

# Chapter 5

## Investigating the Role of Conceptual Understanding on How Students Watch an Experimental Video Using Eye-Tracking



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### Introduction

Understanding chemistry has been challenging for students because it involves conceptualization of chemical phenomena at macroscopic, symbolic, and submicroscopic levels (Johnstone, 1991; Taber, 2013). Macroscopic level involves observable and tangible phenomena such as observing rusting of an iron nail; symbolic level includes the symbols, graphs, and mathematical formulas, such as writing a balanced chemical reaction; finally, submicroscopic level involves the structure and the processes of particles (atoms, ions, molecules, etc.) such as interaction among zinc atoms and copper ions in a solution. When learning chemistry, students should be able to make connection between these levels so that they could conceptually understand the processes. On the other hand, understanding submicroscopic level can be even more challenging for students because they need to visualize the motion and interaction of the particles that they can never see (Nakhleh, 1992; Smith et al., 2006). Thus, chemistry instructors make use of physical or computer-based models representing particles (National Research Council (NRC), 2012; Williamson, 2008). Considering the dynamic nature of chemical processes where there is ongoing interaction among the species, particulate level computer animations have been found to be helpful to students in improving their conceptual understandings (Ardac & Akaygun, 2004; Kelly & Jones, 2007; Williamson & Abraham, 1995). Because the animations depicting the motion and interaction of particles help students visualize the processes occurring at the submicroscopic level, and thus developmental models for chemical phenomena (Akaygun & Jones, 2013; Kelly, 2014).

Chemical reactions is one of the topics for which animations have been used because it involves understanding of how particles are rearranged during a reaction

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process. If the students do not visualize these processes they may develop alternative conceptions (Ahtee & Varjola, 1998; Ben-Zvi et al., 1987; Yaroch, 1985). For instance, Yaroch (1985) stated that students who successfully balanced chemical equations showed no understanding of the relation between macroscopic and particulate levels. Similarly, Ben-Zvi et al. (1987) reported that students perceived chemical reactions as static phenomena; thus they had difficulties in understanding the dynamic processes, that is to say, how the atoms rearrange as the bonds break and form. Redox reactions have been found to be challenging for students to understand, thus various alternative conceptions including electrochemical and electrolytic cells, and the processes of oxidation and reduction have been identified in the previous studies (Acar & Tarhan, 2007; Brandriet & Bretz, 2014; Garnett & Treagust, 1992).

Eye-tracking technology have been used in chemistry education to investigate students' understanding of chemical phenomenon while they are working on a task because it provides information about the cognitive processes during the activity (Rayner, 1998). It has been asserted that there is a relation between where a person is staring at and what he or she is thinking (Just & Carpenter, 1984). The area where the person focuses on is where he or she pays attention (Hoffman & Subramaniam, 1995). To ensure the validity of their attention in terms of where and how much time they focus on the specific areas, the eye movements have been accompanied with verbal explanations through think-aloud protocols (Stieff et al., 2011).

By the inclusion of eye-tracking technology in chemistry education research, especially during the last decade, students' understanding of chemical structure such as the complexity of organic molecules (Havanki, 2012), nuclear magnetic resonance spectroscopic signals and molecular structure (Tang et al., 2012), molecular modeling (Williamson et al., 2013), stoichiometry (Baluyut & Holme, 2019; Tang et al., 2014); and the processes such as oxidation-reduction and double displacement reactions (VandenPlas, 2008), gas laws problems (Tang & Pienta, 2012), chemical change (Hansen, 2014) have been investigated. Even though the type of representations studied in the eye-tracking research varied from static images (Baluyut & Holme, 2019; Stieff et al., 2011) to dynamic computer visualizations (Hansen, 2014; VandenPlas, 2008), the main question to be answered has always been on how the eye movements can be related with understanding chemistry. Considering individual differences, eye-tracking has been used to explore the patterns observed due to the variations in the level of competency or expertise in chemistry. For instance, some researchers sought to identify the differences between the eye movement patterns of experts and novices when looking at different chemical representations (Havanki, 2012; VandenPlas, 2008). In terms of the academic achievement, few studies reported that less successful students spent more time, or fixated their eyes longer, on solving problems than more successful ones because less successful students tend to seek information from the given question (Tang & Pienta, 2012; Tang et al., 2014). Spatial ability which refers to the ability to generate, visualize, retain, and manipulate abstract visual images (Lohman, 1979) has been found to be related with understanding chemistry (Barke & Engida, 2001; Dori & Barak, 2001; Pribyl & Bodner, 1987). To this end, spatial ability was found to be effective on visual problem-solving when eye

