathematical knowledge and poor problem solving skills. Moreover, Bergquist and Heikkinen (1990), and Quilez-Pardo and Solaz-Portoles (1995) emphasize that making numerical calculations and reaching the correct answer could not require conceptual understanding. Although students find the numerical answers, they have difficulty in explaining the concept. For example, students learn to compute equilibrium constants and calculate equilibrium concentrations by repeated drill but they could not interpret the number that they find. The desired behavior in the problem solving is more than calculating the numbers, as Ausubel *et al.* (1978) stated that it is meaningful understanding of the concepts and clear connections between them. Niaz (1995) investigated the relation between the students' performance on conceptual and computational problems of chemical equilibrium and found out that students who have better performance on conceptual problems also have better performance on computational problems. However, students who are good at computational problems are not necessarily successful at conceptual problems. It highlights that being able to solve computational problems about chemical equilibrium may not develop a conceptual understanding of chemical equilibrium.

2.2.2. Misconceptions About the Chemical Equilibrium

Teachers' awareness of the students' misconceptions about the chemical equilibrium was investigated and opposite outcomes were stated. Banerjee (1991) related students' misconceptions to teachers' misconceptions about chemical equilibrium by administering multiple choice and short-answer-type items and indicated that similar misconceptions have been observed in both teachers' and students' explanations. Teachers' misconceptions are retained from their student days even though their master of chemistry and teaching experiences and they transfer their misconceptions to students. It seems that teachers are not aware of not only their misconceptions but also students' ones. Correspondingly, Quilez-Pardo and Solaz-Portoles (1995) worked with students and teachers to indicate their similar problem solving strategies in chemical equilibrium and concluded that the strategies are quite similar. These strategies are algorithmic calculations; students did not develop conceptual understanding and use it as the same way the teacher use.

Nevertheless, Piquettte and Heikkinen (2005) worked with chemistry instructors to report whether they are aware of students' alternative conceptions. They used different types of data sources including open-ended items and realized that chemistry instructors aware of and identified common students' alternative conceptions. Results of these studies showed that there is not a consistency in teacher awareness of students' misconceptions. It can be sourced from some different variables in the researches such as the type of the test items. However, teachers' conceptual understanding of the chemical equilibrium topic is crucial to develop the same conceptual understanding in students' minds. Preservice teachers are the teachers of the tomorrow, so the construction of the appropriate conceptual understanding is important.

Teachers who are aware of students' misconceptions and difficulties about the topic need to overcome them. Piquettte and Heikkinen (2005) investigated the strategies that chemistry instructors used to address students' alternative conceptions in chemical equilibrium. All these strategies have different impact on student's conceptual change because each addresses different condition in Posner *et al.* (1982) conceptual change theory. According to the theory (Posner *et al.*, 1982), the learner dissatisfies his/her preexisting concepts and need a new one. Following that the learner accepts, uses and integrates the new concept into other concepts and new conditions. Although using analogies can point all conditions of Posner *et al.*'s (1982) conceptual change theory, they sometimes lead to a new alternative conception. It means an analogy that is used to cover an alternative conception could give rise to a new alternative conception. Banerjee and Power (1991) claimed that inappropriate analogies that separate the chemical equilibrium reaction as left and right side part induces misinterpretation of the concept. In other words, it prevents the thought that the reactions take place simultaneously at the same beaker. Furthermore, Gussarsky and Gorodetsky (1990) found out that stating a chemical equilibrium as left and right sidedness makes students to think each reaction occurs independently. Concerning these findings, stating the equilibrium reaction as left and right side leads to a misconception about the nature of equilibrium, so this misconception is included in this study.

Making some generalizations also creates new alternative conceptions. Quilez-Pardo and Solaz-Portoles (1995) stated that teachers and some books tend to generalize Le Chatelier's principle as an infallible rule that is if the chemical reaction at the equilibrium is disturbed, the reaction shifts in the opposite direction of the change. This logic could help students to predict the appropriate shift in concentrations but they miss that there is a second-compensating shift due to first compensation (Berquist and Heikkinen, 1990). Moreover, the principle has some limitations; for instance, an increase in mass does not always imply an increase in concentration (Le Chatelier, 1933). Students, who do not differentiate whether the equilibrated system is a homogeneous or heterogeneous, failed to apply this principle (Quilez-Pardo and Solaz-Portoles, 1995; Gorodetsky and Gussarsky, 1986). In this regard teachers' and books' approaches could affect students' understanding adversely or leads to rote learning.

In addition to analogies and generalization, visuals would be a choice to remedy students' misconceptions. Akaygun and Jones (2014) compared students' pictorial and written explanations about chemical equilibrium and found that they refer to different meanings and show different features of the chemical equilibrium. For instance, orientations of molecules were mentioned in pictorial explanations, not in written explanations. Kozma (1991) stated that the visualization of particulate of matter is important to build a mental model. Particles' behaviors could be described and observed better with the aid of visuals. Beyond the static visuals, Stieff and Wilensky (2003) investigated the effect of simulations on students' understanding of chemical equilibrium and concluded that simulations enhanced students' conceptual understanding and logical reasoning. Chemical equilibrium is a dynamic process, thus dynamic visuals facilitate students' understanding.

2.3. Eye Tracking Methodology

Since the technological innovations have taken hold of education, their impacts are investigated whether they support students' learning and teaching environment. Eye-tracking technology that was integrated into the field of education was one of the important technological improvements because it is widely agreed that it provides information about the cognitive process during the activity (Rayner, 1998). However, it has recently applied in the chemistry education research. Eye tracking collects information about eye movements while the subjects are staring at certain points. Subjects complete the work without any new special behavior, as they always do, so this technology provides the researchers a different perspective that other techniques could not capture. Subjects' usual eye movements as a reflection of their cognitive process are evaluated. Just and Carpenter (1980) asserted the eye-mind assumption that there is a significant correlation between where a person is starring at and what he is thinking. Eye movements are the indices of cognitive performance. The area where you focus on shows where your attention is paid (Hoffman and Subramaniam, 1995; Rayner, 1998). Eye gaze could not move independently from attention.

2.3.1. Key Terms in Eye Tracking Technology

In eye tracking technology some key terms are used to collect, analyze and understand the eye movements. Havanki and VandenPlas (2014) defined them as follows:

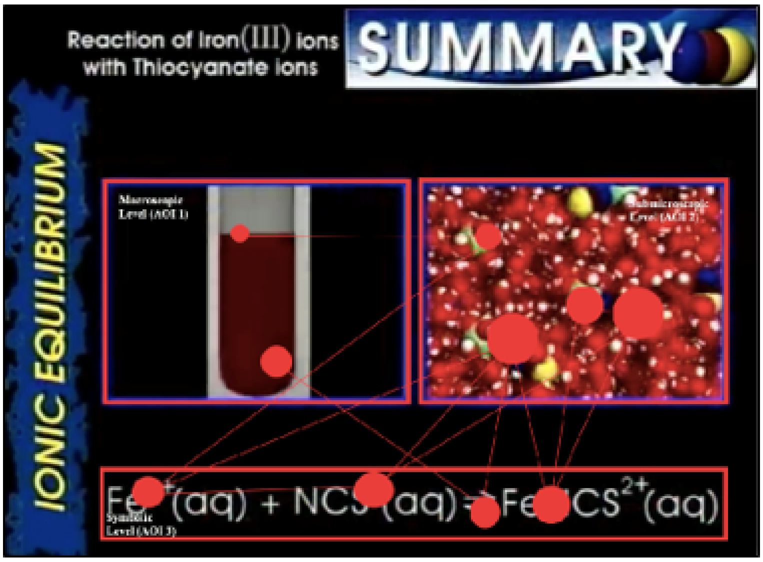


Figure 2.1. Example of a screen capture with areas of interest, a sequence of eye fixations and saccades.

Fixation - eye gaze remains focused in a specific area for a period of time

Dwell time (Gaze duration or fixation duration) - time spent on a fixation

Total dwell time (total gaze duration or total fixation duration) - total time spent on all fixations

Saccade - the transition path between the two adjacent fixations lasting between 10ms and 100ms

Regress - fixation of eye movement on an area where it is focused before

Area of Interest (Region of Interest) - the areas of stimulus that are wanted to study (Figure 2.1)

Scanpath - the path of eye movements during a trial

Heat map - representation of frequency of eye fixations (Figure 2.2) (Redness represents the most visited area whereas greenness shows the least frequently visited area.)

2.3.2. Eye Tracking Data Collection and Analysis

Eye tracking is a good way to collect data about the learner's cognitive approach because the technique does not require any special behavior of the learner (Havanki and VandenPlas, 2014). For instance, if the problem solving strategies are investigated, the learner is needed to solve the problem and his/her natural behavior is observed during the task. Eye movements are recorded through the eye tracker that does not affect the learner's natural behaviors. Eye tracking data reflects all conscious and unconscious eye movements, so the more accurate information is gathered about the process.

Unlike the other data collection methods, eye tracking provides a huge amount of data concerning the area that is mostly preferred, the time that is spent in this area and the eye path that is followed to reach a result (Havanki and VandenPlas, 2014). This large amount of data is a valuable source to determine cognitive process when the participant performs the task. However, it could be a challenge to manage and interpret such data.

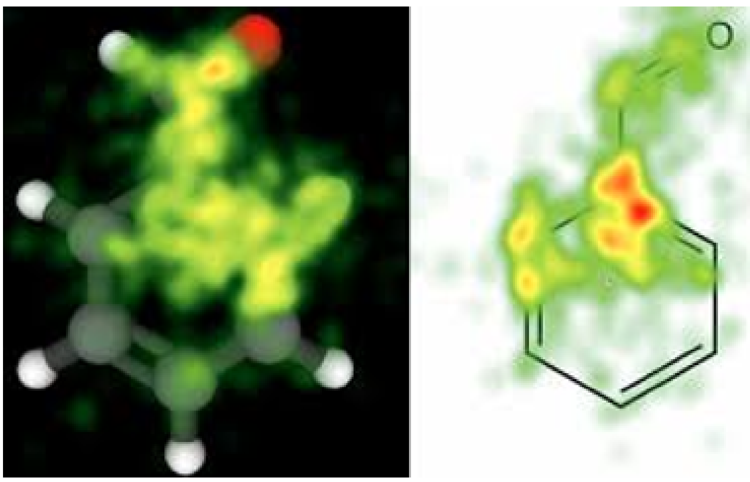


Figure 2.2. Heat maps of the same compound based on fixations (Stieff, 2011).

To analyze the eye tracking data the screen is divided into the parts, which are important or needed to study. These parts are called area of interest (AOI). How many times and what duration the participant visits the AOI is significant to compare the participants. Additionally, scanpath analysis could be used to detect the way while reaching the result. Naming the AOI with a letter and representing the scanpath with letter like ABBCACC (Brandt and Stark, 1997). Relatedly, students' scanpaths could be compared (Brandt and Stark, 1997) and the most preferred can be found. This method also helps researchers to see which AOI are tended to integrate. Finally, heat maps (Figure 2.2) are also used to analyze the eye tracking data. Areas of color range from green through yellow to red represent the gaze duration and red one demonstrates the most frequently visited area whereas green one shows the least frequently visited area. Heat maps just show frequency, not the pattern of staring.

With the aid of the eye tracking data researchers could conclude where and how much time the participants focus on the specific areas, rather than why and how they prefer them. In this respect, Stieff *et al.* (2011) found out that there is a high correlation between eye tracking results and verbal protocols. Therefore, when eye tracking is accompanied by verbal protocols, it provides valid measures to examine learner's cognitive process. Verbal data explain why and how participants focus on the interest areas.

2.3.3. Eye-tracking Technology in Chemistry Education

In the field of chemistry education research eye-tracking methodology has been studied for a decade, so the range of studied chemistry topics is very few, as well as the number of studies. The chemistry topics that were studied with the integration of eye tracking technology were about oxidation-reduction reactions and double displacement reaction (VandenPlas, 2008), multiple representational displays (Stieff *et al.*, 2011), complexity of organic molecules' formula (Havanki, 2012), nuclear magnetic resonance spectroscopic signals and molecular structure (Tang *et al.*, 2012), complexity of gas law problems (Tang and Pienta, 2012), molecular modeling (Williamson *et al.*, 2013) and complexity in stoichiometry (Tang *et al.*, 2014).

Although VandenPlas (2008) and Havanki (2012) focus on different chemistry topics, their results reveal consistency. VandenPlas (2008) studied with undergraduate and graduate level chemistry students and recorded their eye fixations while they were watching an animation about oxidation-reduction reactions and double displacement reactions. Similarly, in her doctoral dissertation Havanki (2012) stated that she grouped the participants as instructors and students and investigated their eye movements while they were reading organic chemistry equations. Even though these two studies used different types of visual materials, an animation at the particulate level and an equation, both concluded that experts showed different eye movement patterns than novices.

How the level of success influences on the eye fixation durations was also examined. Tang and Pienta (2012) worked with twelve university students on topic of gas law problems and they compared students' eye fixation durations based on their success level. Likewise, Tang *et al.* (2014) explored thirteen university students' problem solving approach on stoichiometry problems by recording their eye movements. Although the number of participants in these studies is low to generalize the result, their results are quite similar. Tang and Pienta (2012) and Tang *et al.* (2014) concluded that less successful students spend more time on solving problems than the more successful ones. In other words, less successful students fixated their eyes longer than the more successful students because less successful students tended to seek the information from the question (Tang *et al.*, 2014).

Eye-tracking technology in chemistry education was also used to investigate the students' reference to different representations. Stieff *et al.* (2011) got ten university students to watch an animation in which four different representations, a graph, ball and stick model, a numerical equation and a general equation, provided on a screen. Students in this study solved the problems by thinking aloud and their eye movements are recorded to determine referred representations. In a similar way, Williamson *et al.* (2013) explored university students' reference between ball-stick images and electrostatic potential maps of the same compounds. The results of both study demonstrates that students simply refer to familiar representation. In the former one, students mostly referred ball and stick model and graph rather than equations. In the latter one, the more familiar one was the ball and stick model.

Some chemistry problems require more than one representation and need navigations between them to answer it accurately. Stieff *et al.* (2011) also investigated the correlation between students' tend to coordination of the representations and the accuracy of the answer. It was found out that students were more accurate on the questions that could be answered only with ball and stick model rather than on the questions that could be solved with the integration of ball and stick model and equations. This result highlighted that students have difficulties in integration of different representations.

In addition to consistent findings of the recent studies there are some contradictions. Horowitz *et al.* (2007) and Anderson *et al.* (2004) asserted that long fixation might not be sourced from complexity of the problem; student might stare at the problem without any thinking. Conversely, Tang and Pienta (2012) argued that long fixations mean there is a cognitive complexity in the material. It means the longer the individual stares at the special area, the more complex is the problem. In the present study, eye tracking and think aloud protocol was preceded simultaneously to prevent such fixation challenge and to explain why and how the participant prefers this area of interest. Preservice teachers' explanations would reveal the meaning of their eye movement.

The recent studies of chemical education involving eye tracking are limited in number. This technology helps the researchers and educators to discover students' cognitive behaviors such as how they integrate the representations or visuals in their mind. Therefore, different research could be done and studies could be replicated to observe the consistency in the findings. The present study would be a different research, not a replication and the results of the present study would provide a different perspective to examine preservice chemistry teachers' cognitive behaviors. More importantly, there are only two studies that used dynamic visuals rather than static ones to examine students' eye movements (VandenPlas, 2008; Hansen, 2014). Although this study meets on a common ground about the type of visuals used in these two doctoral dissertations, the studied chemistry topics are different. Chemical equilibrium is a dynamic process and dynamic visuals would be used to measure students' eye movements. It is emphasized that dynamic visuals promote students' learning but all students could not benefit from them equally (Wu and Shah, 2004) because some students could stare at different areas of the dynamic visuals. With the aid of this study, differences in the eye movements and why students could not benefit from the dynamic visual equally will be demonstrated.

2.4. Theoretical Background

2.4.1. Cognitive Theory of Multimedia Learning

Meaningful learning is the main goal in the field of education. Learning occurs with the aid of cognitive systems. According to Paivio's Dual Coding Theory (1990) people have two cognitive systems that are verbal representations and nonverbal representations like images and they are alternative representations of each other. For example, one can think an image of a cat and describe it with words. Pavioi (1990) stated that nonverbal, in other words imaginary, representations are superior to the verbal representations because the former ones could be explained with words but verbal representations could not always pictured. Additionally, she emphasized that representing the ideas in both cognitive systems is better than representing in one system. In this respect, Mayer's (2001) cognitive theory of multimedia learning is based on Paivio's Dual Coding Theory (1990). Mayer (2001) stated that people learn more deeply from the integration of words and images rather than oneself. Figure 2.3 demonstrates the process of learning according to cognitive theory of multimedia learning.

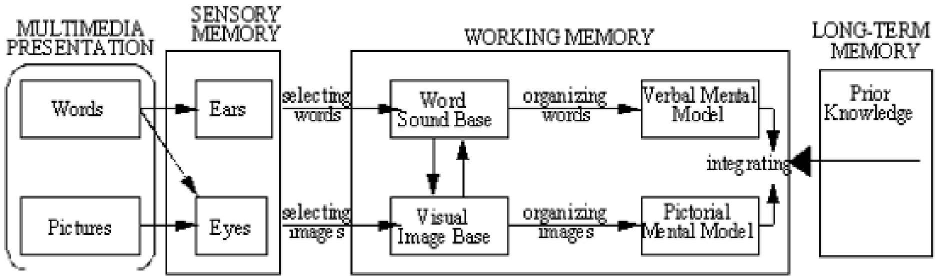


Figure 2.3. Cognitive Theory of Multimedia Learning (Moreno and Mayer, 2000).

The results of previous research from the cognitive theory of multimedia provide consistent findings. Mayer and Anderson (1991) found out that students perform better when visuals and verbal representations are presented simultaneously than they are presented successively because the two representations are not in the memory at the same time. Consistently, Mayer and Sims (1994) studied human respiratory system by presenting the coordination of both verbal and visual explanations and indicated that coordinated presentation lead to better problem solving than the uncoordinated one. Regarding these results in the present study the animation was narrated to provide better meaningful learning. Additionally, according to modality principle of cognitive theory of multimedia learning (Mayer, 2001), if the words are presented as auditory narration rather than on-screen text, the visual attention cannot be split, so the visual channel cannot be overloaded. This principle was also concerned.

2.4.2. Cognitive Load Theory

The capacity of working memory is limited and it is not able to process a lot of information at the same time. Sweller (1994) explained the cognitive load as mental effort in the working memory and argued how to diminish the cognitive load because it has an effect on learning. Sweller (1994) stated that engaging the working memory more than one visual or verbal representation could result in cognitive load because the learner split his/her attention. However, Mousavi *et al.* (1995) found out that mixing the verbal and visual presentation is the most effective way to prevent cognitive load. In this sense, principles of cognitive theory of multimedia learning are consistent with the basic tenets of cognitive load theory (Mayer and Moreno, 2000) because both theories concern the capacity of working memory. In the present study, animation is supported with a narration not a on-screen text, so the cognitive load is reduced.

3. STATEMENT OF THE PROBLEM

3.1. Purpose of the Study

The purpose of this research study is, with the aid of the eye tracking technology, a) to compare the participants' mostly referred representational levels b) to investigate the alignment between the participants' saccades among the representational levels and their verbal explanations and c) to question the correlation between the participants' experience in multiple representations and the kind and number of saccades that they follow while answering the questions. In other words, in the present study participants' experience in multiple representations was taken into consideration to compare their saccades among the representational levels and mostly referred representational levels. Stieff *et al.* (2011) and Williamson *et al.* (2013) reported that students mostly fixated on the familiar representations to answer the questions. Therefore, this study aimed to seek the relation between the preservice chemistry teachers' experience in multiple representations and their fixations on different representational levels displayed with a visualization of chemical equilibrium.

During the course of the study, the preservice chemistry teachers performed their usually behavior and they did not learn a new concept. In other words, their normal cognitive behavior was investigated with the eye tracking technology during this process. Therefore, the present study would provide a different perspective to understand the preservice chemistry teachers' cognitive behavior while staring at the multiple representations to answer content questions on the screen.

From a different standpoint, the number of eye tracking integrated studies was limited in the chemical education research. The findings of the present study would provide a new perspective for chemistry teacher educators in terms of the importance of multiple representations in chemistry education, and thus, would contribute to the body of literature in this field.