tracking patterns between high and low performers were compared on engineering-related computer games (Gomes et al., 2013). Eye-tracking studies have also helped researchers identify the mostly referred representations. For instance, Stieff et al. (2011) found that students answered the questions that could be answered only with the ball and stick models more accurately rather than the ones that involved the integration of ball and stick model and equations. Williamson et al. (2013) reported that students referred mostly on the more familiar, ball-stick images, rather than the electrostatic potential maps when solving a problem. Students' preference of using familiar or simpler representation might have served as a scaffold in learning from visualizations.

In this study, it was aimed to investigate the role of students' level of conceptual understanding on how they navigate while watching an experimental video of a redox reaction.

## Method

This qualitative study adopted phenomenography (Ebenezer & Erickson, 1996) to understand the preservice teachers' level of conceptual understanding of a redox reaction occurring between zinc metal and copper(II) sulfate solution and how their understandings relate with the pattern of their eye movements while watching the experimental video of this reaction. Phenomenography explores how different individuals experience and comprehend a specific phenomenon (Marton, 1986). Thus, phenomenological perspective allowed researchers to make sense of how preservice teachers conceptualize redox reactions and how their understandings relate with the pattern of watching an experimental video of a redox reaction.

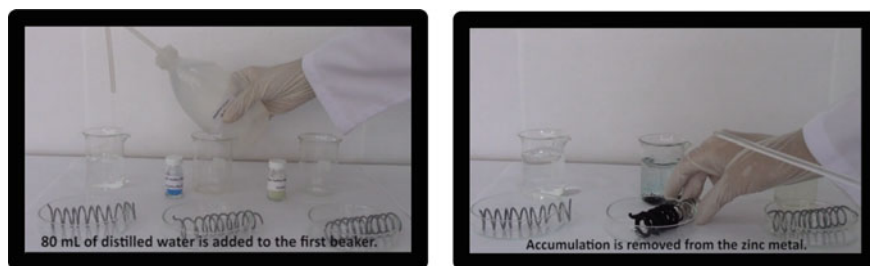
## *Participants*

A total of 20 (12 chemistry and 8 science) preservice teachers (all female) voluntarily participated in the study. They were 3rd- or 4th-year students enrolled in a teaching chemistry/science program of a mid-size university located in a metropolitan city in Turkey. The preservice teachers completed general chemistry and analytical chemistry courses with the laboratory components where the redox reactions are covered. The study was approved by the Institutional Review Board, and all the ethical guidelines were followed throughout the study.

## *Procedure and Data Collection*

In this study, in a 2-hour session, preservice teachers first watched a 4-minute experimental video of a redox reaction occurring between zinc metal and copper(II) sulfate solution. The experimental video was recorded and edited by the researchers at the university's teaching laboratory. The study was conducted in a computer laboratory where the participants worked individually on their own pace and were allowed to watch the video as many times as they wanted. The screenshots of the video and the link to access it were given in Fig. 5.1.

After watching the video, they were asked to write a reflection on determining the experimental evidences of the redox reaction taking place by guiding questions. They were expected to notice all the evidences for a redox reaction to happen, namely, the accumulation of copper metal on the zinc wire, paling color of the copper(II) sulfate solution and almost no change in the conductivity of the solution. After writing this reflection they were asked to represent this reaction at the submicroscopic level by preparing storyboards and generating ChemSense animations to link experimental evidences to the process occurring among the particles. On the storyboards, which are graphical representations that show the sequential flow of a story like a comic book (Lottier, 1986), they were also asked to write explanations to describe their drawing. Next, they were asked to prepare submicroscopic animations by using the software ChemSense, which was developed to prepare stop-motion animations (Schank & Kozma, 2002). One week after this session, they were interviewed to have further information about how they conceptualized the redox reaction. During the interview they were asked to explain the experimental evidences they determined in the video, how they represented the redox reaction at submicroscopic level via storyboarding and animations, and how these submicroscopic representations were connected with the experimental evidence. After the interview, they were invited to watch the experimental video one more time through an eye-tracker (ASL D-6) and think aloud at the same time. The data collection procedure is given in Fig. 5.2.