(i) Is viewing a chemical equilibrium visualization effective on improving:

- the ability of accurately representing the dynamic nature of chemical equilibrium at the macroscopic level?
- the ability of accurately representing the dynamic nature of chemical equilibrium at the submicroscopic level?
- the ability of accurately representing Le Chatelier's principle at the macroscopic level?
- the ability of accurately representing Le Chatelier's principle at the submicroscopic level?

(ii) Is there a relation between the pre-service chemistry teachers' experience in multiple representations and mostly referred area of interest (macroscopic level, symbolic level and submicroscopic level)

- when they answer the questions about dynamic nature of the equilibrium?
- when they answer the questions about Le Chatelier's Principle?

(iii) Is there a correlation between the pre-service chemistry teachers' experience in multiple representations and the kind and number of saccades among the representational levels

- when they answer the questions about dynamic nature of the equilibrium?
- when they answer the questions about Le Chatelier's Principle?

(iv) Is there an alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations

- when they answer the questions about dynamic nature of the equilibrium?
- when they answer the questions about Le Chatelier's Principle?

4. METHODS

4.1. Design of the Study

The study is a mixed method design, specifically convergent parallel design (Creswell, 2003); both qualitative and quantitative data were simultaneously collected to achieve the purpose of the study. After the collection and analysis of both quantitative and qualitative data, the results were related and compared to interpret the research questions. The quantitative data come from pretest, posttest and eye tracker (Figure 4.1). All these data could not explain why the students refer the representational levels. Eye tracking data could demonstrate where the people stare at, not explain why they focus on there. Stieff *et al.* (2011) stated that the combination of think aloud protocols and eye-tracking data could detail why the people stare at the point. Therefore, in this study quantitative data were supported with think aloud protocol where the participants explained how they come up the result while looking at the computer screen. These multiple instruments provided a deeper understanding of how participants solve questions and why they follow this way.

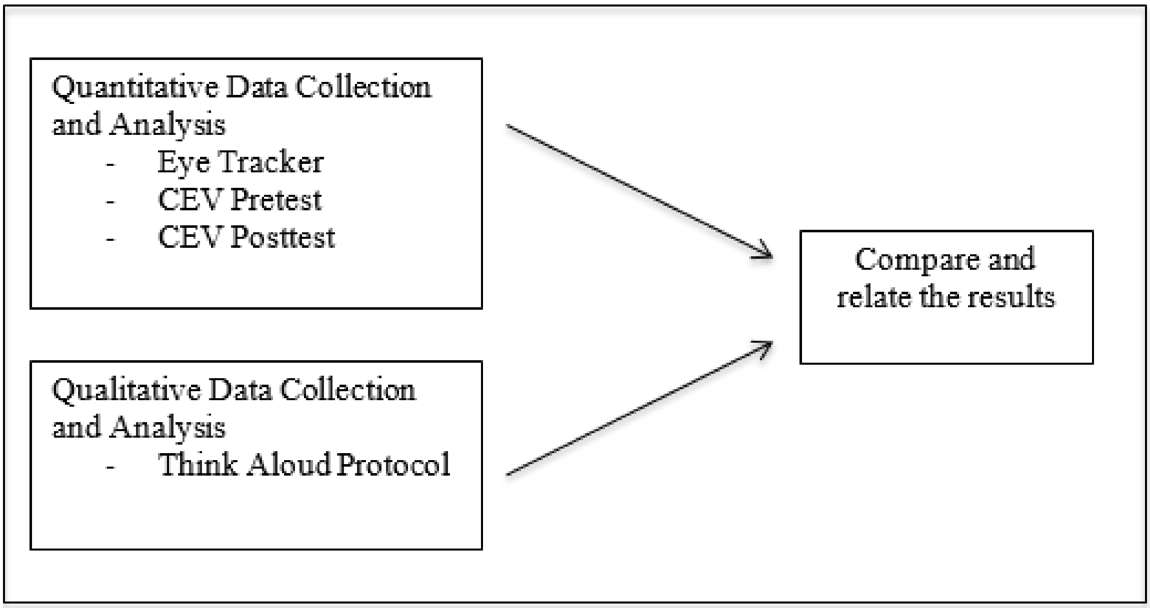


Figure 4.1. Qualitative and quantitative data source of the study.

For the first research question, it was investigated whether participants were able to accurately representing the dynamic nature of chemical equilibrium and Le Chatelier's Principle at different representational levels with the aid of chemical equilibrium visualization. In other words, it was questioned if the visualization could significantly contribute to learning chemical equilibrium. Therefore, the participants' chemical equilibrium visualization (CEV) pretest and posttest results were compared to test the visualization's effectiveness on learning the topic.

Preservice chemistry teachers' eye movements were recorded while they were answering the screen test questions on chemical equilibrium. For the second research question, time spent on each representational level for each screen test question was measured by the eye-tracker. Then mostly referred representational was determined based on time spent on each representational level. Its correlation with the preservice chemistry teachers' experience in multiple representations was examined.

For the third research question, eye-tracking data was used to specify where each participant stared at and navigated from that point. Travel route showed their scanpaths. After the participants' scanpaths were stated, number of saccades between the representational levels was determined. The kind and number of saccades were compared based on the grouping variable, which is the preservice chemistry teachers' experience in multiple representations.

While preservice chemistry teachers were answering the screen test questions, they were allowed to think aloud and explain how they solve the questions. For the last research question the alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations to the screen test questions was investigated. Therefore, both eye tracking data and think aloud protocols were analyzed.

4.2. Participants

Participants of the study were selected from a mid-size public university in Turkey. They were preservice chemistry teachers. Convenience sampling was preferred due to easy accessibility of the eye-tracker instrument. Because the computer that eye tracker was connected was stable and the participants could work on the computer one by one to collect the personal data. 42 volunteer pre-service chemistry teachers attended the work. However, two of the participants' data was not included into the study due to the reflection in the glasses and calibration system. Therefore, 40 participants' data were analyzed to answer the research questions.

During their education, preservice chemistry teachers take a course called Secondary School Chemistry Laboratory Application and coded as SCED 350, where they specifically learn how to represent the basic chemistry concepts like states of matter, physical and chemical composition and solubility at macroscopic, submicroscopic and symbolic level. The course proceeds mainly with inquiry-based experiments during which, preservice chemistry teachers firstly observe an experiment, and then work as a group to explore the nature of the experiment and explain it at the submicroscopic and symbolic levels while developing their scientific understanding of chemistry concepts. For each concept, they represent that concept at different representational levels and make group discussions to compare and relate them.

Additionally, during this course preservice chemistry teachers write reflections about the chemistry concept that they learnt before and after the implementation. Therefore they could face with the misconceptions that they have beforehand. Ultimately, at the end of the course each preservice chemistry teacher presents a new chemistry concept with an experiment to their classmates and creates a discussion environment to explain it at macroscopic, submicroscopic and symbolic levels. All in all, this course has a crucial role to demonstrate the significance of multiple representations in learning chemistry to the preservice chemistry teachers and increases their awareness towards the importance of multiple representations.

Yakmacı-Güzel and Adadan (2013) conducted a study about the instruction of this course. The second author of the study offered the course and created the learning environment. They investigated the preservice chemistry teachers' understanding of the structure of matter by a specific instruction and concluded that the instruction is quite effective in changing preservice chemistry teachers' alternative conceptions and developing more scientific explanations. Similarly, the instructor of SCED 350 course, Adadan (2014) examined how the preservice chemistry teachers' understanding of the particulate nature of matter influences their understanding of solution chemistry and found out that instruction including multiple representations improved preservice chemistry teachers' understanding of solution chemistry regardless of their level of understanding the particulate nature of matter. However, the ones who have higher understanding of particulate nature of matter outperformed the ones who have lower understanding of particulate nature of matter. Concerning the results of the studies, it could be stated that preservice chemistry teachers who took SCED 350 course improve their abilities to explain the chemical phenomenon based on three representational levels.

In the present study, the participants were divided into two groups regarding this course: preservice chemistry teachers who had an experience in multiple representations (called PCT1) and preservice chemistry teachers who did not (called PCT0). Therefore, grouping variable of this study was assumed to be the experience in multiple representations.

Preservice chemistry teachers should cover first year chemistry courses to attend SCED 350 course, so they all had completed at least 13 credits of chemistry courses, which were General Chemistry I and II, Introduction to Practical Chemistry and Qualitative Analysis. Purposefully, it was aimed to work with participants who completed at least first year chemistry courses because those could have an idea of general chemistry topics and either could take that course. Descriptive explanation of the participants was shown in Table 4.1. Preservice chemistry teachers' mostly referred area of interest and their scanpath were compared concerning the grouping variable above. It was aimed to investigate how the preservice chemistry teachers' eye movements differed and how they made connections between representational levels based on their prior knowledge of multiple representations.

Table 4.1. Descriptive explanation of the participants based on the grouping variable.

		Total credits of chemistry courses that have taken	
		Credits between 13-20	More than 20 credits
Participants	Preservice chemistry teachers who had an experience in multiple representations (PCT1)	2	16
	Preservice chemistry teachers who did not have an experience in multiple representations (PCT0)	16	6

Each pre-service chemistry teacher worked individually on the computer, which was connected to the eye-tracking instrument. The duration of the study was about one hour at which they worked with the visualization and completed the tests. Before the study participants were asked for their voluntariness and at the end of the study they were compensated with a gift for their participation.

4.3. Instruments

4.3.1. Demographic Form (DF)

The Demographic Form (DF), given in the Appendix A, consists of 8 questions that were used to gather data about participants' demographics and chemistry background. In this form it was asked participants to list all chemistry courses that they have taken. Some of the courses they took from the department also include chemistry concepts, so they were asked to list them as well. The courses that pre-service chemistry teachers attended informed the researcher about their chemistry background.

Additionally, previously watched dynamic visualizations such as videos, animations and simulations might have an effect on participants' behaviors. Therefore, it was questioned whether the participants have experienced any chemistry visualizations at the submicroscopic level before.

Eye-tracker also has sensitivity for glasses and contact lenses. In some cases, eye-tracker could not work if the user wears glasses or lenses. In this form it was asked whether the participant wears them.

4.3.2. Chemical Equilibrium Visualization (CEV) Pretest and Posttest

Both Chemical Equilibrium Visualization (CEV) Pretest and Posttest, given in Appendix B, consist of four open-ended items and they are identical. The items were developed by the researcher considering the misconceptions about the chemical equilibrium determined in the previous studies (Gorodetsky and Gussarsky, 1989; Bergquist and Heikkinen, 1990; Wheeler and Kass, 1978; Hackling and Garnett, 1985). Table 4.3.4 shows the misconceptions included in this study. After the test was developed, the items were checked for its content validity by the experts: two high school chemistry teachers and one chemistry professor. Additionally, the test was piloted to the six pre-service chemistry teachers before the data collection to check the systematic errors and overcome them.

Each test includes four items (Figure 4.2). Two of them are related with the dynamic nature of chemical equilibrium and two of them are on Le Chatelier's Principle. The items about dynamic nature of chemical equilibrium consist of one macroscopic and one submicroscopic question. It is same for the items about Le Chatelier's Principle.

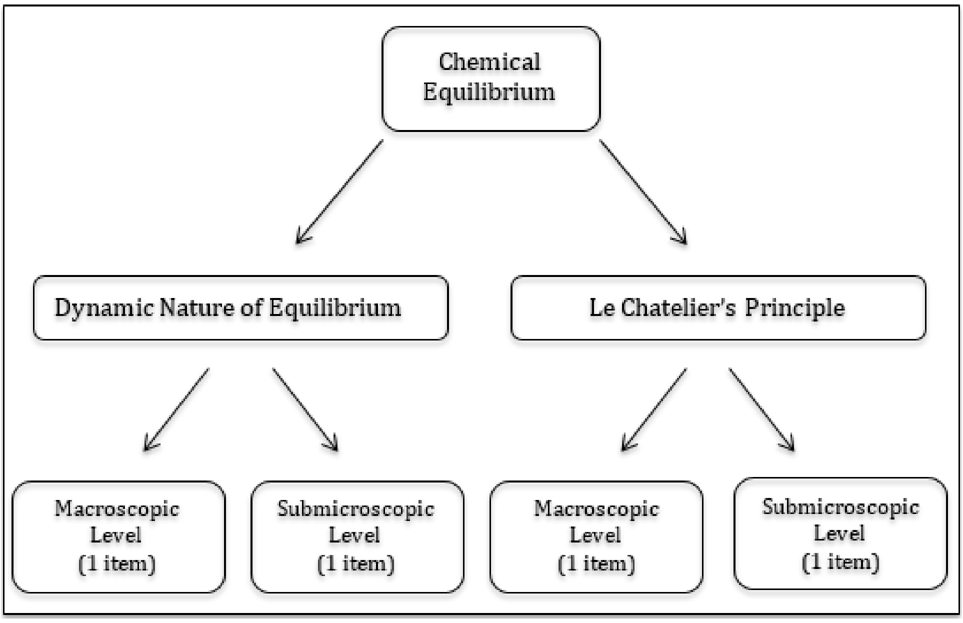


Figure 4.2. Number and topics of CEV pretest and posttest items.

4.3.3. Chemical Equilibrium Dynamic Visualization

The dynamic visualization, used in this study, was designed by Roy Tasker and the VisChem team. The VisChem visualizations were designed including all three levels of representation for a deeper understanding of chemistry. The visualization used in the study, was showing the process of chemical equilibrium at all representational levels. More importantly, macroscopic visuals of the concept are followed by submicroscopic ones. Symbolic representation of the process is demonstrated on the screen concurrently with macroscopic and submicroscopic representation. Williamson *et al.* (2012) emphasized that viewing submicroscopic representations of the phenomenon after macroscopic demonstrations foster conceptual understanding. In this study, it was aimed to promote conceptual understanding with the aid of dynamic chemical equilibrium visualization.

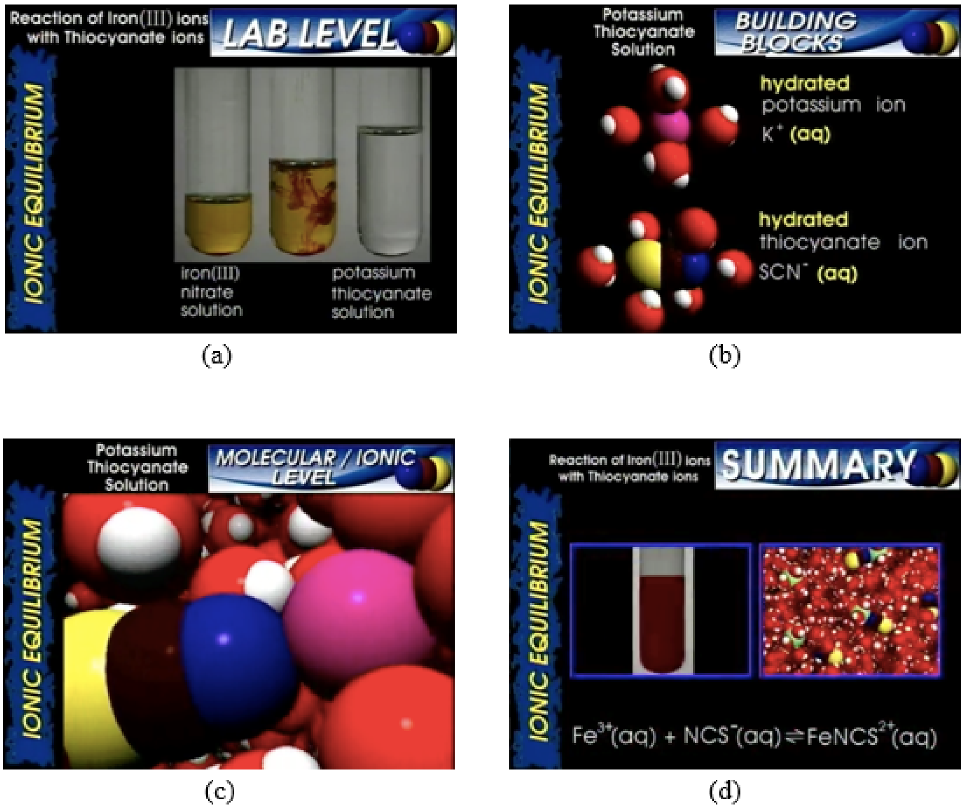


Figure 4.3. Screenshots from the chemical equilibrium visualization.

Additionally, the chemical equilibrium visualization is about thirteen minutes long and it consists of two parts. The first part focuses on the nature of chemical equilibrium when two solutions, which are iron (III) nitrate and potassium thiocyanate, are mixed. In the visualization, firstly the experiment is presented at macroscopic level (Figure 4.3a). Then each reactant is introduced at the submicroscopic level and their interaction with the water is pictured (Figure 4.3b and c). Finally, equilibrium reaction is simultaneously represented at all levels of chemistry (Figure 4.3d). The second part focuses on Le Chatelier's principle in which the equilibrium solution is disturbed by the addition of a substance, potassium fluoride. After the introduction of added substance at the submicroscopic level, the changes in the equilibrium solution are again represented with three levels of chemistry.

In the present study, participants watched the chemical equilibrium visualization from beginning to the end. Then the eye tracker was started to record and a part of the chemical equilibrium animation, from 8.20 minutes to 8.32 minutes, was demonstrated, in which the three levels of representations were simultaneously used to explain the process.

4.3.4. Chemical Equilibrium Visualization (CEV) Screen Test

Chemical Equilibrium Visualization Screen Test, given in Appendix C, consists of twelve multiple-choice items. The first two items were aimed to let the participants get used to the eye tracker and screen test. The remaining items were analyzed in this study. There were five choices for each screen test item. The items were developed by the researcher considering the previously determined misconceptions about the chemical equilibrium (Gorodetsky and Gussarsky, 1989; Bergquist and Heikkinen, 1990; Wheeler and Kass, 1978; Hackling and Garnett, 1985). The misconceptions were listed in Table 4.3.4. After the test was developed, the items were checked for its content validity by three experts: two high school chemistry teachers and one chemistry professor. Additionally, the screen test was piloted with the six preservice chemistry teachers before the data collection to see and overcome the systematic errors.

Table 4.2. Misconceptions that are included in this study.

Misconceptions about nature of chemical equilibrium and Le Chatelier's Principle	**Reference**
· Each side of the chemical equation is separate physical entity.	Gorodetsky and Gussarsky, 1989
· A reaction is reversible yet goes to completion.	Bergquist and Heikkinen, 1990 Huddle and White, 2000
· The forward reaction must be completed before the reverse one starts.	Wheeler and Kass, 1978; Hackling and Garnett, 1985; Bergquist and Heikkinen, 1990; Huddle and White, 2000 Özmen, 2008 Demircioğlu et al., 2013
· At equilibrium the forward and reverse reaction are completed.	Hackling and Garnett, 1985 Özmen, 2008 Demircioğlu et al., 2013
· Concentrations fluctuate as equilibrium is established.	Bergquist and Heikkinen, 1990; Hackling and Garnett, 1985

Table 4.2. Misconceptions that are included in this study (Cont.).

Misconceptions about nature of chemical equilibrium and Le Chatelier's Principle	**Reference**
· Addition of more reactant changes only that reactant concentration.	Bergquist and Heikkinen, 1990
· Addition of more reactant changes only the product concentrations.	Bergquist and Heikkinen, 1990
· Addition of a species changes concentration of all species present except the added one.	Bergquist and Heikkinen, 1990
· Addition of more reactant changes only the concentration of the other reactant in the equation.	

4.3.5. Eye-Tracker

While the participants were staring at the macroscopic, symbolic and submicroscopic representation of the reaction and answering the chemical equilibrium visualization screen test question questions, they were eye-tracked with D6 Desk Mounted Optics (Figure 4.4) remote eye-tracking system in order to examine how often and when the participant's fixation shifted between different representations. The system consists of a control unit, a subject display monitor, a D6 Optics module and an interface PC. Additionally, Paradigm software program was used to show the screenshots of the visualization and the test questions.

Eye tracker, which is used in this study, works with monocular tracking method in which one camera was used to track one eye. Eye movements were recorded by Desk

Mounted Optics remote eye tracker. It was placed directly under a nineteenth-inch display monitor (Figure 4.4) and the participants were seated approximately 60 cm away from the monitor. When the eye-tracker session started, firstly the calibration was carried out. The participants were instructed to look at the nine successive points, so the pupil and corneal reflections were recognized. After the calibration, the screen test was applied.

Figure 4.4. The picture of eye tracker that was used in the present study and its position according to the screen.