**Fig. 5.1** Screenshots of the redox reaction video (Akaygun & Adadan, 2019). [https://www.dropbox.com/s/o62epab4k0dkr06/Redoks\\_Video\\_06112017\\_ingilizce.avi?dl=0](https://www.dropbox.com/s/o62epab4k0dkr06/Redoks_Video_06112017_ingilizce.avi?dl=0)

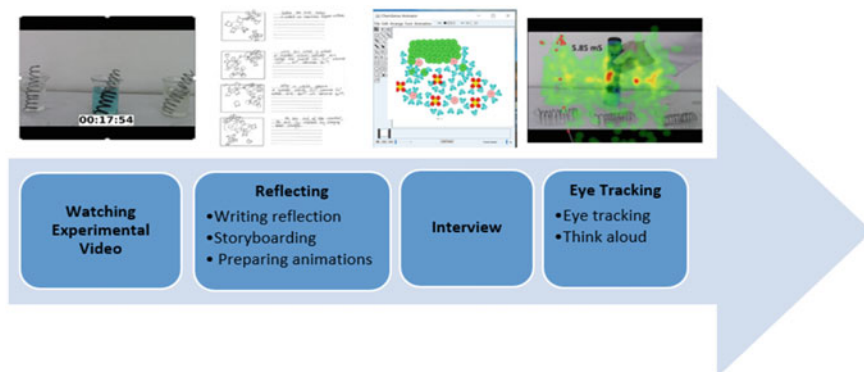


Fig. 5.2 Data collection procedure

## Data Analysis

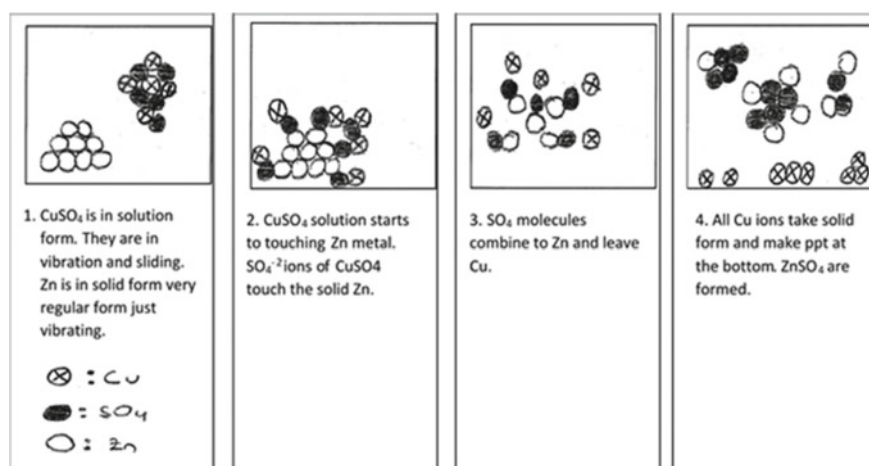
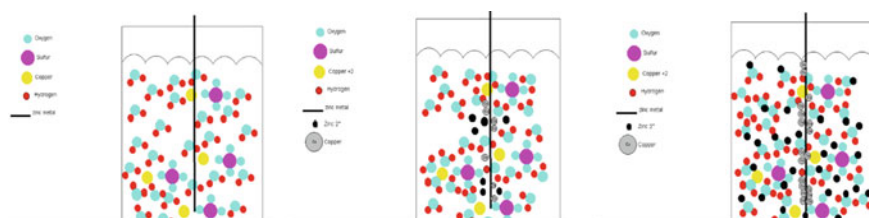
The data analysis was carried out in two parts: by analyzing *level of understandings* and *eye movements*. In the first part, participating preservice teachers' conceptual understandings were identified through their reflections, representations (storyboards and animation), and interviews. The participants' written, oral, and drawn responses were analyzed by utilizing the qualitative content analysis method (Hsieh & Shannon, 2005). During this process, the transcribed reflections and interviews were divided into meaningful units, and each unit was coded, and then the meaningfully similar codes were classified into the particular categories. Similarly, preservice teachers' representations were coded to convey their understandings and compared with the results obtained from the analysis of responses in the reflections and interviews. Thus, based on the preservice teachers' responses in these data resources their level of conceptualizations was determined through a scale ranging from 1 to 4; *alternative understanding*, *weak understanding*, *moderate understanding*, and *scientific understanding*, as reported earlier (Akaygun & Adadan, 2019; Akaygun et al., 2019). Table 5.1 describes the criteria for each level of understanding, and Figs. 5.3 and 5.4 illustrate sample representations for different levels of understanding.