4.4. Data Collection

Before the study, a pilot study was conducted with six preservice chemistry teachers to see and overcome the systematic errors. Not only tests that are used during the study but also eye-tracker were piloted. After the refinements, the study was explained to a new group of preservice chemistry teachers. They were asked whether they were volunteers for the study. The volunteers signed the consent form and a meeting was arranged for the next steps of the study. Table 4.3 shows the data collection steps.

A week before the eye-tracking study the preservice chemistry teachers filled out the demographic form and did CEV pretest individually. The participants had about twenty minutes to complete CEV pretest. On the days of the eye-tracking study each participant was welcomed in the eye-tracking laboratory at the university and they worked on the computer alone. First of all, the researcher clearly explained directions and repeated them for each participant because unclear and uncertain explanations could affect participants' approach. Then, the participant watched 13-minute long chemical equilibrium visualization. After that, the eye-tracker was calibrated and the participant started to do CEV screen test, which was consisted of ten questions. For each question on the CEV screen test, the participants watched a part of the visualization, from 8.20 to 8.32 minutes, in which the reaction was represented with the three levels of chemistry.

While the participants were staring at the macroscopic, symbolic and submicroscopic representation of the reaction and answering the chemical equilibrium visualization screen test question questions, the eye-tracker saved their eye movements. Each screen question was followed by think aloud protocol that was carried by the researcher. Here the participant explained how s/he comes up the result and why s/he follows this way.

When the participants completed CEV screen test and think aloud protocols, the eye-tracker was stopped. Immediately after it, the participants did the CEV posttest that is the identical form of the CEV pretest. Twenty minutes was given to complete it.

Table 4.3. Overview of data collection steps.

Step	**Instrument**	**Format**	**Time**	**Duration**
1	Demographic Form	Paper-pencil	A week before the study	5 minutes
2	CEV Pretest	Paper-pencil	A week before the study	20 minutes
3	Chemical Equilibrium Visualization	Computer	During the study	15 minutes
4	CEV Screen Test	Computer (Eye-tracking)	During the study	20 minutes
	Think-aloud protocol	Oral	During the study	
5	CEV Posttest	Paper-pencil	Just after the study	20 minutes

4.5. Data Analysis

The aim of this study is to better understand how a dynamic visualization affects preservice chemistry teachers' understanding of chemical equilibrium. The experience in multiple representations might have an effect on their reference on the screen and preservice chemistry teachers' explanation about their reference point on the screen. Qualitative and quantitative data were collected through the pretests, posttests, eye-tracker and think aloud protocols to achieve the aim of this study. Coordination of both qualitative and quantitative data provided more detailed information about preservice chemistry teachers' approach to three levels of representations concerning their experience in multiple representations. Following four subsections present how the data was analyzed for each research question.

4.5.1. Research Question 1

It was investigated whether viewing chemical equilibrium visualization effective on improving the ability of accurately representing the dynamic nature of chemical equilibrium and Le Chatelier's Principle at the macroscopic and submicroscopic level. Preservice chemistry teachers' answers to CEV pretest and posttest were analyzed to answer this research question.

CEV pretest and posttest have open-ended questions. Adadan (2014) used five categories to evaluate preservice chemistry teachers' understanding in an open-ended question about particle nature of matter in solution chemistry: Scientific understanding, partial understanding, partial understanding with alternative conceptions, alternative conceptions and no understanding. Likely, Tarsan (2015) used five similar categories to analyze students' responses to gas law questions: good understanding, partial understanding, partial understanding with specific misconception, no understanding and no explanation. In the present study, participants' answers in CEV pretest and posttest were analyzed by referring five categories as shown in Table 4.5.1.

The effectiveness of viewing the chemical equilibrium visualization on the ability of accurately representing the dynamic nature of chemical equilibrium and Le Chatelier's Principle at the macroscopic level and submicroscopic level was analyzed with the Wilcoxon Signed-Rank Test. Each question of the pretest and posttest, which were identical, was compared to come up the results.

It was assumed that if p-value was smaller than .05, the Wilcoxon Signed-Rank Test would show that there is a significant difference between the median of posttest ranks and the median of pretest ranks. Additionally, if the median of each question in the posttest was higher than the median of each question in the pretest, the chemical equilibrium visualization would be effective on the ability to accurately represent the dynamic nature of chemical equilibrium and Le Chatelier's Principle at the macroscopic level and submicroscopic level.

Table 4.4. Analysis criteria and examples for the explanations of CEV pretest and posttest questions.

Points	**Coding**	**Explanation**	**Examples**
0	No Understanding (NU)	The participant's answer is irrelevant or unclear	*Becoming more acidic medium.* Participant 022 Pretest / Q4b
1	Misconceptions (Ms)	The participant's answer includes one or more misconceptions	H^+, CrO_4^2-, $H_2(CrO_4)$ *and Cl- exist together.* Participant 009 Pretest / Q4b
2	Partial Understanding with Misconceptions (PU/Ms)	The participant's answer includes both partial understanding and some misconceptions	H^+, Cl-, CrO_4^2-, $Cr_2O_7^2$- and H2O are seen together. Participant 009 Posttest / Q4b

Table 4.4. Analysis criteria and examples for the explanations of CEV pretest and posttest questions (Cont.).

Points	Coding	Explanation	Examples
3	Partial Understanding (PU)	The participant's answer does not include any misconception but it is insufficient.	*There is high H^+ concentration in the solution and reaction to reach the equilibrium reaction again* CrO_4^2- ions and H+ ions forms $Cr_2O_7^2$- and H_2O so concentration of CrO_4^2- decreases and color become orange. Participant 005 Posttest / Q4b
4	Good Understanding (GU)	The participant's answer indicates a correct understanding of the phenomenon.	There are excess amount of H^+ in the solution and CrO_4^2- is less than 'a', *$Cr^2O_7^2$- is more. However, forward and back side reaction is occurring.* Participant 003 Posttest / Q4b

Additionally, three assumptions of the Wilcoxon Signed-Rank Test were checked for this research question. Firstly, preservice chemistry teachers' understanding of the nature of chemical equilibrium and Le Chatelier's Principle at macroscopic level and submicroscopic level were ordered, so the dependent variable was ordinal. Secondly, same participants' measurements were compared considering CEV pretest and posttest. Thirdly, the distribution of the differences between the scores of CEV pretest and posttest needs to be symmetrical in shape, so they were checked. Table 4.5 shows the summary of research question 1.

Table 4.5. Summary table for Research Question 1.

Research Question	Data Source	Analysis	Meaning of Analysis
1. a. Is viewing the chemical equilibrium visualization effective on the ability of accurately representing the dynamic nature of chemical equilibrium at the macroscopic level?	CEV Pretest & Posttest (Question 1)	The Wilcoxon Signed-Rank Test	If the p value was smaller than .05, the difference between the CEV pretest and posttest would be significant · It meant the chemical equilibrium visualization was effective on the ability of accurately representing the dynamic nature of chemical equilibrium at the macroscopic level.

Table 4.5. Summary table for Research Question 1 (Cont.).

Research Question	**Data Source**	**Analysis**	**Meaning of Analysis**
b. Is viewing the chemical equilibrium animation visualization effective on the ability of accurately representing the dynamic nature of chemical equilibrium at the submicroscopic level?	CEV Pretest & Posttest (Question 2)	The Wilcoxon Signed-Rank Test	If the p value was smaller than .05, the difference between the CEV pretest and posttest would be significant. It meant the chemical equilibrium visualization was effective on the ability of accurately representing the dynamic nature of chemical equilibrium at the submicroscopic level.
c. Is viewing the chemical equilibrium visualization effective on the ability of accurately representing Le Chatelier's Principle at the macroscopic level?	CEV Pretest & Posttest (Question 3)	The Wilcoxon Signed-Rank Test	If the p value was smaller than .05, the difference between the CEV pretest and posttest would be significant · It meant the chemical equilibrium visualization was effective on the ability of accurately representing Le Chatelier's Principle at the macroscopic level.
d. Is viewing the chemical equilibrium visualization effective on the ability of accurately representing Le Chatelier's Principle at the submicroscopic level?	CEV Pretest & Posttest (Question 4)	The Wilcoxon Signed-Rank Test	If the p value was smaller than .05, the between the CEV pretest and difference posttest would be significant. It meant the chemical equilibrium animation was effective on the ability of accurately representing Le Chatelier's Principle at the submicroscopic level.

4.5.2. Research question 2

The relation between the pre-service chemistry teachers' experience in multiple representations and mostly referred area of interest (macroscopic level, symbolic level and submicroscopic level) about dynamic nature of the equilibrium was investigated. First six questions of screen test and a part of the visualization were used to answer this research question.

To analyze this research question firstly preservice chemistry teachers were classified as the ones who have an experience in multiple representation (PCT1) and who did not (PCT0) (Table 4.6). Also their reference points on the screen categorized as question, macroscopic level, submicroscopic level, symbolic level and choices of the question (Table 4.7). Among these reference points only representational levels were used to determine mostly referred area of interest. Mostly visited area of interest was determined based on the fixation durations. The ratio of fixation durations on each area of interest to total fixation duration showed mostly visited area of interest. For example, Table 4.8 shows how much time spent on one of the screen test questions by one of the participants. According to this table, the participant spent 7.391 seconds to read the screen test question. S/he stared at macroscopic level for 0.284 seconds, submicroscopic level for 1.952 seconds, symbolic level for 5.923 seconds and the choices of the question for 0.934 seconds. Totally, s/he solved the question in 16.484 seconds. The proportion of time spent on the symbolic level (5.923 seconds) to the total time spent on this question (16.484 seconds) is 35.9%, which has the highest percent among the other representational level. Therefore, symbolic representation was the mostly referred area of interest for this question. To explore the relationship between two categorical variables, which are the preservice chemistry teachers' experience in multiple representations and their mostly referred area of interest, Chi-Square Test for Independence was used.

Table 4.6. Groups of preservice chemistry teachers.

Groups	**Preservice chemistry teachers**
PCT0	Not have an experience in multiple representation
PCT1	Have an experience in multiple representation

Table 4.7. Codes for the area of interests.

Code	**Area of Interests**
M	Macroscopic Level
P	Submicroscopic (Particulate) Level
S	Symbolic Level

Table 4.8. Total fixation duration and its percentage according to area of interests.

Area of Interests	**Total fixation duration (second)**	**Percent of fixation duration**
Question	7,391	44.8
Macroscopic Level (M)	0.284	1.8
Submicroscopic Level (P)	1,952	11.8
Symbolic Level (S)	5,923	35.9
Choices of question	0.934	5.9
Total time spent on this question	**16,484**	-

Additionally, in this research question it was asked whether there was a correlation between preservice chemistry teachers' experience in multiple representation and mostly referred area of interest (macroscopic level, symbolic level and submicroscopic level) about Le Chatelier's principle. Last four questions of screen test and a part of the animation were used to answer this research question. While the participants were staring at the macroscopic, symbolic and submicroscopic representation of the reaction and answering the screen questions, their eye-movements were recorded. For each participant, mostly visited area of interest were determined by proportioning the time spent each area of interest to all time spent. To explore the relationship between two categorical variables Chi-Square Test for Independence were used. Table 4.9 shows the summary of research question 2.

Table 4.9. Summary table for research question 2.

Research Question	**Data Source**	**Analysis**	**Meaning of Analysis**
2. a. Is there a relation between the preservice chemistry teachers' experience in multiple representations and mostly referred area of interest when they answer the questions about dynamic nature of the equilibrium?	Eye-tracker CEV Screen Test (first six questions)	Chi Square Test for Independence	If a significant relation was found (p ¡ .05), it would show that there was a correlation between the preservice chemistry teachers' experience in multiple representations and mostly referred area of interest when they answered the questions about dynamic nature of the equilibrium.
b. Is there a relation between the preservice chemistry teachers' experience in multiple representations and mostly referred area of interest when they answer the questions about Le Chatelier's Principle?	Eye-tracker CEV Screen Test (last four questions)	Chi Square Test for Independence	If the p value was smaller than .05, it would show that there was a relation between the preservice chemistry teachers' experience in multiple representations and mostly referred area of interest when they answered the questions about Le Chatelier's Principle.

4.5.3. Research question 3

It was asked whether there was a correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades when they answered the questions about the nature of the equilibrium. First of all, the participants were grouped as stated in Table 4.6. Then, areas of interests were coded with letters (Levenshtein, 1966). The area of interest that shows macroscopic representation was coded as M, the area of interest that demonstrates submicroscopic (particulate) representation was coded as P and the area of interest that shows symbolic representation was coded as S (Table 4.7). Then with the aid of eye-tracking data, each participant's scanpath was presented with letter strings. For example, if the participant's eye movement went through respectively M, S, S, P, M and P, it would be represented as MSSPMP.

After stating scanpaths for each screen test question about the dynamic nature of equilibrium, the kind and number of saccades like how many times the participants navigated from macroscopic representation to symbolic representation were counted. Table 4.10 demonstrates two of the participants' kind and total number of saccades between the representational levels for the first six screen questions.

To analyze this research question statistically, Mann Whitney U Test was used because the relationship between a categorical variable (the preservice chemistry teachers' experience in multiple representations) and a continuous variable (the kind and number of saccades) were investigated. If the p-value was smaller than .05, it would show the significant correlation between the variables.

Table 4.10. Kind and number of saccades between the representational levels.

	Number of saccades between		
Participants	macroscopic and symbolic representation (MS)	macroscopic and submicroscopic (particulate) representation (MP)	symbolic and submicroscopic (particulate) representation (SP)
5	16	34	29
34	22	36	44

Additionally, in this research question the correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades when they answer the questions about Le Chatelier's Principle was investigated. After all participants were classified according to the grouping variable and their scanpath were stated for the last four questions of screen test, kind and number of saccades between the representational levels were determined. The relation between the variables was analyzed with Mann Whitney U Test. If the p-value was smaller than .05, it would show the significant correlation between the variables. Table 4.11 shows the summary of research question 3.

Table 4.11. Summary table for research question 3.

Research Question	**Data Source**	**Analysis**	**Meaning of Analysis**
3. a. Is there a correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades among the representational levels when they answer the questions about dynamic nature of the equilibrium?	Eye-tracker CEV Screen Test (first six questions)	Mann Whitney U Test	If the p value was smaller than 0.05, it would show that there was a correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades among the representational levels when they answered the questions about dynamic nature of the equilibrium.
b. Is there a correlation between the pre-service chemistry teachers' experience in multiple representations and the kind and number of saccades among the representational levels when they answer the questions about Le Chatelier's Principle?	Eye-tracker CEV Screen Test (last four questions)	Mann Whitney U Test	If the p value was smaller than 0.05, it would show that there was a correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades among the representational levels when they answer the questions about Le Chatelier's Principle.

4.5.4. Research question 4

It was questioned whether there is an alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answer the screen test questions about dynamic nature of equilibrium and Le Chatelier's Principle.

Think-aloud protocols and eye-tracking data were utilized to analyze this research question. Each participant's scanpaths for each screen test question was found out and saccades between the representational levels were determined. Additionally, while the participants were solving the screen test questions, they thought aloud and explained how they came up the result. All verbal utterance were audiotaped and fully transcribed. Each response was open coded (Creswell, 2003) concerning the reference a) macroscopic representation, b) submicroscopic representation and c) symbolic representation (Table 4.12). The order of representational levels in the verbal explanation was also stated like a scanpath. Then the kind of transitions in the verbal explanation (macroscopic - symbolic representation, submicroscopic - symbolic representation and macroscopic - submicroscopic representation) was coded as present or not (Table 4.13).

The alignment between the kind of transitions in the verbal explanation and in the eye movement was analyzed with Chi-square test for independence. If the p-value was greater than .05, it would indicate that there was an alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answered the screen test questions about dynamic nature of equilibrium and Le Chatelier's Principle. Table 4.14. Summary table for research questions 4.

Table 4.12. Codes for reference points on the screen concerning preservice chemistry teachers' verbal utterances.

Codes	**Reference points on the screen**
M	Macroscopic representation
P	Submicroscopic (particulate) representation
S	Symbolic representation

Table 4.13. Example of data coding for saccades of eye movement and verbal explanations between the representational levels for the same screen test question.

	Saccades of eye movement			Verbal explanation		
participants	Mac. Sym. transition (MS)	Mac. Submic. transition (MP)	Sym. Submic. transition (SP)	Mac. Sym. transition (MS)	Mac. Submic. transition (MP)	Sym. Submic. transition (SP)
002	present	absent	present	absent	absent	present
036	present	present	present	absent	absent	present

Table 4.14. Summary table for the Research Question 4.

Research Question	**Data Source**	**Analysis**	**Meaning of Analysis**
4. a. Is there an alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answer the questions about dynamic nature of the equilibrium?	Think-aloud protocol Eye-tracker CEV Screen Test (first six questions)	Open Coding Qualitative content analysis Chi-Square Test for Independence	If the p value was greater than 0.05, it would show that there was an alignment between the preservice chemistry teachers' saccades among the representational levels and the frequency of codes emerged in their verbal explanations when they answered the questions about dynamic nature of the equilibrium.
b. Is there an alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answer the questions about Le Chatelier's Principle?	Think-aloud protocol Eye-tracker CEV Screen Test (last four questions)	Open Coding Qualitative content analysis Chi-Square Test for Independence	If the p value was greater than 0.05, it would show that there was an alignment between the preservice chemistry teachers' saccades among the representational levels and the frequency of emerged in their verbal explanations when they answered the questions about Le Chatelier's Principle.

5. RESULTS

In this section, detailed information about the results of the study was provided. Both statistical and descriptive analysis of research questions was given separately under subsections.

5.1. The Effectiveness of Chemical Equilibrium Visualization (CEV)

The effectiveness of chemical equilibrium visualization on improving preservice chemistry teachers' ability of representing the dynamic nature of equilibrium and Le Chatelier's principle at the macroscopic and submicroscopic level was investigated. CEV pretest and posttest scores were compared to observe this effect.

CEV pretests and posttests were scored by two raters: the researcher and a chemistry teacher who also completed her master's degree in this area. Cohen's kappa was run to determine if there was agreement between two raters' judgments on six preservice chemistry teachers' (15% of the participants) pretest and posttest scores. There was a strong agreement between the two raters' judgments, $\kappa = .888$ and $p < .001$.

In order to decide to use whether a parametric or nonparametric test, the normality of distribution of CEV pretest and posttest scores was checked. As shown in Table 5.1, Shapiro-Wilk Test was used to check the normality of distribution of scores in CEV pretest and posttest because the number of participants was less than 50. Shapiro-Wilk Test showed that both test scores are not normally distributed ($p < .01$) Therefore, a nonparametric test, Wilcoxon Signed-Rank Test, was used to compare the means of scores.

Table 5.1. Descriptive statistics and test of normality for all questions in pretest and posttest.

				Shapiro-Wilk		
		Mean	Std. Dev.	Statistic	*df*	*p*
Macroscopic Level	CEV Pre-Q1	9.27	4.16	.924	41	.009
	CEV Post-Q1	14.15	3.49	.593	41	.000
Submicroscopic Level	CEV Pre-Q2	7.54	2.1	.935	41	.021
	CEV Post-Q2	9.44	2.36	.921	41	.007
Macroscopic Level	CEV Pre-Q3	8.71	4.55	.922	41	.008
	CEV Post-Q3	13.27	3.87	.723	41	.000
Submicroscopic Level	CEV Pre-Q4	7.12	2.76	.966	41	.259
	CEV Post-Q4	9.95	2.28	.946	41	.052

Research Question 1.a. The effect of chemical equilibrium visualization on improving the ability of accurately representing the dynamic nature of chemical equilibrium at the macroscopic level was investigated. To test this research question, the first questions on the CEV pretest and posttest were evaluated. In the pretest, the mean score of participants was found to be *M = 9.27 (SD = 4.16)*; however, in the posttest it was found to be *M=14.15 (SD = 3.49)* as given in Table 5.1.

Unlike the scores were found to be normally distributed; the Wilcoxon Signed-Rank Test was used to compare the mean scores of the first questions in the CEV pretest and posttest. As shown in Table 5.2 the mean scores of the first questions in CEV pretest and posttest scores were significantly different from each other ($p < .001$). The results of the analysis suggested that the chemical equilibrium visualization was effective on the improving the ability of accurately representing the dynamic nature of chemical equilibrium at the macroscopic level (*Effect size, r= .676*).

Table 5.2. Wilcoxon Signed-Rank Test results for comparing CEV pretest and posttest question scores.

	Negative ranks			Positive ranks			Test statistics		
	N	Mean rank	Sum of ranks	*N*	Mean rank	Sum of ranks	Ties	*Z*	*p*
CEV-pretest-posttest-q1	6	9.25	55.50	29	19.81	574.5	6	-4.273[a]	.000*
CEV-pretest-posttest-q2	6	12.33	74.00	30	19.73	592.00	5	-4.099[a]	.000*
CEV-pretest-posttest-q3	5	10.10	50.50	27	17.69	477.50	9	-4.005[a]	.000*
CEV-pretest-posttest-q4	7	9.79	68.50	32	22.23	711.50	2	-4.505[a]	.000*
*Indicates statistically significant change									
[a]Based on negative ranks									

Research Question 1.b. The effectiveness of the chemical equilibrium visualization on improving the ability of accurately representing the dynamic nature of chemical equilibrium at the submicroscopic level was questioned. The second questions of the CEV pretest and posttest were also analyzed through the Wilcoxon Signed-Rank Test as the scores were found to be not normally distributed. In the pretest, the mean score of the participants was found to be $M = 7.54$ $(SD = 2.1)$; however, in the posttest it was found to be $M=9.44$ $(SD = 2.36)$ as given in Table 5.1.

The results of the analysis of Wilcoxon Signed-Rank Test indicated that the chemical equilibrium visualization elicited a statistically significant improvement in the ability of accurately representing the dynamic nature of chemical equilibrium at the submicroscopic level because there was a significant difference between the mean scores of the second questions in the CEV pretest and posttest $(p < .001, r= .648)$. As shown in Table 5.2.

Research Question 1.c. It was questioned whether viewing chemical equilibrium visualization was effective on improving the ability of accurately representing Le Chatelier's principle at the macroscopic level. The third questions of the CEV pretest and posttest were analyzed with the Wilcoxon Signed-Rank Test, again, due to not having normal distribution. In the pretest, the mean score of participants was found to be $M = 8.71$ $(SD = 4.55)$; however, in the posttest it was found to be $M = 13.27$ $(SD = 3.87)$ as given in Table 5.1.

As shown in Table 5.2 the mean scores of the third question in CEV pretest and posttest were significantly different from each other (p < .001). The results of the analysis meant that viewing chemical equilibrium visualization was effective on the improving the ability of accurately representing the Le Chatelier Principle at the macroscopic level $(r= .634)$.

Research Question 1.d. The effectiveness of the chemical equilibrium animation on improving the ability of accurately representing Le Chatelier's principle at the submicroscopic level was investigated. The fourth questions of the CEV pretest and posttest were analyzed with the aid of the Wilcoxon Signed-Rank Test. In the pretest, the mean scores of the participants was found to be $M = 7.12$ $(SD = 2.76)$; however, in the posttest it was found to be $M = 9.95$ $(SD = 2.28)$ as given in Table 5.1.

The results of the Wilcoxon Signed-Rank Test analysis indicated that the posttest scores were statistically higher than the pretest scores $(Z = -4.505,\ p < .001)$. This result suggested that the chemical equilibrium visualization was effective on improving the ability of accurately representing the Le Chatelier's Principle at the submicroscopic level $(r= .713)$.

5.2. The Correlation Between the Pre-Service Chemistry Teachers' Experience in Multiple Representations and Mostly Referred Areas of Interest

It was investigated whether there was a relation between the preservice chemistry teachers' experience in multiple representations and mostly referred areas of interest (macroscopic level, symbolic level and submicroscopic level) about dynamic nature of the equilibrium and Le Chatelier's Principle. In order to test the research question, the mostly referred areas of interest while answering screen test's questions and preservice chemistry teachers' experience in multiple representations were compared.

Preservice chemistry teachers were categorized as PCT0 and PCT1 (Table 4.6). The preservice chemistry teachers who had an experience in multiple representations were coded as PCT1, whereas the ones who did not were coded as PCT0. Additionally, mostly visited area of interests were determined based on the fixation durations. The ratio of fixation durations on each area of interest to total fixation duration showed mostly visited area of interest. For example, while answering a screen test question, 20 seconds spent on the macroscopic representation, 30 seconds spent on the submicroscopic representation and 50 seconds spent on symbolic representation. Symbolic representation had the highest ratio to total time spent in this question, $\frac{50}{100}$. Therefore, symbolic representation was the mostly visited area of interest and macroscopic representation was the rarely visited area of interest. Chi-Square Test for Independence Test was applied to explore the relationship between these two nominal variables. Table 5.3 and Table 5.4 show the number of preservice chemistry teachers with different experiences in multiple representations and their mostly referred areas of interest. According to given values in Table 5.3, two of the preservice chemistry teachers, who had an experience in multiple representations (PCT1), mostly referred to the macroscopic representation for screen test question 1. However, ten of the preservice chemistry teachers, who did not have an experience in multiple representations (PCT0), mostly referred to the macroscopic representations. Another clarification for Table 5.3, seven of PCT1 visited mostly to the submicroscopic representations for the screen test question 1. Whereas, this area of interest was visited by only four of the PCT0. Additionally, according to Table 5.4, same number of preservice chemistry teachers (PCT1 and PCT0) referred the submicroscopic representation frequently for the screen test question 10. From another perspective, there were 22 PCT0 in the present study.

In the present study there were 22 PCT0. According to Table 5.3 for the screen test question 1, macroscopic level of representations were visited frequently by 10 of them, whereas submicroscopic level of representations were viewed mostly by 4 of them and finally symbolic level of representations were observed more frequently by 8 of them.

Furthermore, regardless of the experience in multiple representations, Table 5.3 and Table 5.4 demonstrate that symbolic level was the mostly visited area of interest among the other areas of interest for almost all the screen test questions.

Table 5.3. The mostly visited areas of interest cross classified by the number of preservice chemistry teachers for each screen test questions about dynamic nature of equilibrium.

	Dynamic Nature of Equilibrium / Screen Tests Questions											
	Q1		Q2		Q3		Q4		Q5		Q6	
Area of interests	PCT0	PCT1	PCT0	PCT1	PCT0	PCT1	PCT0	PCT1	PCT0	PCT1	PCT0	PCT1
Macroscopic	10	2	0	0	1	0	2	0	3	1	3	0
Submicroscopic	4	7	3	4	2	2	8	6	4	4	5	6
Symbolic	8	9	19	14	19	16	12	12	15	13	14	12
Total	22	18	22	18	22	18	22	18	22	18	22	18

Table 5.4. The mostly visited areas of interest cross classified by the number of preservice chemistry teachers for each screen test questions about Le Chatelier's Principle.

	Le Chatelier's Principle / Screen Tests Questions							
	Q7		Q8		Q9		Q10	
Area of interests	PCT0	PCT1	PCT0	PCT1	PCT0	PCT1	PCT0	PCT1
Macroscopic	3	0	6	0	1	1	1	0
Submicroscopic	2	3	3	4	3	0	2	2
Symbolic	17	15	13	14	18	17	19	16
Total	22	18	22	18	22	18	22	18

Research Question 2.a. The relation between the pre-service chemistry teachers' experience in multiple representations and the mostly referred areas of interest (macroscopic level, symbolic level and submicroscopic level) about dynamic nature of the equilibrium were investigated. First six questions of screen test and the visualization were used to answer this research question. Mostly visited area of interest about dynamic nature of equilibrium was determined based on the fixation durations. The ratio of fixation durations on each area of interest to total fixation duration about the dynamic nature of equilibrium showed mostly visited area of interest. As shown in Table 5.5, the results indicated that there was not a statistically significant relation between preservice chemistry teachers' experience in multiple representations and the mostly referred areas of interest about dynamic nature of chemistry (χ^2 (2, N=40) = 1.255, p = .534).

Table 5.5. Chi-Square analysis for the pre-service chemistry teachers' experience in multiple representations and the mostly referred area of interests about dynamic nature of equilibrium.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.255[a]	2	.534
Likelihood Ratio	1.630	2	.443
Linear-by-Linear Association	.001	1	.974
N of Valid Cases	40		

[a] 4 cells (66.7%) have expected count less than 5. The minimum expected count is .45

Additionally, Figure 5.1 and Figure 5.2 were the heat maps of eye movements. These heat maps belong to two different preservice chemistry teachers for screen test question 2. Even though preservice chemistry teachers' experience in multiple representations differs, they refer all representational levels in the screen as shown in Figure 5.1 and Figure 5.2.

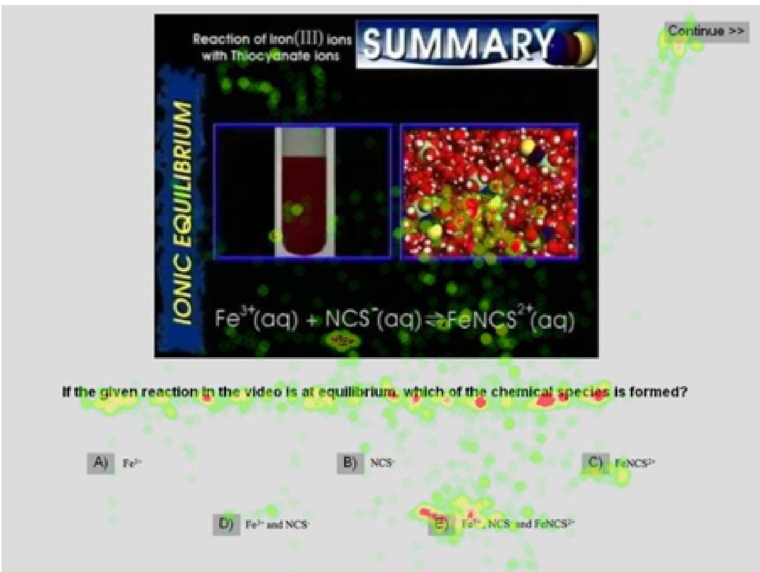


Figure 5.1. One of the PCT1's heat map for screen test question 2.

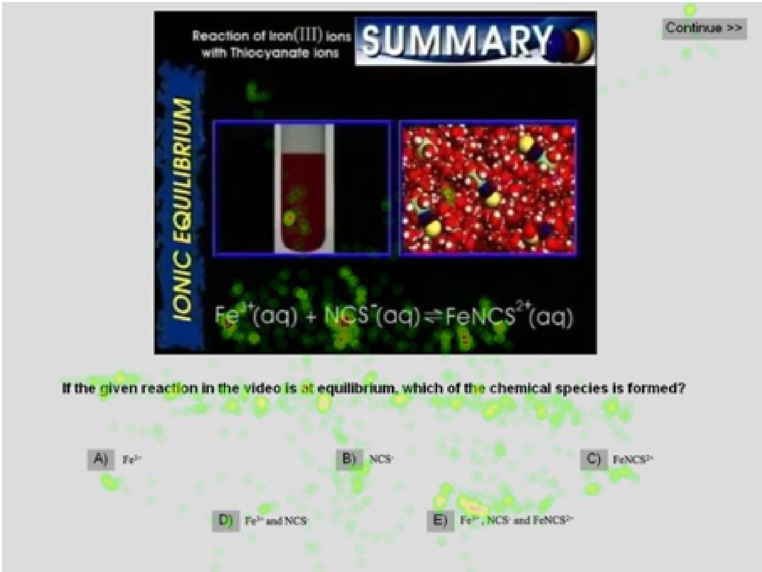


Figure 5.2. One of the PCT0's heat map for screen test question 2.

Research Question 2.b. It was analyzed whether there was a relation between the preservice chemistry teachers' experience in multiple representations and the mostly referred areas of interest (macroscopic level, symbolic level and submicroscopic level) about Le Chatelier's principle. Last four questions of screen test and the visualization were used to reply this research question. Table 5.6 demonstrates the results that there is not a statistical significant relation between preservice chemistry teachers' experience in multiple representations and mostly referred areas of interest about Le Chatelier's principle (χ^2 *(2, N=40) = 1.055, p=.590*).

Table 5.6. Chi-Square analysis between the pre-service chemistry teachers' experience in multiple representations and mostly referred area of interest about Le Chatelier's Principle.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.055[a]	2	.590
Likelihood Ratio	1.437	2	.488
Linear-by-Linear Association	.966	1	.326
N of Valid Cases	40		

[a] 4 cells (66.7%) have expected count less than 5. The minimum expected count is 45.

In addition to statistical analysis, Figure 5.3 and Figure 5.4 demonstrated that preservice chemistry teachers stared at all representational levels regardless of their experience in multiple representations.

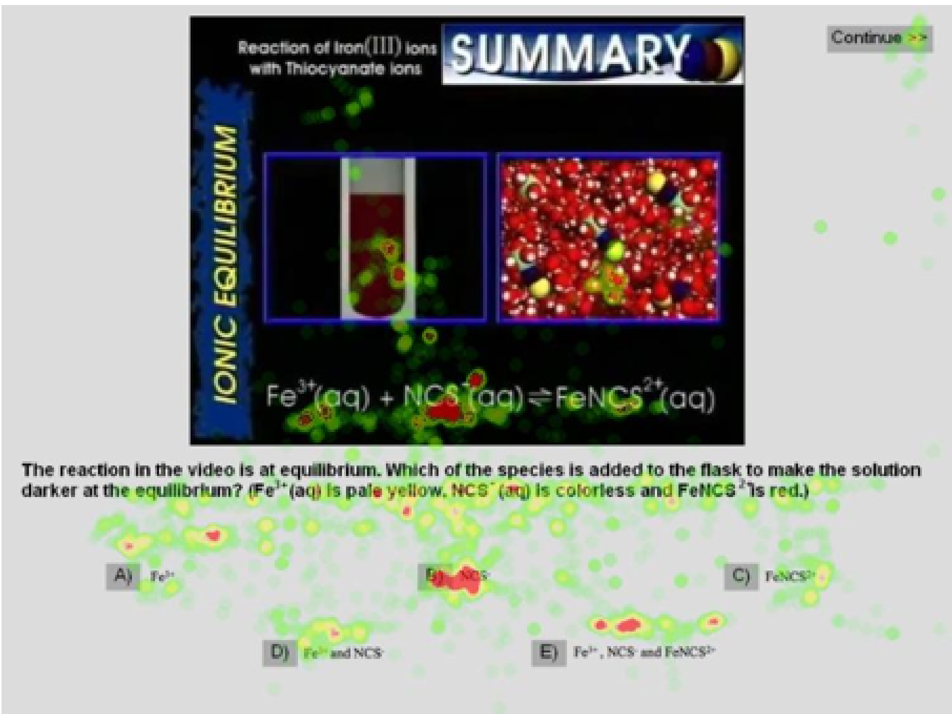


Figure 5.3. One of the PCT1's heat map for screen test question 7.

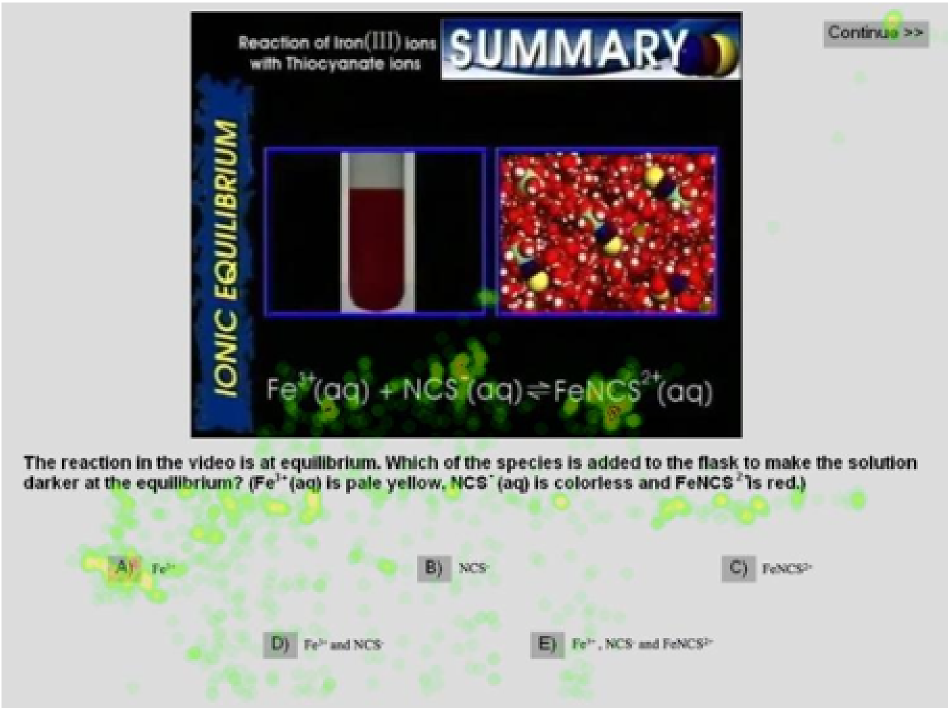


Figure 5.4. One of the PCT0's heat map for screen test question 7.

5.2.1. The Association Between the Preservice Chemistry Teachers' Experience in Multiple Representations and the Kind and Number of Saccades

Research Question 3.a. It was examined whether there was a correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades when they answered the questions about the nature of the equilibrium. The kind and number of saccades were determined based on the scanpaths that the participants follow while they were answering first six questions of CEV screen test. The relationship between the preservice chemistry teachers' experience in the multiple representations and the kind and number of saccades was analyzed with Mann Whitney U Test. The assumptions of test were checked. The independent variable was preservice chemistry teachers' experience in multiple representations, which is categorical. However, the dependent variable was the kind and number of saccades, which is continuous. Additionally, distribution of values in both groups of preservice chemistry teachers had similar shape. Therefore, all assumptions of Mann Whitney U

Test were met.

As shown in Table 5.7, the result of Mann Whitney U Test analysis indicated that there was a statistically significant relation between preservice chemistry teachers' experience in multiple representations and the number of saccades between symbolic and submicroscopic levels of representations (p = .026). The preservice chemistry teachers who had experience in multiple representations (PCT1) made significantly more transitions between symbolic and submicroscopic levels about the nature of equilibrium than the ones who did not (PCT0).

Table 5.7. Results of Mann Whitney U Test analysis for the questions about the dynamic nature of the equilibrium.

	Macroscopic-symbolic transition	Macroscopic-submicroscopic transition	Symbolic-submicroscopic transition
Mann Whitney U	181,000	178,500	116,500
Wilcoxon W	434,000	431,500	369,500
Z	-.463	-.531	-2,219
N of Valid Asymp. Sig (2-tailed)	.644	.595	.026

Research Question 3.b. It was questioned whether there was a correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades when they answered the questions about Le Chatelier's Principle. The relationship between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades was analyzed with Mann Whitney U test. The assumptions of test were checked and all they were met.

As stated in Table 5.8, the results of Mann Whitney U Test analysis demonstrated that there was a statistically significant relation between preservice chemistry teachers' experience in multiple representations and the number of saccades between symbolic and submicroscopic levels of representation (p = .033). The preservice chemistry teachers who had an experience in multiple representations (PCT1) made significantly more transitions between symbolic and submicroscopic levels about Le Chatelier's Principle than the ones who do not (PCT0).

Table 5.8. Results of Mann Whitney U Test analysis for the questions about Le Chatelier's Principle.

	MS	MP	SP
Mann Whitney U	177,500	141,000	119,500
Wilcoxon W	430,500	394,000	372,500
Z	-.559	-1,566	-2,138
N of Valid Asymp. Sig (2-tailed)	.576	.117	.033

Furthermore, Figure 5.5 and Figure 5.6 demonstrated two different preservice chemistry teachers' saccades between the areas of interests for screen test question 2. As the red line indicated the preservice chemistry teachers who had experience in multiple representation made more transitions between symbolic and submicroscopic level than the one who did not.