In the second part, the eye-tracking data were analyzed qualitatively and confirmed by the transcribed think aloud protocols. At this stage, after the gaze plots embedded on the video were formed, the video was segmented with respect to the information displayed. The incidences displayed in the video segments follow:

1. Introductory text
2. Preparation for the experiment
3. Showing the chemicals
4. Preparing the solutions
5. Initial conductivity measurements
6. Immersion of zinc wire into the beakers
7. Course of reaction (speeded up)

**Table 5.1** Criteria for the levels of understanding of redox reactions

Level of Understanding (LU)	Criteria
Scientific understanding	Including all particulate entities (electrons, ions, atoms, and molecules) and properly showing all the changes in entities along the reaction process
Moderate understanding	Not including all particulate entities, and showing some changes in entities along the reaction process, but not all of them
Weak understanding	Not including all particulate entities, and not showing changes in entities along the reaction process <ul style="list-style-type: none"> <li>• not referring to electron transfer between zinc atoms and copper ions as part of the reaction process but not showing any alternative understanding</li> </ul>
Alternative understanding	In addition to weak understanding criteria, the representations included one or more of the following alternative conceptions: <ul style="list-style-type: none"> <li>• showing copper(II) sulfate in water as molecules not as ions</li> <li>• showing zinc sulfate as molecular precipitate</li> </ul>

**Fig. 5.3** Storyboard of a preservice teacher having an alternative understanding of redox reactions (Akaygun et al., 2019)**Fig. 5.4** Animation frames of a preservice teacher having scientific understanding of redox reactions

8. Removing of zinc wire from the beakers
9. Final conductivity measurements
10. Removal of accumulated copper metal from the zinc wire.

The experimental evidences were shown in the segments of 3, 5, and 7, therefore, it is important to pay attention to the conductivity measurements and the beaker containing  $\text{CuSO}_4$  solution with the zinc wire.

## Results

In Fig. 5.3, the storyboard of a preservice teacher with alternative understanding is given. This participant showed both zinc and copper(II) sulfate as a solid, did not indicate the charges of copper and sulfate ions, represented zinc sulfate in the molecular form and precipitated copper atoms.

In Fig. 5.4, the scenes from the animation prepared by a preservice teacher with scientific understanding is given. This participant showed both zinc, copper, and sulfate ions in the solution as well as water. After the zinc wire is immersed into the beaker, the preservice teacher represented the transfer of  $\text{Zn}^{2+}$  ions into the solution and deposition of Cu atoms on the wire. She did not represent the electron transfer occurring between the species but described it during the interview, so her level of understanding was identified as *scientific*.

Based on the qualitative analysis of the eye tracking data accompanied with the think aloud protocols, the characteristic features with respect to each level of understandings were outlined. Table 5.2 shows the eye movement patterns of preservice teachers with different levels of understanding of redox reactions.

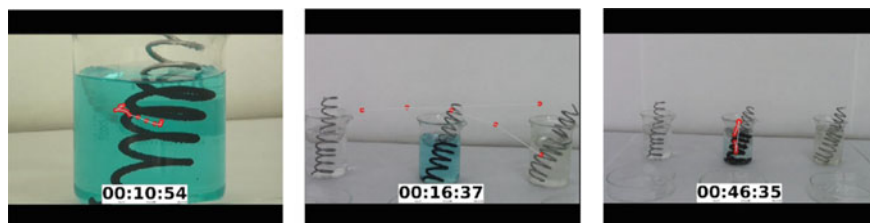
The results of the analysis showed that the preservice teacher having a *scientific understanding* first just briefly gazed at all the materials and then focused only on the experimental evidences which is shown in the second beaker where redox reaction takes places, and the conductivity measurements. Then she looked through all the three beakers for comparison. This preservice teacher did not look at the background details such as laboratory instructor. Some of the scenes from the gaze plot of this preservice teacher are given in Fig. 5.5.

The preservice teacher with a moderate understanding of redox reactions briefly gazed through materials and mostly focused on the experimental evidences, to the beaker where the reaction takes place. She neither looked at the beakers at both sides nor the other details. Some of the scenes from the gaze plot of this preservice teacher are given in Fig. 5.6.