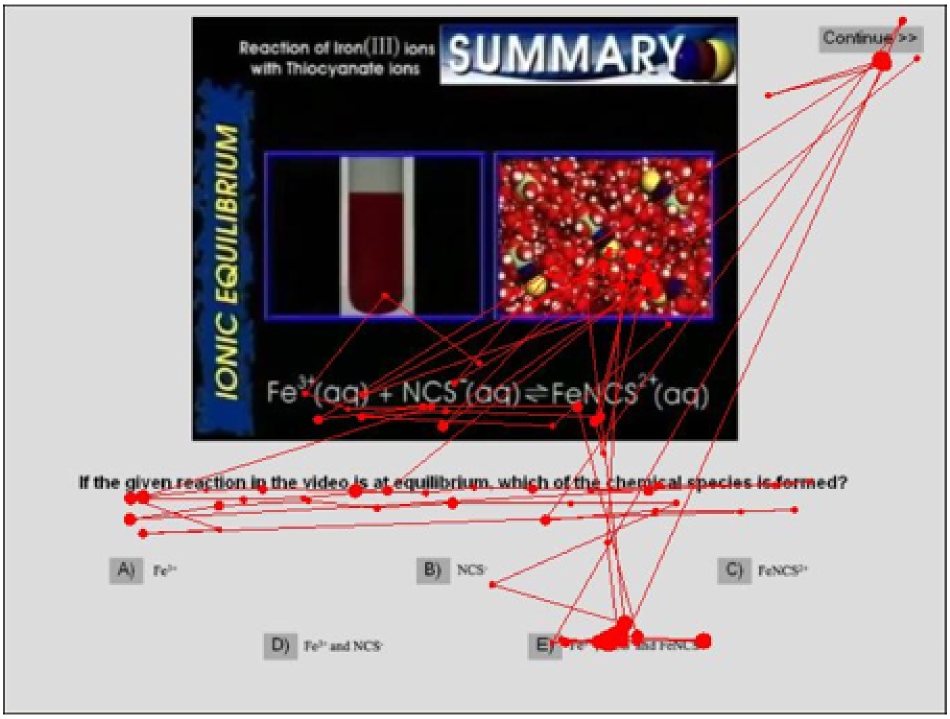


Figure 5.5. One of PCT1's scanpath for screen test question 2.

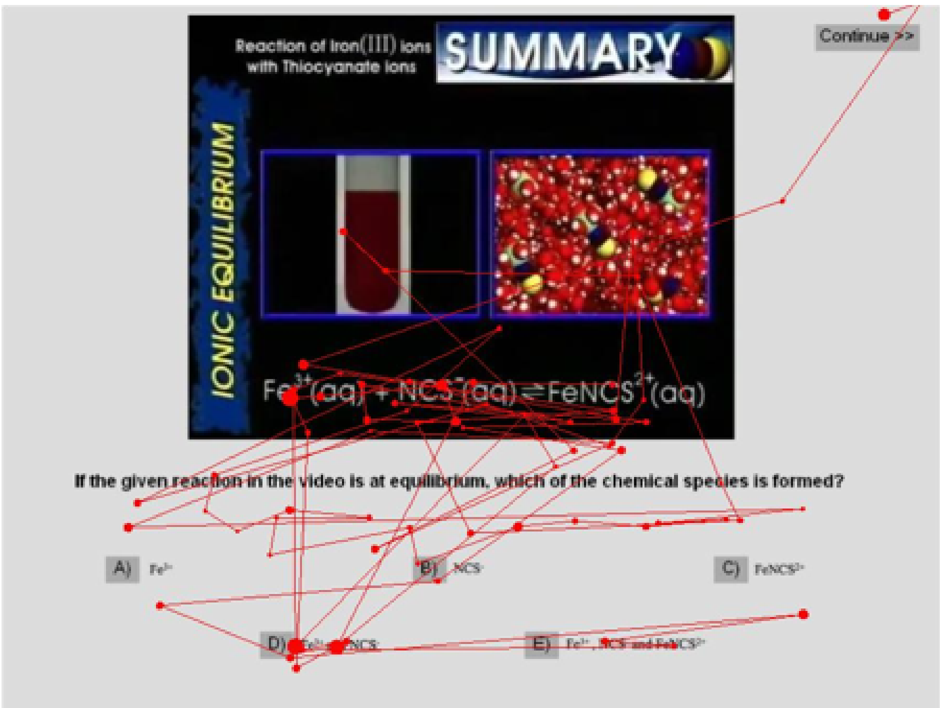


Figure 5.6. One of PCT0's scanpath for screen test question 2.

5.3. The Alignment Between the Preservice Chemistry Teachers' Saccades Among the Representational Levels and Their Verbal Explanations

It was investigated whether there was an alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answered the screen test questions about dynamic nature of equilibrium and Le Chatelier's Principle.

To analyze this research question, all verbal explanations during the screen test were transcribed and the responses were open coded as macroscopic representation, submicroscopic representation and symbolic representation. The order of representational levels in verbal explanations was stated like a scanpath. Finally, the transition between the representational levels was coded as stated in Table 4.7. The following excerpt for screen test question 2 belongs to one of the preservice chemistry teachers. This verbal explanation was accepted at the submicroscopic level because of the expression of dissociation process and ions' reactions and coded as PP. The first P represents the dissociation process, whereas the second one shows the ions' reactions.

"All of them are present at the equilibrium because equilibrium means like that. The others are also forming; there is a continuous dissociation. Both iron produces a complex with thiocyanate and this complex dissociates into iron and thiocyanate. That is why all are in the solution, so option e [one of choices of the question]". (Equilibriumda yine hepsi var aslında çünkü equilibrium öyle birşey demek. Yani diğerinden de bir miktar oluyor sürekli bir dissociation oluyor. Hem demir komplex oluşturuyor thiociyante ile hemde o kompleks ayrılıyor demire ve thiocyanate. O yüzden hepsi var solüsyonun içinde o yüzden e şıkkı). (Participant 007).

Another response to the same screen test question was quoted below. This verbal explanation was at the symbolic level because of the expression of left and right side and reactants and products of the equilibrium reaction. The answer was coded as SS. The former one was for the explanation of left and right side of the reaction, however the latter one was for the statement of reactants and products of the reaction.

"It contains all because it says equilibrium, so I am marking all [one of choices of the question]. It is at equilibrium, reaction will go to left and right side, therefore I don't think there will be only a product or a reactant. All of them should be". (Equilibrium dediği için hepsinden var o yüzden hepsini işaretliyorum. Equilibriumda sonuçta reaksiyon bir sağa gidecek bir sola gidecek o yüzdende bir tek ürün ya da bir tek girenlerin olduğunu düşünmüyorum hepsinden olması gerekiyor) (Participant 012).

The following excerpt was for screen test question 4. The answer of the preservice chemistry teacher was coded as PMP because the explanations were respectively about the concentrations, color and amount of iron thiocyanate in the solution.

"It says equilibrium, so I will say all [one of choices of the question]. But the video said that concentrations stay constant even though forward and reverse reactions take place. Therefore the color stays same. So I will say none at the equilibrium. Until the equilibrium iron cyanate increases but at the equilibrium I will say it will stay same". (Equilibriumda dediği için artık hepsini diyeceğim. Ama videoda şey diyordu ne kadar ileri geri de olsa konsantrasyonlar aynı kalıyor o yüzden renkde aynı kalıyor diyordu o zaman at the equilibriumda none dicem. Equilibriuma gelene kadar demir cyanate artıyor, equilibriumda artık aynı diyeceğim) (Participant 026).

In addition to the verbal utterance, eye-tracking data were analyzed. While the participants were answering the screen test questions they were staring at the representational levels on the screen. After the scanpath was created with the aid of eye tracker, the saccades between these representational levels was investigated and coded as shown in Table 4.7.

Research Question 4.a. The alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answer the screen test questions about dynamic nature of equilibrium was searched. Chi-square test for independence Test was performed to examine the alignment between the kind of transitions in the verbal explanation and in the eye movement. The difference between the kind of transition in the verbal explanation and in the eye movement was not significant for the first six questions of the screen test. This means that the kind of transition in verbal explanation and eye movement was aligned. Table 5.9 demonstrates the Chi-square values for each screen test questions about dynamic nature of equilibrium.

Research Question 4.b. The alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answer the screen test questions about Le Chatelier's Principle was examined. Chi-square test for independence was used to analyze the alignment between the kind of transitions in the verbal explanation and in the eye movement. The difference between the kind of transition in the verbal explanation and in the eye movement was not significant for the last four questions of the screen test. Therefore, the kind of transition in the verbal explanations and eye movements was similar ($p > .05$). Table 5.10 demonstrates the chi square values for each screen test questions about Le Chatelier's Principle.

As shown in Table 5.9 and Table 5.10, no statistics were computed for some of the screen test questions, because the number of transition in verbal utterance or in the eye movement was constant. When the data was examined it was observed that preservice chemistry teachers made transitions between representational levels in their eye movements; however, for some screen test questions any of them made transitions in their verbal explanation. By taking these into considerations Table 5.9 indicated that any of preservice chemistry teachers made transitions between macroscopic and symbolic levels in their verbal explanations for screen test question 3. Therefore, no statistics were computed in screen test question 3 for this transition. Additionally, Table 5.10 revealed that only transitions between symbolic and submicroscopic levels were made in the verbal explanations or eye movements for screen test question 9 and 10. Nevertheless, any transition between macroscopic and symbolic level or macroscopic and submicroscopic level was done in verbal explanations for screen test 9 and 10.

Table 5.9. Results of Chi-square test analysis for each screen test question about dynamic nature of equilibrium.

Screen test question	N	χ^2			p
		MS	MP	SP	
1	40	3.64	0.18	1.43	$> .05$
2	40	0.08	0.45	1.23	$> .05$
3	40	-	2.33	0.63	$> .05$
4	40	0.12	0.61	0.26	$> .05$
5	40	-	0.68	0.05	$> .05$
6	40	1.13	-	101	$> .05$

Table 5.10. Results of Chi-square test analysis for each screen test question about Le Chatelier's Principle.

Screen test question	N	χ^2			p
		MS	MP	SP	
7	40	1.29	1.78	0.56	$> .05$
8	40	0.59	0.02	3.26	$> .05$
9	40	-	-	0.31	$> .05$
10	40	-	-	1.32	$> .05$

6. DISCUSSION AND CONCLUSION

The aim of the present study is, with the aid of the eye tracking technology,

(i) to compare the preservice chemistry teachers' mostly referred representational levels according to their experience in multiple representations

(ii) to examine the correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades that they follow while answering the screen test questions about chemical equilibrium

(iii) to investigate the alignment between the participants' saccades among the representational levels and their verbal explanations while they answering the screen test questions about chemical equilibrium.

In order to achieve these aims in this study, mixed method design, specifically convergent parallel design, (Creswell, 2003) was applied. Both quantitative (eye tracker data, CEV pretests, CEV posttests) and qualitative (Think aloud protocols) data were collected by two groups of preservice chemistry teachers: the ones who had an experience in multiple representations (PCT1, N=18) and the ones who did not (PCT0, N=22). The preservice chemistry teachers were studying at a mid-size public university in Turkey. They were selected conveniently because of the easy accessibility of the eye-tracker instrument.

Chemical equilibrium topic was studied in the present study because it was found one of the challenging chemistry topics. One of the reasons is that the topic is abstract (Wheeler and Kass, 1978; Ben-Zvi, *et al.*, 1987; Huddle and Pillay, 1996; Piquette and Heikkinen, 2005; Chiu *et al.*, 2002). Another reason is that students understand the concept as static rather than a dynamic process (Chiu *et al.*, 2002). Moreover, equilibrium has different meanings in different disciplines. Gussarsky and Gorodetsky (1990) stated that whilst equilibrium is static in physics, it is dynamic in chemistry and this complicates the comprehension of the topic. Concerning these reasons in the current study a chemical equilibrium visualization was used to investigate its effectiveness on preservice chemistry teachers' ability of representing the dynamic nature of equilibrium and Le Chatelier's principle at the macroscopic and submicroscopic levels.

In the first research question, it was investigated whether the chemical equilibrium visualization is effective on improving the preservice chemistry teachers' ability of representing the dynamic nature of equilibrium and Le Chatelier's principle at the macroscopic and submicroscopic level. Therefore, means of CEV pretest and posttest scores were compared with Wilcoxon Signed-Rank Test to observe the effect of chemical equilibrium visualization. The analysis showed that the chemical equilibrium visualization was effective on the improving the ability of accurately representing the dynamic nature of chemical equilibrium and Le Chatelier's Principle at both macroscopic and submicroscopic level. One of the reasons behind this finding might be the order of representations in the chemical equilibrium visualization because the animation started with the macroscopic representation, which is the most familiar one. The preservice chemistry teachers watched the changes at this level beforehand. The submicroscopic and symbolic representations were introduced respectively. Then all the representational levels were demonstrated simultaneously on the screen. Williamson *et al.* (2012) found that it is easier for students to explain a phenomenon at the submicroscopic level after they see a macroscopic visualization. Thus, students move from concrete model to the abstract one and submicroscopic representation would make sense. Another reason for this finding might be that dynamic nature of matter cannot be seen with naked eye but the dynamic visualization could demonstrate the participants the dynamic nature of matter at the submicroscopic level. Therefore, the preservice chemistry teacher might start thinking dominantly about the process of dynamic nature of equilibrium and Le Chatelier's Principle at the submicroscopic level. Additionally, Velázquez-Marcano *et al.* (2004), Kelly *et al.* (2004) and Akaygun and Jones (2013) stated that dynamic visuals that integrates the different levels of representations enhances students' conceptual understanding rather than by oneself. The findings of the present study support the results of the other studies.

Second Research Question asked whether there was a correlation between the preservice chemistry teachers' experience in multiple representations and the mostly referred areas of interest (macroscopic level, symbolic level and submicroscopic level) about dynamic nature of the equilibrium and Le Chatelier's Principle. The preservice chemistry teachers' experience in multiple representations was the grouping variable of the study. They were grouped as the ones who had an experience in multiple representation (PCT1) and the ones who did not (PCT0). Mostly referred areas of interest were determined for each of the question with the aid of eye tracking data. Chi-Square Test for Independence was applied to explore the relationship between these two nominal variables. The result of the analysis indicated that there was not a statistically significant relation between preservice chemistry teachers' experience in multiple representation and mostly referred area of interests about dynamic nature of chemistry and Le Chatelier's Principle. As stated before, chemical equilibrium is one of the challenging topics for students. Therefore, preservice chemistry teachers might have fixated on each area of interest to find solutions to the chemical equilibrium screen test questions regardless of their experience in multiple representations. In other words, they might have sought a hint on the screen.

However, symbolic representation was the mostly referred area of interest regardless of the experience in multiple representations. Preservice chemistry teachers were mostly exposed to symbolic representations in other chemistry classes including high school, and this might have affected their behavior while solving the screen test questions. They might have tended to stare at that representation to find out a solution way. Williamson *et al.* (2013) and Stieff *et al.* (2011) recorded students' eye movements while they were looking at the different representations of the same phenomenon on the screen. Both studies resulted that students preferred to the familiar representation on the screen. This result was supported by the finding of the present study. Eye-tracking technology proved that regardless of the experience in multiple representations preservice chemistry teachers frequently visited the symbolic representation, which is the most familiar area of interest to them among others.

The aim of the third Research Question was to examine whether there existed any correlation between the preservice chemistry teachers' experience in multiple representations and the kind and number of saccades when they answered the questions about the nature of the equilibrium and Le Chatelier's Principle. With the aid of eye tracking technology, the number of saccades between the representational levels was determined for each topic. Then the correlation was analyzed with Mann Whitney U Test. The result of statistical analysis indicated that there was a statistically significant relation between preservice chemistry teachers' experience in multiple representations and the number of saccades between symbolic and submicroscopic representations. The preservice chemistry teachers who had experience in multiple representations (PCT1) made significantly more transitions between symbolic and submicroscopic representations about the nature of equilibrium and Le Chatelier's Principle than the ones who did not (PCT0). PCT1 had more experience in representations of a topic at the submicroscopic level. This might have promoted them to integrate symbolic and submicroscopic representations. In her doctoral dissertation, VandenPlas (2008) worked with undergraduate and graduated chemistry students and concluded that novices and experts viewed the particulate level animation in different ways. Consistently, the finding of the present study figured out that the preservice chemistry teachers who had experience in multiple representations solved the screen test questions in different ways than the others. They could make more integration between symbolic and submicroscopic representations.

In the last Research Question it was examined whether there was an alignment between the preservice chemistry teachers' saccades among the representational levels and their verbal explanations when they answer the screen test questions about dynamic nature of equilibrium and Le Chatelier's Principle. After all verbal explanations were transcribed, coded as macroscopic, symbolic and submicroscopic, and stated like a scanpath, the alignment between eye saccades and verbal explanations was analyzed with Chi-Square Test for Independence. The result of the statistical analysis indicated that the difference between the kind of transition in the verbal explanation and in the eye movement was not significant. The result means that when preservice chemistry teachers answered the screen test questions about the nature of equilibrium and Le Chatelier's Principle, there was an alignment between the kind of transition in their verbal explanation and the eye movements. Stieff *et al.* (2011) found out that there is a high correlation between eye tracking results and verbal protocols. In this respect, the result of this study supported the finding of previous study. Verbal protocols and eye tracking technology provided consistent measures for cognitive process.

6.1. Limitations of the Study

The chemical equilibrium visualization is an available dynamic visual on the Internet. The participant could watch it beforehand. In the present study it was assumed that all participants saw the visualization for the first time. If the participants watched it before, it might influence their attention and eye movements.

In the present study the preservice chemistry teachers were grouped based on their experience in multiple representation. One of the groups had trained in a course before the study, whereas the other one had not. Their reference point on the screen and their eye movements between the levels of representations were compared. Although one group of participants took the course, their achievement in the course might vary. It means their ability of representing a phenomenon accurately might differ according to their success in this course.

CEV-pretest and CEV-posttest were identical and CEV-pretest was administered one week before the eye tracking study and CEV-posttest. Preservice chemistry teachers might have remembered their answers in the pretest while they were doing posttest. This might have caused a limitation in the current study.

The chemical equilibrium visualization provides three representational levels simultaneously; therefore the viewer could integrate and interpret them. However, three representational levels include two visuals, which are macroscopic and submicroscopic representations, and one written explanation, which is symbolic representation. Presenting these representational levels simultaneously on the screen might have caused cognitive load. This could make a way for the further researches to investigate the effect of perceived cognitive load.

Last, the participants permit to record their voice during the think aloud protocols. However, some of them were shy, hesitant and afraid of expressing the screen test questions in a wrong way. Therefore, these participants could not explain their ideas in detail.

6.2. Suggestions for Further Research

Participants of the study were 40 preservice chemistry teachers from a mid-size public university in Istanbul. They were accepted extremely high achieving students according to their scores on a central university entrance exam. It might be interpreted that participants of the study were above average when compared with the other preservice chemistry teachers in Turkey. Therefore, in order to generalize the results, a larger study with varied sample from different universities is needed.

During the high school years students could have a chance to watch submicroscopic visualizations and do experiments about a topic in chemistry courses. In other words, they could have experience in multiple representations, however some of the high school students could not. A further research might be carried with high school students to compare the eye movements while watching a visualization that combines all representational levels.

The contribution of eye tracking technology to this study was crucial. It proved that preservice chemistry teachers were capable of coordinating symbolic and submicroscopic levels about dynamic nature of equilibrium and Le Chatelier's Principle if they had an experience in multiple representations. This finding suggested a further research to demonstrate why the preservice chemistry teachers had difficulty to integrate the symbolic and macroscopic representations or submicroscopic and macroscopic representations.

The result of the current study revealed that eye tracking data and verbal protocols were highly correlated. The correlation implies that when the participants were answering the screen test questions, their eye movements and verbal explanations reflected the similar cognitive processes. Combination of eye tracking and verbal protocols might be suggested to the further researches to gain a deeper understanding of cognitive processes and strategies learner use while learning chemistry.

Finally, high school chemistry teachers should take the multirepresentational displays into account while teaching chemical equilibrium because it fosters the conceptual understanding (Akaygun and Jones, 2013). However, when the different levels of representation are presented simultaneously, students might not coordinate them. Meaningful directions and guidance are suggested to improve understanding of chemical equilibrium.

REFERENCES

Adadan E., "Investigating the Influence of Pre-Service Chemistry Teachers' Understanding of the Particle Nature of Matter on Their Conceptual Understanding of Solution Chemistry", *Chemistry Education Research and Practice*, Vol. 15, No. 2, pp. 219-238, 2014.

Adadan E., K.E. EIrving, and K.C. Trundle, "Impacts of Multi-Representational Instruction on High School Students' Conceptual Understanding of the Particulate Nature of Matter", *International Journal of Science Education*, Vol. 31, No. 13, pp. 1743-1775, 2009.

Akaygun S. and L.L. Jones, "Research-Based Design and Development of a Simulation of Liquid-Vapor Equilibrium", *Chemistry Education Research and Practice*, Vol. 14, pp. 324-344, 2013.

Akaygun S. and L.L. Jones, "Words or Pictures: a Comparison of Written and Pictorial Explanations of Physical and Chemical Equilibria", *International Journal of Science Education*, Vol. 36, No. 5, pp. 783-807, 2014.

Allsop R.T. and N.H. George, "Le Chatelier - a Redundant Principle", *Education in Chemistry*, Vol. 21, pp. 54-56, 1984.

Anderson J., D. Bothell and S. Douglass, "Eye Movements Do Not Reflect Retrieval Processes", *Psychological Science*, Vol. 15, No. 4, pp. 225-231, 2004.

Ardac D. and S. Akaygun, "Effectiveness of Multimedia-Based Instruction That Emphasizes Molecular Representations on Students' Understanding of Chemical Change", *Journal of Research in Science Teaching*, Vol. 41, No. 4, pp. 317-337, 2004.

Ausubel D.P., J.D. Novak and H. Hanesian, *Educational Psychology: A Cognitive view, Holt*, Rinehart and Winston, New York, 1978.

Banerjee A.C., “Misconceptions of Students and Teachers in Chemical Equilibrium”, *International Journal of Science Education*, Vol. 13, No. 4, pp. 487-494, 1991.

Banerjee A.C. and C.N. Power, “The Development of Modules for the Teaching of Chemical Equilibrium”, *International Journal of Science Education*, Vol. 13, No. 3, pp. 355-362, 1991.

Ben-Zvi R., B. Eylon, J. Silberstein, “Students’ Visualization of Some Chemical Reactions”, *Education in Chemistry*, Vol. 24, pp. 117-120, 1987.

Bergquist W. and H. Heikkinen, “Students Ideas Regarding Chemical Equilibrium”, *Journal of Chemical Education*, Vol. 67, No. 12, pp. 1000-10003, 1990.

Brandt S.A. and L.W. Stark, “Spontaneous Eye Movemenets During Visual Imagery Reflect the Content of the Visual Scene”, *Journal of Cognitive Neuroscience*, Vol. 9, No. 1, pp. 27-38, 1997.

Buell R.R. and G.A. Bradley, “Piagetian Studies in Science: Chemical Equilibrium Understanding from Study of Solubility: a Preliminary Report from Secondary School Chemistry”, *Science Education*, Vol. 56, No. 12, pp. 23-29, 1972.

Burke K., T. Greenbowe and M. Windschitl, “Developing and Using Conceptual Computer Animations for Chemistry Instruction”, *Journal of Chemical Education*, Vol. 75, No. 12, pp. 1658-1661, 1998.

Camacho M. and R. Good, “Problem Solving and Chemical Equilibrium: Successful Versus Unsuccessful Performance”, *Journal of Research in Science Teaching*, Vol. 26, No. 3, pp. 251-272, 1989.

Chandrasegaran A.L., D. Treagust and M. Mocerino, “The Development of a Two-Tier Multiple-Choice Diagnostic Instrument for Evaluating Secondary School Students’ Ability to Describe and Explain Chemical Reactions Using Multiple Levels of Representation”, *Chemistry Education Research and Practice*, Vol. 8, pp. 293-

307, 2007.

Chittleborough G. and D. Treagust, “Correct Interpretation of Chemical Diagrams Requires Transforming from One Level of Representation to Another”, *Research in Science Education*, Vol. 38, pp. 463-482, 2008.

Chiu M., C. Chou and C. Liu, “Dynamic Processes of Conceptual Change: Analysis of Constructing Mental Models of Chemical Equilibrium”, *Journal of Research in Science Teaching*, Vol. 39, No. 8, pp. 688-712, 2002.

Creswell J.W., *Research Design: Qualitative, Quantitative and Mixed Method Approaches*, Sage Publications, Thousand Oaks, 2003.

Çalik M., A. Alipasa and R. Coll, “Investigating the Effectiveness of Teaching Methods Based on a Four-Step Constructivist Strategy”, *Journal of Science Education and Technology*, Vol. 19, No. 1, pp. 32-48, 2010.

Demircioğlu G., H. Demircioğlu and M. Yadigaroğlu, “An Investigation of Chemistry Student Teachers' Understanding of Chemical Equilibrium”, *International Journal on New Trends in Education and Their Implications*, Vol. 4, No. 2, pp. 192-199, 2013.

Dori Y. and M. Hameiri, “Multidimensional Analysis System for Quantitative Chemistry Problems: Symbol, Macro, Micro and Process Aspects”, *Journal of Research in Science Teaching*, Vol. 40, No. 3, pp. 278-302, 2003.

Durmus J., Ş. Bayraktar, “Effects of Conceptual Change Texts and Laboratory Experiments on Fourth Grade Students' Understanding of Matter and Change Concepts”, *Journal of Science Education Technology*, Vol. 19, pp. 498-504, 2010.

Ebenezer J.V. and G.L. Erickson, “Chemistry Students' Conceptions of Solubility: a Phenomenography”, *Science Education*, Vol. 80, No. 2, pp. 181-201, 1996.

Ebenezer J.V. and P.J. Gaskell, “Relational Conceptual Change in Solution Chemistry", *Science Education*, Vol. 79, No. 1, pp. 1-17, 1995.

Finley F.N., J. Stewart and W.L. Yarroch, "Teachers' Perceptions of Important and Difficult Science Content", *Science Education*, Vol. 66, pp. 531-538, 1982.

Gabel D., "Enhancing the Conceptual Understanding of Science", *Educational Horizons*, Vol. 81, No. 2, pp. 70-76, 2003.

Gabel D., K. Samuel and D. Hunn, "Understanding The Particulate Nature of Matter", *Journal of Chemical Education*, Vol. 64, No. 8, p. 695, 1987.

Gilbert J.K., D.F. Treagust, *Multiple Representations in Chemical Education*, Springer, Dordrecht, 2009.

Goodwin A., "Is salt melting when it dissolves in water", *Journal of Chemical Education*, Vol. 79, No. 3, pp. 393-396, 2002.

Gorodetsky M. and E. Gussarsky, "Misconceptualization of the Chemical Equilibrium Concept as Revealed by Different Evaluation Methods", *European Journal of Science Education*, Vol. 8, No. 4, pp. 427-441, 1986.

Gussarsk E. and M. Gorodetsky, "Chemical Equilibrium: the Associative Framework", *Journal of Research in Science Teaching*, Vol. 27, No. 3, pp. 197-204, 1990.

Hackling M.W. and P.J. Garnett, "Misconceptions of Chemical Equilibrium", *European Journal of Science Education*, Vol. 7, No. 2, pp. 205-214, 1985.

Hansen S., *Multimodal Study of Visual Problem Solving in Chemistry with Multiple Representations*, Doctoral Dissertation, Columbia University, 2014.

Havanki K., *A Process Model for the Comprehension of Organic Chemistry Notation, Doctoral Dissertation*, The Catholic University of America, 2012.

Havanki K. and J. VandenPlas, *In Tools of Chemistry Education Research, American*

Chemical Society, Washington, DC, 2014.

Hoffman J.E. and B. Subramaniam, "The Role of Visual Attention in Saccadic Eye Movements", *Perception & Psychophysics*, Vol. 57, No. 6, pp. 787-795, 1995.

Horowitz T., E. Fine, D. Fencsik, S. Yurgenson and J. Wolfe, "Fixational Eye Movements Are Not an Index of Covert Attention", *Psychological Science*, Vol. 18, No. 4, pp. 356-363, 2007.

Huddle P. and A. Pillay, "An In-Depth Study of Misconceptions in Stoichiometry and Chemical Equilibrium at a South African University", *Journal of Research in Science Teaching*, Vol. 33, No. 1, pp. 65-77, 1996.

Huddle P. and M. White, "Simulations for Teaching Chemical Equilibrium", *Journal of Chemical Education*, Vol. 77, No. 7, pp. 920-926, 2000.

Johnstone A.H., "Macro- and Micro-Chemistry", *School Science Review*, Vol. 64, pp. 377-379, 1982.

Just M.A. and P.A. Carpenter, "A Theory of Reading: From Eye Fixations to Comprehension", *Psychological Review*, Vol. 87, pp. 329-354, 1980.

Kelly R., A. Phelps and M. Sanger, "The Effects of a Computer Animation on Students' Conceptual Understanding of a Can-Crushing Demonstration at the Macroscopic, Microscopic, and Symbolic Levels", *The Chemical Educator*, Vol. 9, No. 3, pp. 184-189, 2004.

Kozma R.B., "Learning with Media", *Review of Educational Research*, Vol. 61. No. 2, pp. 179-212, 1991.

Kozma R.B., "The Material Features of Multiple Representations and Their Cognitive and Social Affordances for Science Understanding", *Learning and Instruction*, Vol. 13, No. 2, pp. 205-226, 2003.

Kozma R.B. and J. Russell, "Multimedia and Understanding: Expert and Novice Responses to Different Representations of Chemical Phenomena", *Journal of Research in Science Teaching*, Vol. 34, No. 9, pp. 949-968, 1997.

Le Chatelier H.L., "Sur La Loi Du Déplacement De L´Équilibre Chimique", *Comptes Rendus Académie des Sciences*, Vol. 196, pp. 1557-1560 and 1753-1757, 1933.

Levenshtein V., "Binary Codes Capable of Correcting Deletions, Insertions and Reversals", *Soviet Physics Doklady*, Vol. 10, No. 8, pp. 707-710, 1966.

Maskill R. and A. Cachapuz, "Learning About the Chemistry Topic of Equilibrium: the Use of Word Association Tests to Detect Developing Conceptualizations", *International Journal of Science Education*, Vol. 11, No. 1, pp. 57-69, 1989.

Mayer R., *Multimedia learning*, Cambridge University Press, New York, 2001.

Mayer R.E. and R.B. Anderson, "Animations Need Narrations: An Experimental Test of a Dual-Coding Hypothesis", *Journal of Educational Psychology*, Vol. 83, No.4, pp. 484-490, 1991.

Mayer R. and V. Sims, "For Whom Is a Picture Worth a Thousand Words" Extensions of A Dual-Coding Theory of Multimedia Learning", *Journal of Educational Psychology*, Vol. 86, No. 3, pp. 389-401, 1994.

Moreno R. and R. Mayer, "Cognitive Principles of Multimedia Learning: The Role of Modality and Contiguity", *Journal of Educational Psychology*, Vol. 91, No. 2, pp. 358-368, 1999.

Moreno R. and R. Mayer, "A Learner-Centered Approach to Multimedia Explanations: Deriving Instructional Design Principles from Cognitive Theory", *Interactive Multimedia Electronic Journal of Computer - Enhanced Learning*, Vol. 2, pp, 2000.

Mousavi S., R. Low and J. Sweller, "Reducing Cognitive Load by Mixing Auditory and Visual Presentation Modes", *Journal of Educational Psychology*, Vol. 87, No. 2, pp. 319-334, 1995.

Nakhleh M., "Why Some Students Don't Learn Chemistry", *Journal of Chemical Education*, Vol. 69, No. 3, pp. 191-196, 1992.

Niaz M., "Cognitive Conflict as A Teaching Strategy in Solving Chemistry Problems: A Dialectic-Constructivist Perspective", *Journal of Research in Science Teaching*, Vol. 32, No. 9, pp. 959-970, 1995.

Osborne R., P. Freyberg, *Learning in science: the implications of children's science*, Heinemann, Auckland, 1985.

Özmen H., "Determination of Students' Alternative Conceptions About Chemical Equilibrium: A Review of Research and The Case of Turkey", *Chemistry Education Research and Practice*, Vol. 9, pp. 225-233, 2008.

Paivio A., *Mental Representations*, Oxford University Press, New York, 1990.

Pierri E., A. Karatrantou, C. Panagiotakopoulos, "Exploring The Phenomenon of Change of Phase of Pure Substances Using the Microcomputer-Based-Laboratory (MBL) System", *Chemistry Education: Research and Practice*, Vol. 9, pp. 234-239, 2008.

Piquette J.S. and H.W. Heikkinen, "Strategies Reported Used by Instructors to Address Student Alternate Conceptions in Chemical Equilibrium", *Journal of Research in Science Teaching*, Vol. 42, No. 10, pp. 1112-1134, 2005.

Posner G.J., K.A. Strike, P.W. Hewson and W.A. Gertzog, "Accommodation of A Scientific Conception: Toward A Theory of Conceptual Change", *Science Education*, Vol. 66, pp. 211-227, 1982.

Prieto T., A. Blanco, A. Rodriguez, "The Ideas of 11 To14-Year-Old Students About the Nature of Solutions", *International Journal of Science Education*, Vol. 11, No. 4, pp. 451-463, 1989.

Quilez-Pardo J. and J. Solaz-Portoles, "Students' and Teachers' Misapplication of Le Chatelier's Principle: Implications for The Teaching of Chemical Equilibrium", *Journal of Research in Science Teaching*, Vol. 32, No. 9, pp. 939-957, 1995.

Rayner K., "Eye Movements in Reading and Information Processing: 20 Years of Research", *Psychological Bulletin*, Vol. 124, No. 3, pp. 372-422, 1998.

Russell J.W., R.B. Kozma, T. Jones, J. Wykoff, N. Marx and J. Davis, "Use of Simultaneous-Synchronized Macroscopic, Microscopic, and Symbolic Representations to Enhance the Teaching and Learning of Chemical Concepts", *Journal of Chemical Education*, Vol. 74, No. 3, pp. 330-334, 1997.

Sanger M., "Using Particulate Drawings to Determine and Improve Students' Conceptions of Pure Substances and Mixtures", *Journal of Chemical Education*, Vol. 77, No. 6, pp. 762-766, 2000.

Sanger M., A. Phelps and J. Fienhold, "Using a Computer Animation to Improve Students' Conceptual Understanding of a Can-Crushing Demonstration", *Journal of Chemical Education*, Vol. 77, No. 11, pp. 1517-1520, 2000.

Smith K., M. Nakhleh, "University Students' Conceptions of Bonding and Melting and Dissolving Phenomena", *Chemistry Education Research and Practice*, Vol. 12, pp. 398-408, 2011.

Stieff M., "Improving Representational Competence Using Molecular Simulations Embedded in Inquiry Activities", *Journal of Research in Science Teaching*, Vol. 48, No. 10, pp. 1137-1158, 2011.

Stieff M., M. Hegarty and G. Deslongchamps, "Identifying Representational Competence with Multi-Representational Displays", *Cognition and Instruction*, Vol. 29, No. 1, pp. 123-145, 2011.

Stieff M. and U. Wilensky, "Connected Chemistry-Incorporating Interactive Simulations into The Chemistry Classroom", *Journal of Science Education and Technology*, Vol. 12, No. 3, pp. 285-302, 2003.

Suits J.P. and M. Sanger, *In Pedagogic Roles of Animations and Simulations in Chemistry Courses*, American Chemical Society, Washington, DC, 2013.

Sweller J., "Cognitive Load Theory, Learning Difficulty, and Instructional Design", *Learning and Instruction*, Vol. 4, No. 4, pp. 295-312, 1994.

Taber K.S., "Three Levels of Chemistry Educational Research", *Chemistry Education Research and Practice*, Vol. 14, No. 2, p. 151, 2013.

Tang H. and N. Pienta, "Eye-Tracking Study of Complexity in Gas Law Problems", *Journal of Chemical Education*, Vol. 89, pp. 988-994, 2012.

Tang H., J. Topczewski, A. Topczewski and N. Pienta, "Permutation Test for Groups of Scanpaths Using Normalized Levenshtein Distances and Application in NMR Questions", *Proceedings of the Symposium on Eye Tracking Research and Applications*, pp. 169-172, 2012.

Tang H., J. Kirk and N. Pienta, "Investigating the Effect of Complexity Factors in Stoichiometry Problems Using Logistic Regression and Eye Tracking", *Journal of Chemical Education*, Vol. 91, No. 7, pp. 969-975, 2014.

Tarsan N., *The Effect of Working With IPad Applications Including Macroscopic And Submicroscopic Level Representations In Different Orders On Students' Conceptual Understanding of Gas Laws*, M.S., Boğaziçi University, 2015.

Treagust D., G. Chittleborough and T. Mamiala, "The Role of Submicroscopic and Symbolic Representations in Chemical Explanation", *International Journal of Science Education*, Vol. 25, No. 11, pp. 1353-1368, 2003.

Uzuntiryaki E., O. Geban, "Effect of Conceptual Change Approach Accompanied with Concept Mapping on Understanding of Solution Concepts", *Instructional Science*, Vol. 33, pp. 311-339, 2005.

VandenPlas J., *Animations in Chemistry Learning: Effect of Expertise and Other user Characteristics*, Ph.D., The Catholic University of America, 2008.

Velázquez-Marcano A., V. Williamson, G. Ashkenazi, R. Tasker and K. Williamson, "The Use of Video Demonstrations and Particulate Animation in General Chemistry", *Journal of Science Education and Technology*, Vol. 13, pp. 315-323. 2004,

Vygotsky L.S., *Mind in Society Development of Higher Psychological Processe*s, Harvard University Press, Cambridge, 1978.

Wheeler, A.E., and H., Kass, 1978, "Students' Misconceptions in Chemical Equilibrium", *Science Education*, Vol. 62, No. 2, pp. 223-232.

Williamson V.M. and M.R. Abraham, "The Effects of Computer Animation on the Particulate Mental Models of College Chemistry Students", *Journal of Research in Science Teaching*, Vol. 32, No. 5, pp. 521-534, 1995.

Williamson V.M., M. Hegarty, G. Deslongchamps, K.C. Williamson and M.J. Shultz, "Identifying Student Use of Ball-And-Stick Images Versus Electrostatic Potential Map Images Via Eye Tracking", *Journal of Chemical Education*, Vol. 90, No. 2, pp. 159-164, 2013.

Williamson V.M., S.M. Lane, T. Gilbreath, R. Tasker, G. Ashkenazi, K.C. Williamson and R.D. Macfarlane, "The Effect of Viewing Order of Macroscopic and Particulate Visualizations on Students' Particulate Explanations", *Journal of Chemical Education*, Vol. 89, pp. 979-987, 2012.

Wu H., "Linking the Microscopic View of Chemistry to Real-Life Experiences: Intertextuality in a High-School Science Classroom", *International Journal of Science Education*, Vol. 87, pp. 868-891, 2003.

Wu H. and P. Shah, "Exploring Visuospatial Thinking in Chemistry Learning", *Inter-*

national Journal of Science Education, Vol. 88, pp. 465-492, 2004.

Yakmacı-Güzel B. and E. Adadan, “Use of Multiple Representations in Developing Preservice Chemistry Teachers’ Understanding of the Structure of Matter”, *International Journal of Environmental and Science Education*, Vol. 8, No. 1, pp. 109-130, 2013.

Yezierski E.J. and J.P. Birk, “Misconceptions About the Particulate Nature of Matter. Using Animations to Close the Gender Gap”, *Journal of Chemical Education*, Vol. 83, pp. 954-960, 2006.

APPENDIX A: DEMOGRAPHIC FORM (DF)

1. Participant Code: ________________
2. Gender: Female ☐ Male ☐
3. Age: __________
4. GPA: __________
5. Which chemistry courses have you taken? Please state your grade for the courses that you have taken.

	I have taken; My Grade	I haven't taken.	I am taking now.
a. CHEM 103 (General Chemistry I)	_____	☐	☐
b. CHEM 104 (General Chemistry II)	_____	☐	☐
c. CHEM 107 (Introduction to Practical Chemistry)	_____	☐	☐
d. CHEM 108 (Qualitative Analysis)	_____	☐	☐
e. CHEM 201 (Organic Chemistry I)	_____	☐	☐
f. CHEM 202 (Organic Chemistry II)	_____	☐	☐
g. CHEM 203 (Organic Chemistry Lab I)	_____	☐	☐
h. CHEM 204 (Organic Chemistry Lab II)	_____	☐	☐
i. CHEM 245 (Inorganic Chemistry I)	_____	☐	☐
j. CHEM 250 (Principles of Analytic Chemistry)	_____	☐	☐
k. CHEM 331 (Inorganic Chemistry II)	_____	☐	☐
l. CHEM 351 (Physical Chemistry I)	_____	☐	☐

Figure A.1. Demographic Form 1.

	I have taken; My Grade	I haven't taken.	I am taking now.
m. CHEM 353 (Introduction to Physical Chemistry)	_____	☐	☐
n. CHEM 352 (Physical Chemistry II)	_____	☐	☐
o. CHEM 371 (Textile Chemistry)	_____	☐	☐
p. CHEM 435 (Int. to Polymer Science and Chemistry)	_____	☐	☐
q. CHEM 471 (Environmental Chemistry)	_____	☐	☐
r. CHEM 473 / 481 (Research Techniques in Chemistry I)	_____	☐	☐
s. CHEM 474 / 482 (Research Techniques in Chemistry II)	_____	☐	☐
t. CHEM 417 (Polymer Chemistry Laboratory)	_____	☐	☐
u. CHEM 413 (Medicinal Chemistry)	_____	☐	☐
v. CHEM 421 (Computational Chemistry)	_____	☐	☐
w. CHEM 488 (Sp. Tp. Chemistry of Everyday Life)	_____	☐	☐
x. CHEM 318 (Survey of Textile Chemistry)	_____	☐	☐
y. CHEM ______________________________	_____	☐	☐
z. CHEM ______________________________	_____	☐	☐

Figure A.2. Demographic Form 2.