In general, preservice teachers with a weak understanding of redox reactions less focused on the experimental evidences and occasionally looked at the beakers. For instance, at the 34th minute, toward the end of the video, one of the preservice teachers did not look at solution or the wire inside the solution, but the metal outside the beaker as seen in Fig. 5.7. Some of the scenes from the gaze plot of this preservice teacher are given in Fig. 5.7.

**Table 5.2** The eye movement patterns of preservice teachers with different levels of understanding of redox reactions

Level of understanding	N	Features of the eye movement patterns
Scientific	1	<ul style="list-style-type: none"> <li>• Focusing <b>only</b> on the experimental evidences               <ul style="list-style-type: none"> <li>– metal deposition</li> <li>– paling solution</li> <li>– conductivity measures</li> </ul> </li> <li>• Very briefly gazing through the other beakers</li> <li>• <b>Not looking</b> at any other details</li> </ul>
Moderate	1	<ul style="list-style-type: none"> <li>• Focusing <b>mostly</b> on the experimental evidences               <ul style="list-style-type: none"> <li>– metal deposition</li> <li>– paling solution</li> <li>– conductivity measures <b>briefly</b></li> </ul> </li> <li>• <b>Not looking</b> at any other details</li> </ul>
Weak	5	<ul style="list-style-type: none"> <li>• Focusing <b>less</b> on the experimental evidences               <ul style="list-style-type: none"> <li>– metal deposition</li> <li>– conductivity measures <b>very briefly</b></li> </ul> </li> <li>• <b>Occasionally looking</b> through the other beakers</li> </ul>
Alternative	13	<ul style="list-style-type: none"> <li>• Focusing <b>less</b> on the experimental evidences               <ul style="list-style-type: none"> <li>– metal deposition</li> <li>– conductivity measures <b>very briefly</b></li> </ul> </li> <li>• <b>Frequently looking</b> through the other beakers</li> </ul>

**Fig. 5.5** Gaze plot of a preservice teacher having a scientific understanding of redox reactions**Fig. 5.6** Gaze plot of a preservice teacher having a moderate understanding of redox reactions



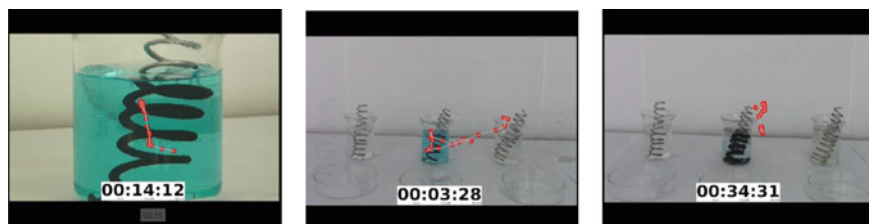


Fig. 5.7 Gaze plot of a preservice teacher having a weak understanding of redox reactions

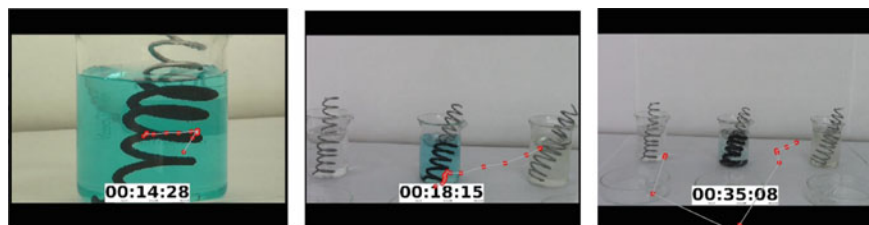


Fig. 5.8 Gaze plot of a preservice teacher having an alternative understanding of redox reactions

Generally, preservice teachers with a weak understanding of redox reactions less focused on the experimental evidences and frequently looked at the beakers nearby. For instance, at the 35th minute of the reaction, toward the end of the video, one of the preservice teachers mostly looked at all three beakers, not much at solution or the wire inside as seen in Fig. 5.8. Some of the scenes from the gaze plot of this preservice teacher are given in Fig. 5.8.

The analysis of eye-tracking data was confirmed with the analysis of think aloud protocols revealed the features preservice teachers demonstrated while watching an experimental video as shown in Table 5.2.