6. Which courses have you taken? Please state your grade for the courses that you have taken.

	I have taken; My Grade	I haven't taken.	I am taking now.
a. SCED 350 (Secondary School Science Laboratory Application I	_____	☐	☐
b. SCED 320/420 (Teaching Methods in Science and Mathematics)	_____	☐	☐
c. SCED 370 (Assessment and Evaluation of Learning in Science and Mathematics)	_____	☐	☐
d. SCED 421 (Teaching Methods in Chemistry)	_____	☐	☐
e. SCED 450 (School Experience in Teaching Mathematics and Science I)	_____	☐	☐
f. SCED 414 (Seminar on Practice Teaching in Chemistry)	_____	☐	☐
g. SCED 422 (Practice Teaching in Chemistry)	_____	☐	☐
h. CET 360 (Instructional Technologies and Material Development)	_____	☐	☐
i. ______________________ (Name an elective course which you benefited the most.)	_____	☐	☐

7. Have you ever watched any chemistry animation or simulation at the particulate level?

   a. If yes, please explain what it was about.

   ____

   ____

   b. How did you like it? Why/Why not?

   ____

   ____

8. Do you wear glasses or contact lenses? ______________________________

9. Do you have ADHD (Attention Deficit Hyperactivity Disorder)? ________________

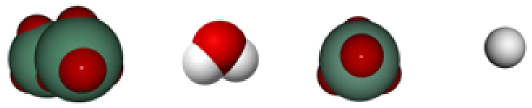
Figure A.3. Demographic Form 3.

APPENDIX B: CHEMICAL EQUILIBRIUM VISUALIZATION PRETEST & POSTTEST

Participant Code: ....

Potassium dichromate, which is very bright **red-orange** colored solid, is placed in the flask and dissolved in water. Resulting solution is **yellow-orange** colored. The dichromate ions ($Cr_2O_7^{2-}$) in aqueous solution are in equilibrium with the chromate ions (CrO_4^{2-}) as shown in the equation.

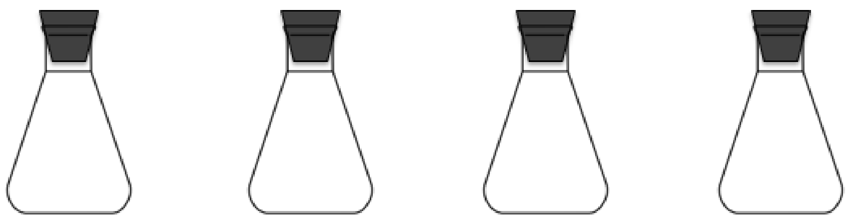
$$Cr_2O_7^{2-} + H_2O \rightleftharpoons 2CrO_4^{2-} + 2H^+$$



Answer the following questions considering the reaction given above.

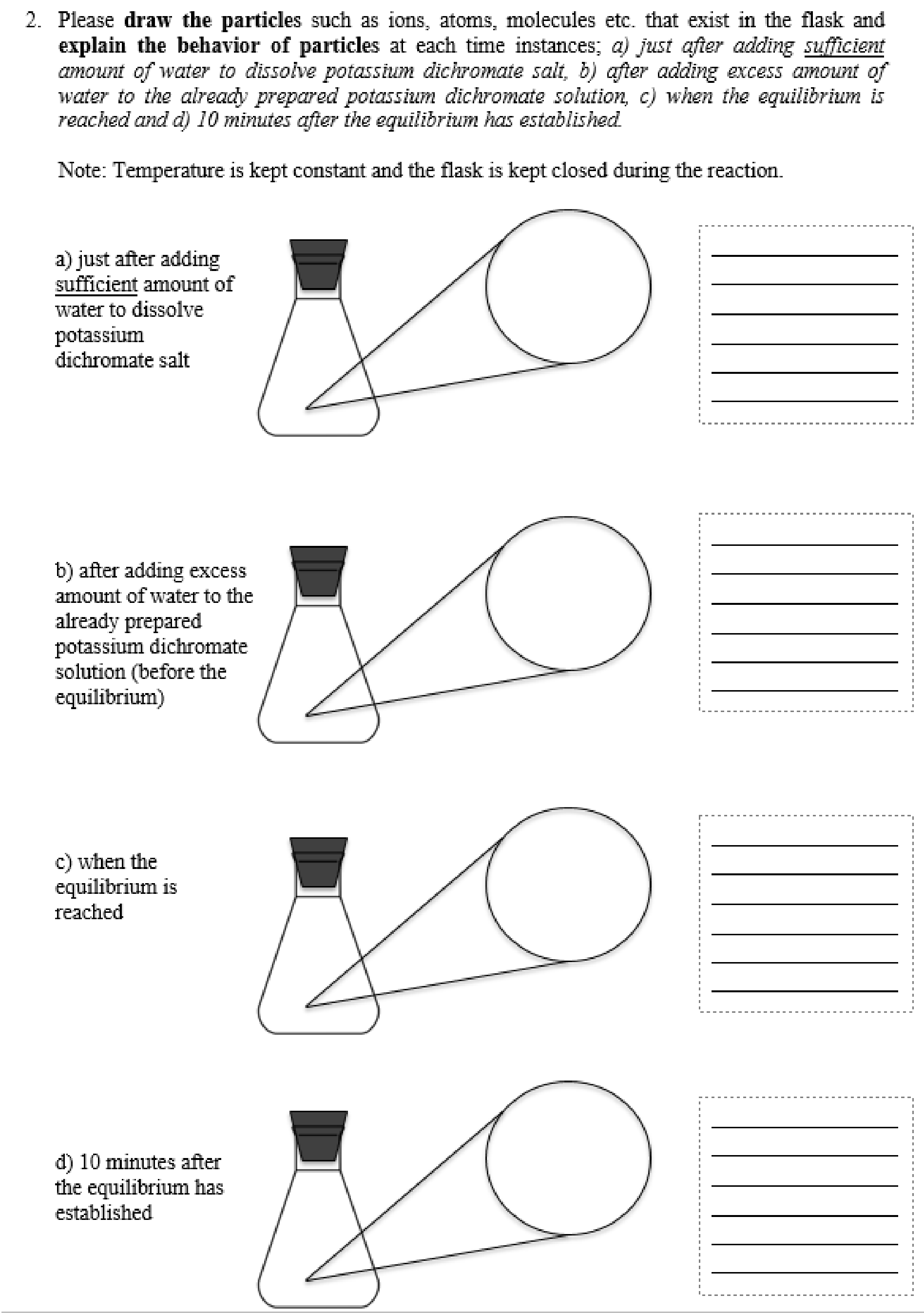
1. Please explain the color change that you will observe <u>with your own eyes</u> at each time instances; *a) just after adding <u>sufficient amount</u> of water to dissolve potassium dichromate salt, b) after adding excess amount of water to the already prepared potassium dichromate solution, c) when the equilibrium is reached and d) 10 minutes after the equilibrium has established.*

   <u>Note:</u> Temperature is kept constant and the flask is kept closed during the reaction.



a) just after adding <u>sufficient amount</u> of water to dissolve potassium dichromate salt	b) after adding excess amount of water to the already prepared potassium dichromate solution (before the equilibrium)	c) when the equilibrium is reached	d) 10 minutes after the equilibrium has established
____________	____________	____________	____________

Figure B.1. Participant Code 1.



2. Please **draw the particles** such as ions, atoms, molecules etc. that exist in the flask and **explain the behavior of particles** at each time instances; *a) just after adding sufficient amount of water to dissolve potassium dichromate salt, b) after adding excess amount of water to the already prepared potassium dichromate solution, c) when the equilibrium is reached and d) 10 minutes after the equilibrium has established.*

Note: Temperature is kept constant and the flask is kept closed during the reaction.

a) just after adding sufficient amount of water to dissolve potassium dichromate salt

b) after adding excess amount of water to the already prepared potassium dichromate solution (before the equilibrium)

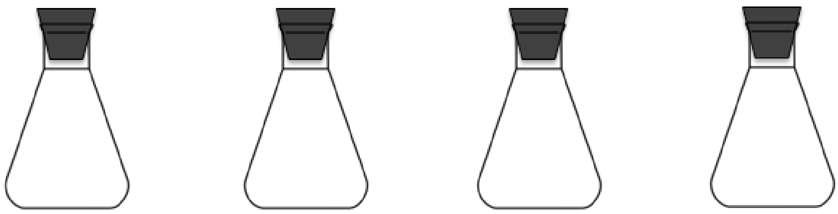
c) when the equilibrium is reached

d) 10 minutes after the equilibrium has established

Figure B.2. Participant Code 2.

3. When the reaction at equilibrium is disturbed by the addition of *HCl*, how does the color of the solution change? Please explain what you will observe with your own eyes at each time instances; *a) at the initial state (before HCl is added), b) after the equilibrium is disturbed but prior to the new equilibrium, c) at equilibrium and d) 10 minutes after the equilibrium has established.*

Note: HCl is a strong acid. Temperature is kept constant and the flask is kept closed during the reaction.



a) at the initial state (before HCl is added)

b) after the equilibrium is disturbed (that is, HCl added but prior to the new equilibrium)

c) at equilibrium

d) 10 minutes after the equilibrium has established

Figure B.3. Participant Code 3.

4. When the reaction at equilibrium is disturbed by the addition of HCl, how is the system affected? Please **draw all the particles** such as ions, atoms, molecules etc. that exist in the flask and **explain the particles' behaviors** at each time instances; *a) at the initial state (before HCl is added), b) after the equilibrium is disturbed but prior to the new equilibrium, c) at equilibrium and d) 10 minutes after the equilibrium has established.*

   Note: HCl is a strong acid. Temperature is kept constant and the flask is kept closed during the reaction.

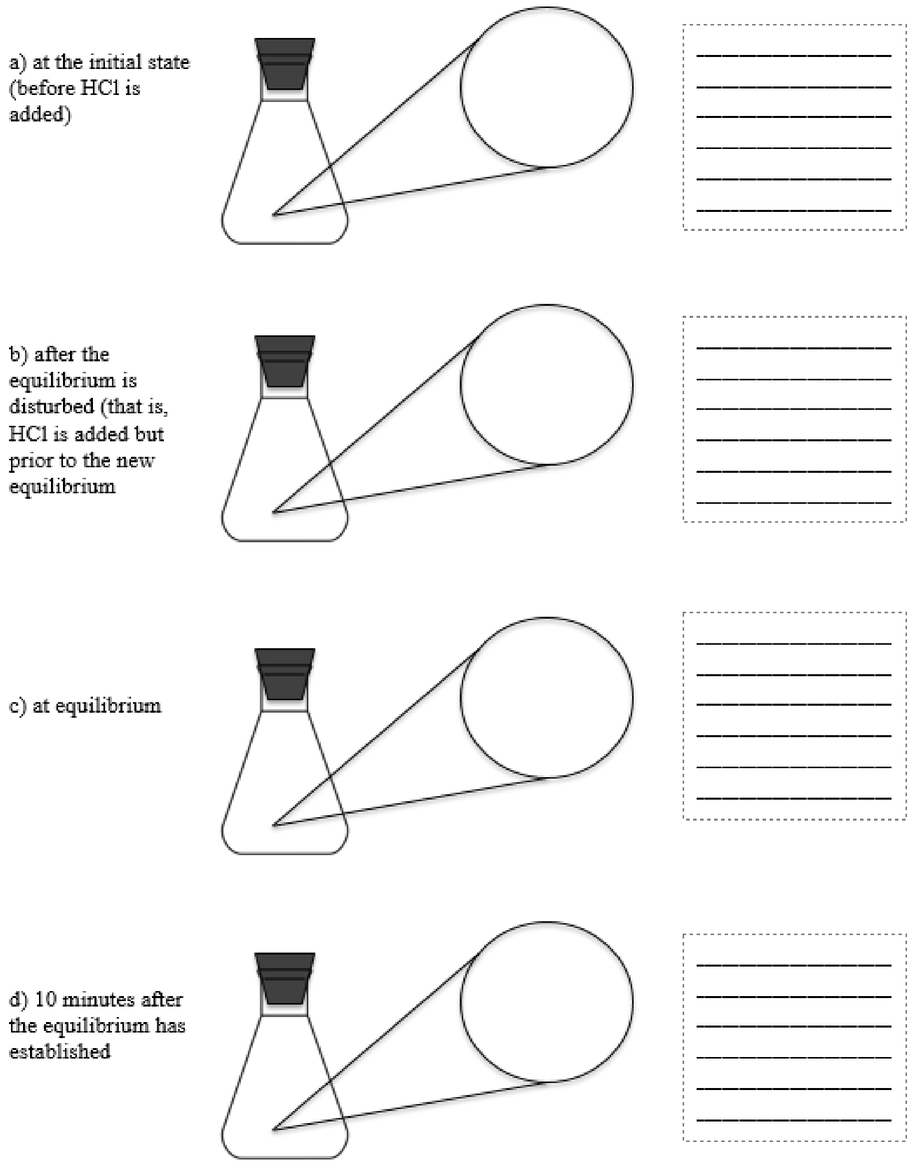


Figure B.4. Participant Code 4.

APPENDIX C: CHEMICAL EQUILIBRIUM VISUALIZATION SCREEN TEST

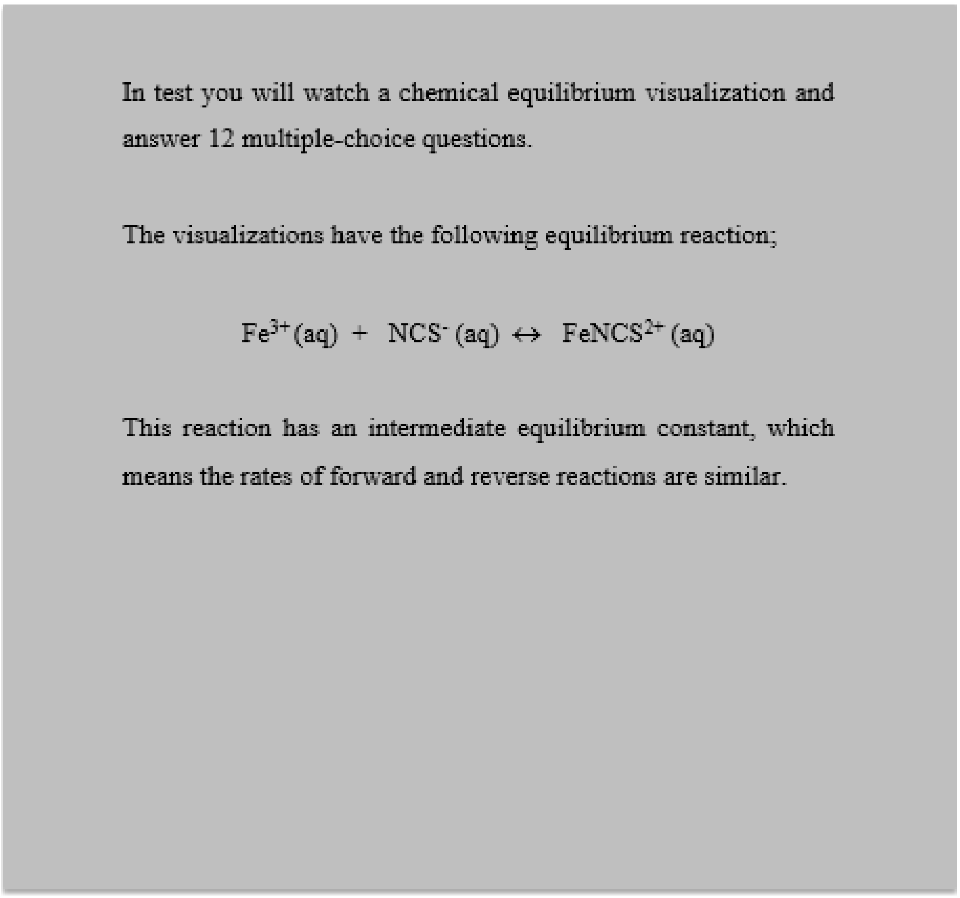
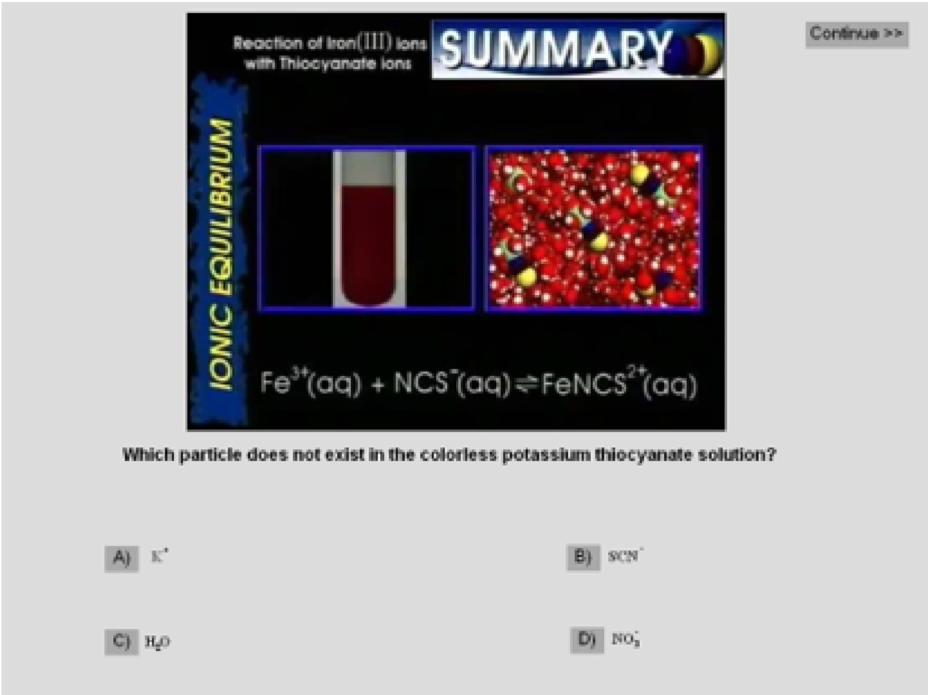


Figure C.1. Chemical Equilibrium Visualization Screen Test 1.

1.



2.

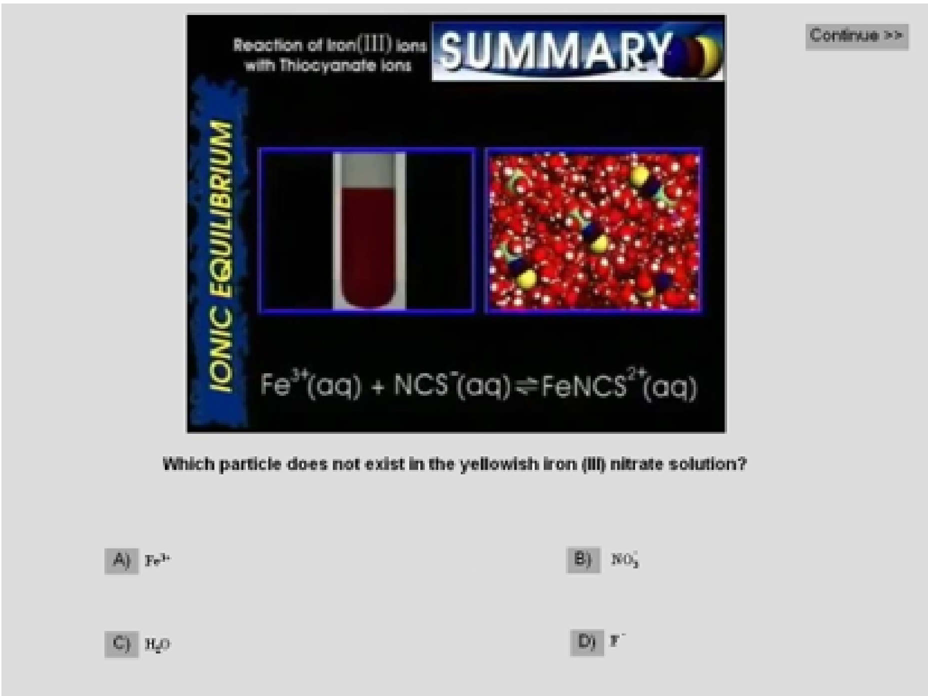
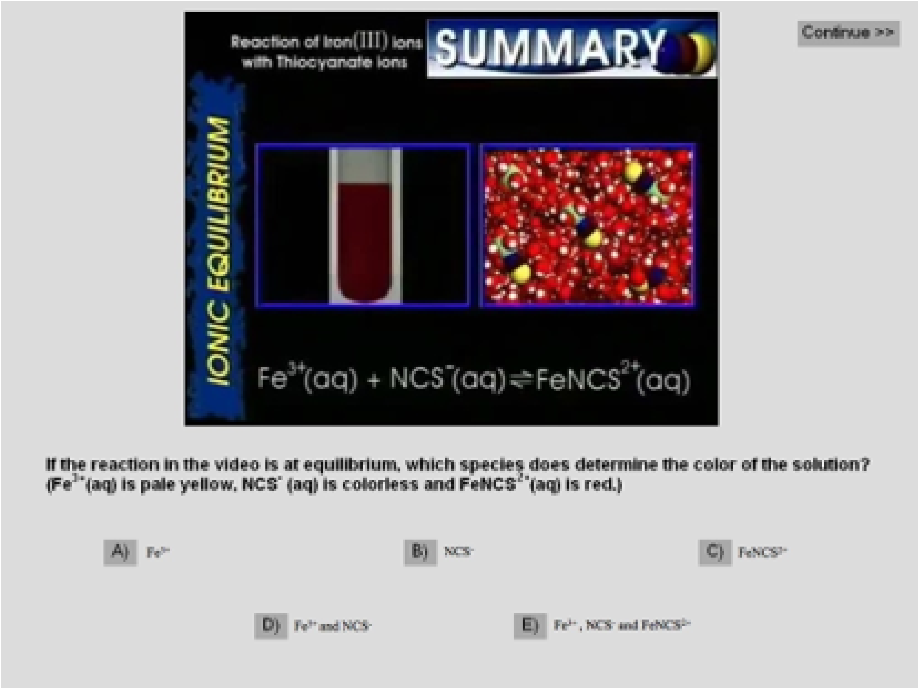


Figure C.2. Chemical Equilibrium Visualization Screen Test 2.

1.



2.

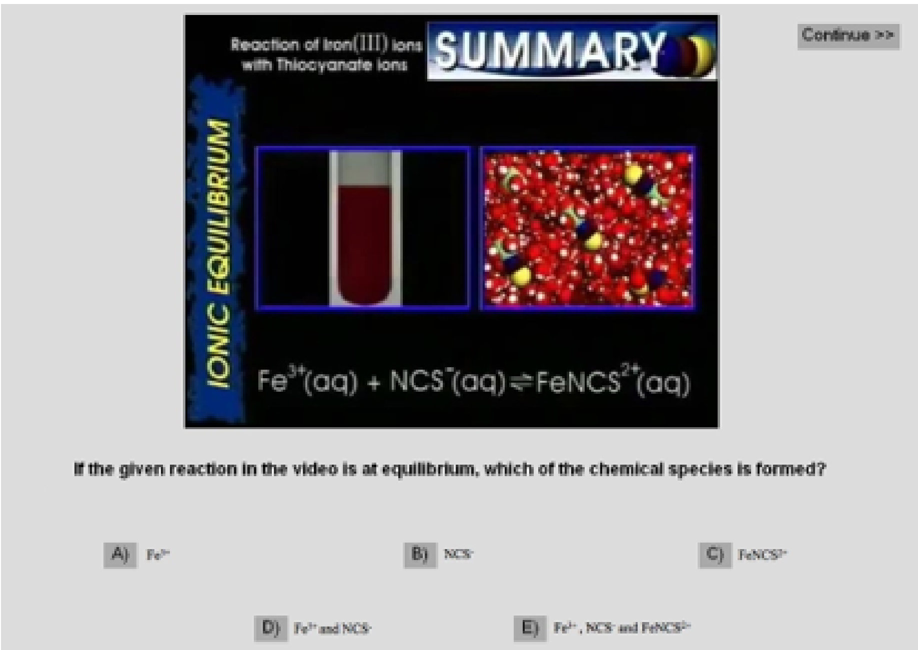
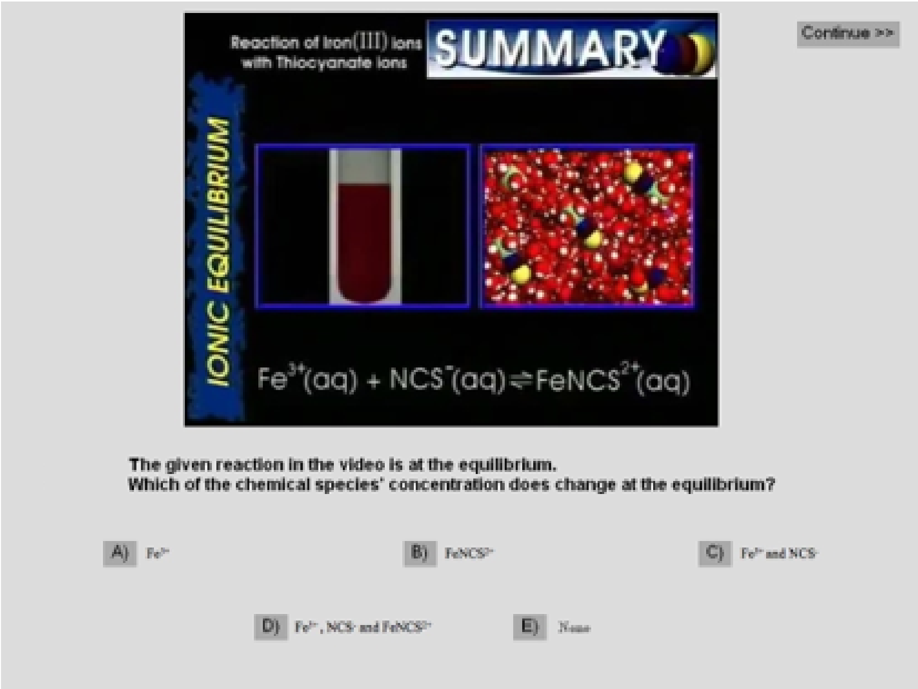


Figure C.3. Chemical Equilibrium Visualization Screen Test 3.

3.



4.

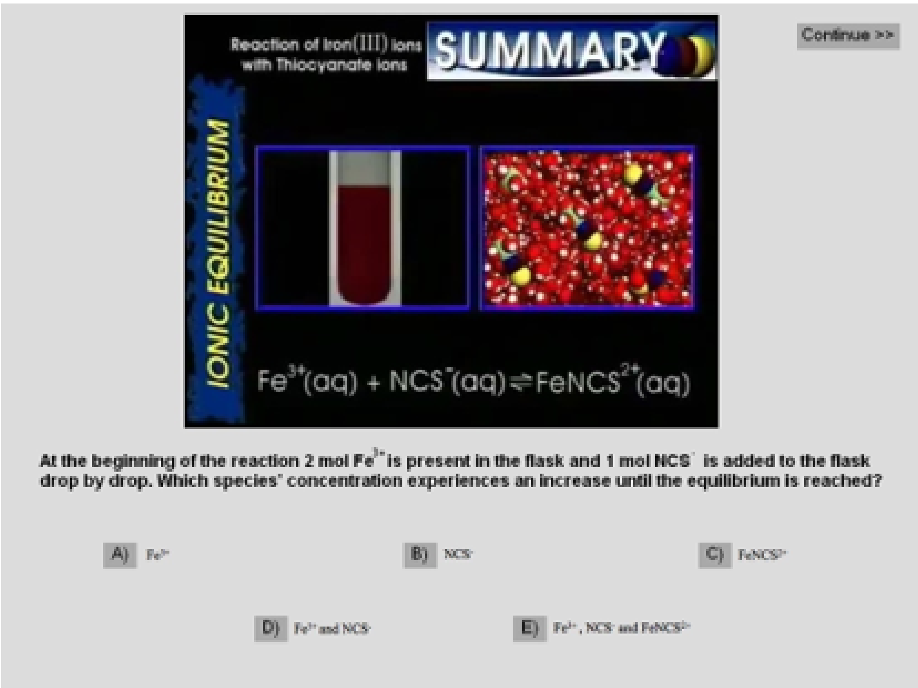
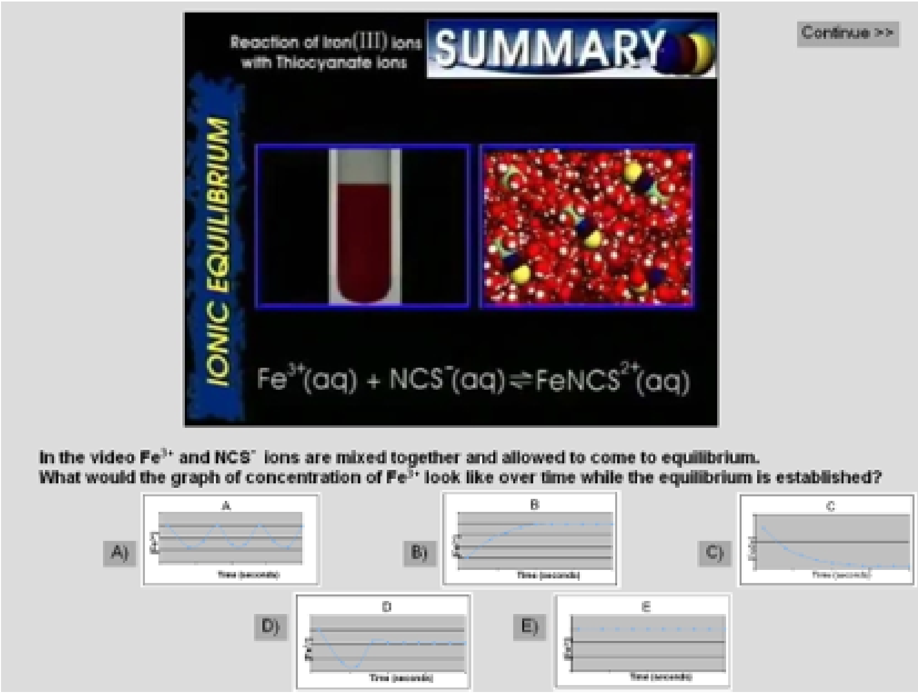


Figure C.4. Chemical Equilibrium Visualization Screen Test 4.

5.



6.

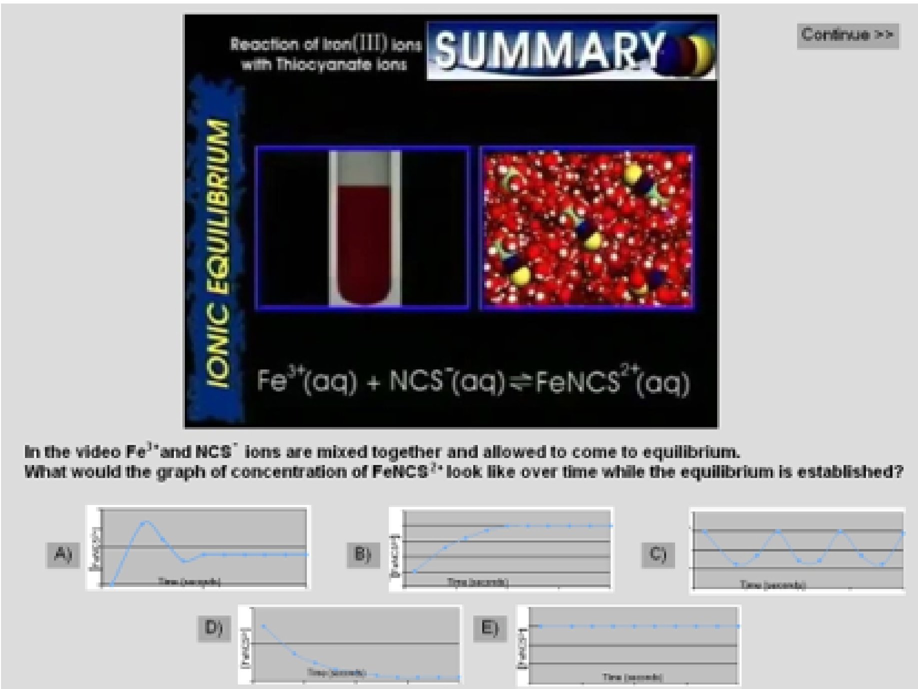
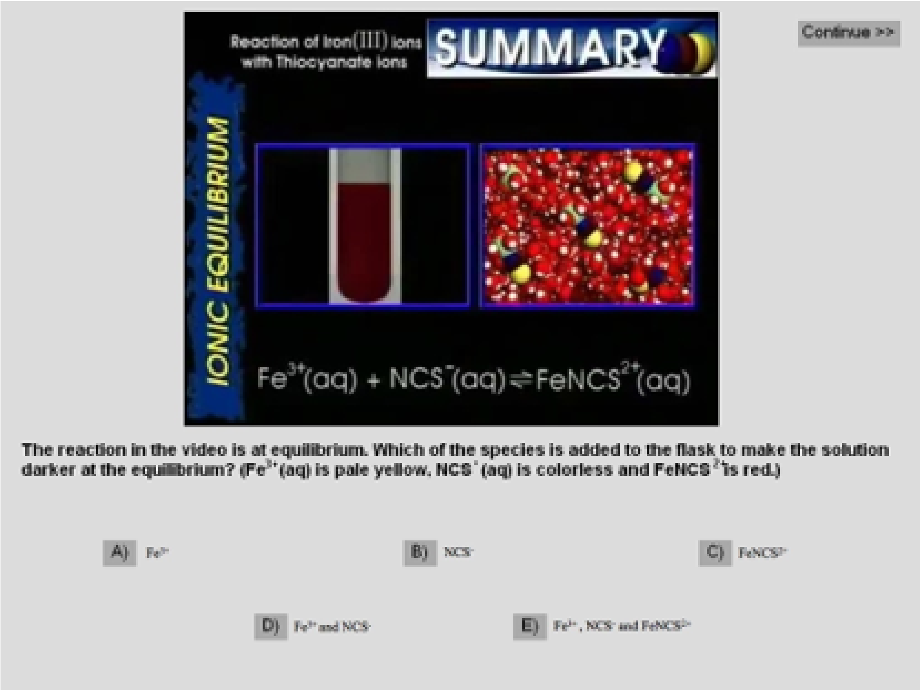


Figure C.5. Chemical Equilibrium Visualization Screen Test 5.

7.



8.

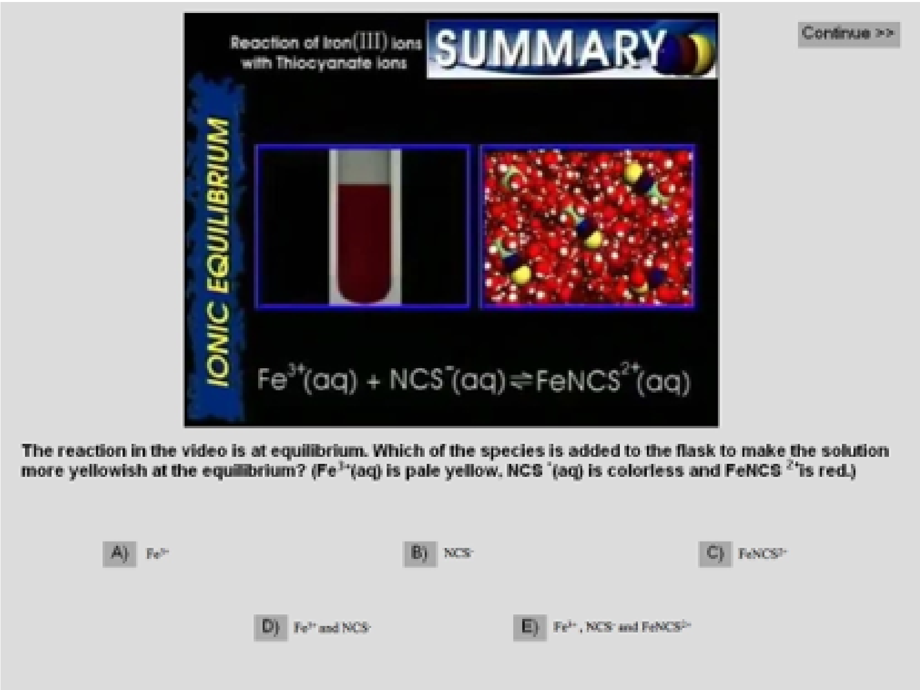
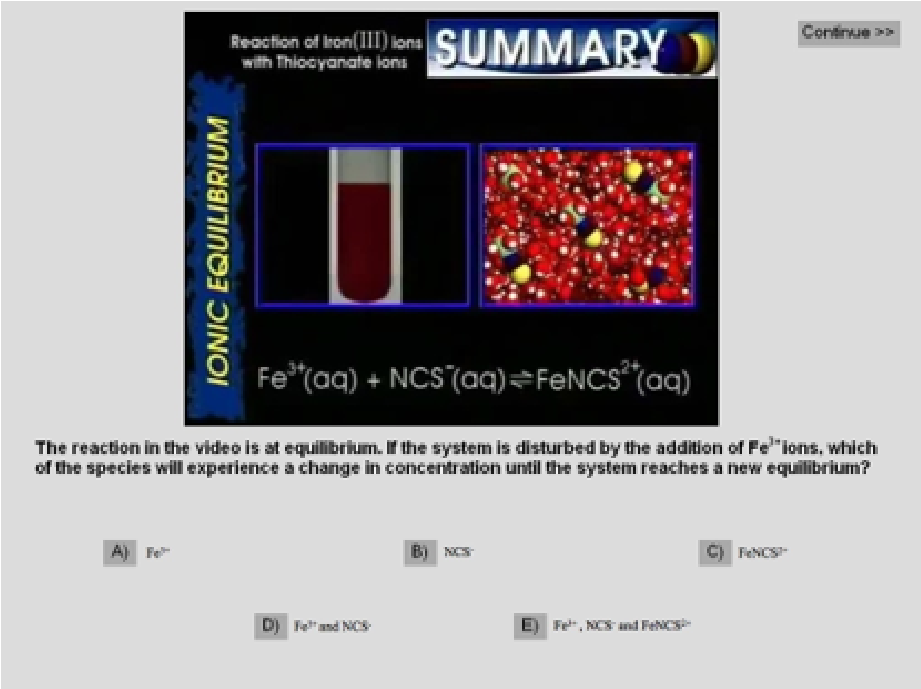


Figure C.6. Chemical Equilibrium Visualization Screen Test 6.

9.



10.

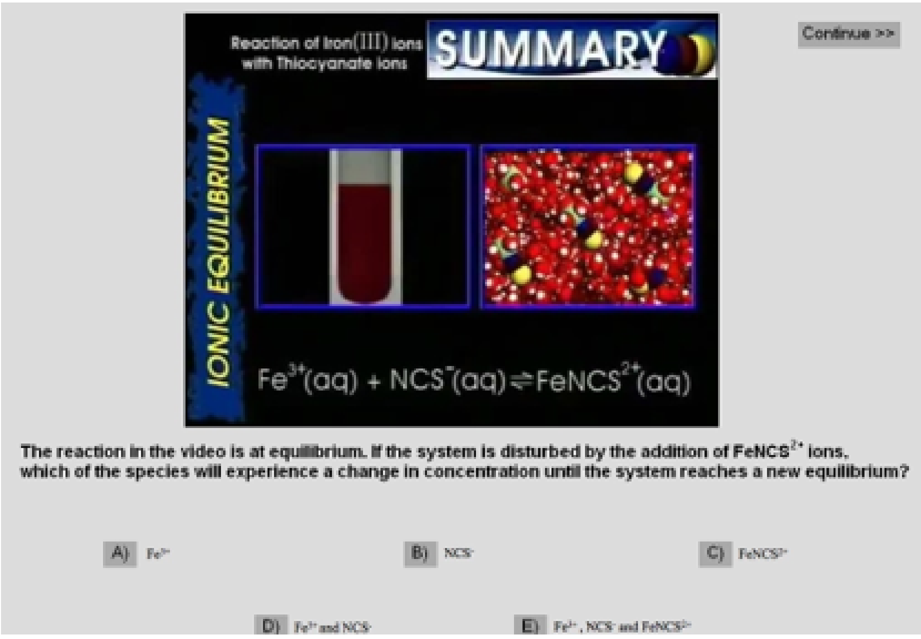


Figure C.7. Chemical Equilibrium Visualization Screen Test 7.