It was observed that the differences in their eye movement patterns can be grouped into three main categories: *looking where they need to look*, *staying focused*, and *ignoring the details*. First of all, it was observed that preservice teachers who had scientific or moderate understanding mostly focused on the experimental evidences, not the other beakers or parts. On the other hand, preservice teachers who had weak or alternative understanding, did not focus on the experimental evidences which were mostly observed in the beaker in the middle, instead they looked through the other beakers. So, a difference was observed in terms of looking where the experimental evidences were mostly observed. Secondly, preservice teachers with scientific or moderate understanding, stay focused and keep looking at the experimental evidences whereas preservice teachers with weak or alternative understanding, changed their focus occasionally or even some did frequently. Thirdly, preservice teachers with scientific or moderate understanding ignored the details given in the video, however, preservice teachers with weak or alternative understanding, also looked at these

details such as the piece of metal outside the solution. Thus, it seemed that preservice teachers' levels of understanding of redox reactions had an effect on the patterns of their eye movements.

## Discussion and Conclusion

Understanding chemical reactions, including redox reactions, has been challenging for students (Acar & Tarhan, 2007; Brandriet & Bretz, 2014) due to the difficulty of making connection between macroscopic and submicroscopic levels (Ahtee & Varjola, 1998; Ben-Zvi et al., 1987).

Eye-tracking technology has been used in chemistry education to better evaluate students' conceptualizations of chemical phenomenon while they are working on a particular task because it informs educators about students' cognitive processes during the activity (Rayner, 1998). In this study, eye-tracking technology was used to explore the role of students' level of understandings of redox reactions on how they navigate while watching an experimental video of a redox reaction. Specifically, the patterns they followed and the aspects they mostly focused were determined and compared across different levels of understandings.

The results of the study revealed that, based on the levels of understanding of redox reactions, preservice teachers exhibited different patterns of eye movements and focuses while watching an experimental video. These differences between the levels of understandings suggested three main categories: *looking where they need to look*, *staying focused*, and *ignoring the details*. First, preservice teachers who had scientific or moderate understanding mostly focused on the experimental evidences, not the other beakers or parts. On the other hand, preservice teachers who had weak or alternative understanding, did not focus much on the experimental evidences which were mostly observed in the beaker in the middle, instead they looked through the other beakers. So, it can be suggested that preservice teachers with higher levels of understanding could better make connections between macroscopic and submicroscopic levels as they paid more attention to the experimental evidences. Secondly, these preservice teachers also stayed focused throughout the video and kept looking at the experimental evidences whereas preservice teachers with weak or alternative understanding, changed their focus occasionally or even some did frequently. This might have happened due to being mentally engaged on what is happening in the reaction vessel. Finally, preservice teachers with scientific or moderate understanding ignored the details given in the video, whereas the ones with weak or alternative understanding, also looked at these details such as the piece of metal outside the solution. This might have been observed due to the lack of understanding what is happening and trying to look for evidence at other parts.

In conclusion, in this study, it can be suggested that the preservice teachers' levels of understanding of redox reactions played a role on the patterns of their eye movements as they looked at where they needed to look, stayed focused, and ignored the details, as they were more mentally engaged. In other words, as the

level of understanding approach to an expert-like understanding, the eye movements conveyed this understanding as also captured in this study by eye-tracking. It was also reported in the previous studies that there existed differences between the eye movements of experts and novices (Havanki, 2012; VandenPlas, 2008).

It was also observed that when the second beaker where the redox reaction takes place zoomed in all the preservice teachers looked at the experimental evidence, the copper metal depositing on zinc wire. So, the action of zooming helped them better recognize the experimental evidences. When it was zoomed out, preservice teachers with a low level of understanding also looked at the other parts and lost their focus. It can be said that they needed more scaffolding such as zooming to catch important aspects.

In this study, the majors of the preservice teachers, as studying chemistry or science, were not considered because the level of understanding was the main cause of conveying differences in the eye movement patterns, that was also revealed by the findings. Even though they were majoring at different subject areas, they had taken similar chemistry classes and developed similar understandings independent of their major. Therefore, in this study they were all grouped and called as preservice teachers.

As an implication for teaching, experimental videos can be used in teaching chemistry in- or out-of-classroom setting as they help students make connection between macroscopic and submicroscopic phenomena. Yet, when the experimental videos are used in chemistry classes, teachers may help students direct their attentions to experimental evidences or important aspects, such that in this study, it was the beaker where the redox reaction took place. As an implication for research, visual tools can be used to scaffold students' attention to the main aspects and stay focused. For instance, zooming, labels, or other cues can be included in the video.

As a limitation, this study utilized qualitative analysis that might have missed some of the minor changes in the eye movements. Repeating the study with quantitative methods may provide further evidence about students' eye movement as they view experimental video recording.

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