

***Using Eye Tracking Systems to Assess the Impact of a Hybrid Problem-based Distance-learning Environment on Chemistry Students' Problem-solving Skills***

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**Abstract**

Blended learning is used as a teaching strategy to improve students' chemistry performance. It reverses the traditional learning environment delivering instructional content, often online, outside of the classroom. How blended learning improves performance has not yet been examined using objective measurements. Eye-tracking is a useful tool to objectively study and measure learners' visual attention. This study measured chemistry students' visual attention while solving word problems in an online environment before and after participating in a blended learning environment, effectively answering the research question: *What is the impact of blended instruction on students' chemistry problem-solving skills?* Data were collected from nine students in a General Chemistry course where two conditions were measured: time and group type. Mixed ANOVA using SPSS analysis was conducted. Results show that on average, students spent slightly longer fixated on the periodic table (targeted as the area of interest) during the post-test ( $M = 19.81$ ,  $S.D. = 17.96$ ) than in the pre-test ( $M = 9.34$ ,  $S.D. = 10.63$ ). There was a significant interaction between time and condition. The experimental group (blended learning) spent longer looking at the periodic table online during the post-test ( $M = 28.26$ ,  $S.D. = 21.88$ ) than during the pre-test ( $M = 0.02$ ,  $S.D. = 0.00$ ). Performance on the nomenclature test revealed that the experimental group scored higher on the post-test than the control group (traditional lecture), reflecting fixation behaviors recorded on the eye-tracking system. These research findings have implications for chemistry education and software development to improve chemistry education.

Keywords: (eye-tracking, distance learning, online learning, historically black colleges and universities, HBCU, chemistry education, chemistry problem solving)

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## Introduction

Blended learning is a teaching strategy suggested to improve students' performance in chemistry. Currently, chemistry educators use pedagogical strategies like blended classrooms to increase students' engagement and focus. The working hypothesis is that with increased engagement comes increased interest and focus. Subsequently, students' concept understanding increases and ultimately, their performance on exams with multiple-choice word problems improves.

How do we increase engagement? Well, our eyes don't lie. Which is why researchers are using eye-tracking technology during distant online learning. By evaluating students' focus and attention, particularly while solving nomenclature word problems, we can help them maximize their time and perform better during exams. How? Eye-tracking is a tool used to study visual attention in a variety of science, biology, chemistry and mathematics educational settings. Objective measurements of eye movements provide vital insight into the cognitive strategy students use while solving chemistry word problems.

Why is knowing where students focus their attention during online learning so important? Throughout undergraduate chemistry courses, students are required to take timed exams to assess their knowledge of chemistry concepts. Knowing where to focus their attention can be the difference between a pass or fail. To elaborate, if students are inexperienced at focusing on the right part of a problem their eyes may wander and cost them valuable seconds. Furthermore, focusing on the wrong area of a problem hinders students from detecting embedded clues that aid in problem solving.

Consequently, the likeliness that they will complete exams or perform well is low. Furthermore, eye wandering may be an indication of word problem difficulty, conceptual difficulty or deficiency. With Eye-Tracking technology, we can better equip our students with the strategies necessary to efficiently solve chemistry problems in online learning settings.

## Statement of the Problem

Chemistry educators have attempted to increase students' engagement and focus in chemistry for years. However, researchers have not discussed the aspects within blended learning classrooms that increase students' focus. The discourse is often about using these pedagogical strategies to improve students' performance in chemistry classrooms. Therefore, the question not yet examined with objective measurement resources is, *how do blend instructional strategies to improve chemistry performance?* It is not common for educational researchers to use eye-tracking glasses. However, this tool objectively measures students' real-time cognitive engagement, specifically focused attention, second to second, while completing chemistry word problems in an online environment. Unobtrusive measures of students' engagement and attentional focus in online environments has not been thoroughly explored as a method to improve online learning and engagement, even though universities spend billions of dollars for online or e-learning experiences. Few universities use objective eye-tracking data to improve online learning management systems, learners' online experiences, and engagement with difficult to grasp subject matter or concepts.

## Literature

Eye tracking is a window into the science and mathematics learner's cognitive processes. While it has gained popularity in the last decade, eye tracking is gaining traction as a useful tool to study visual attention in a variety of science and mathematics learning settings; mathematics (Chesney, McNeil, Brockmole & Kelley, 2013; Merkley & Ansari, 2010; Moeller, Klein, Nuerk & Willmes, 2011); and biology (Cook, Wiebe & Carter, 2008). In chemistry, several researchers have conducted studies to measure chemistry learners' cognitive processes while solving complex chemistry word problems (Tang & Pienta, 2012; Williamson, Hegarty, Deslongchamps, Williamson & Shultz, 2013). Eye tracking is also used for exploring problem solving (Liu & Shen, 2011) and problem difficulty (Tang & Pienta, 2012). Other studies discovered that perceptual properties can guide attention and eye movements in ways that assist in developing the problem-solving insights which lead to improved reasoning (Grant & Spivey, 2003; Thomas & Lleras, 2007).

Objective measurement of eye movements gives new insights into students' strategies used for solving multiple-choice science problems, showing that visual attention plays an important role in successful problem solving (Tai, Loehr & Brigham, 2006; Tsai, Hou, Lai, Liu & Yang, 2012). By understanding how different aspects of the knowledge process shape educational outcomes, researchers can effectively design, evaluate, and improve teaching and learning specifically in gatekeeping science and mathematics courses like general chemistry. Furthermore, eye tracking helps educational researchers interested in cognitive development and learning discover a) differences in information gathering; b) differences in problem-solving skills; c) differences in learning strategies and d) how different educational materials work. In this study, researchers use the eye-tracking system to discover students' chemistry word problem-solving processes in an online learning environment.

Eye movements are indices of cognition; eye-tracking data typically include the location, duration, and sequence of subjects' fixations on visual representations. Eye-tracking data serve as a proxy for learning attention, cognitive load and cognitive processing. Eye-tracking data has been beneficial in understanding the development of chemistry students' cognitive processing or problem difficulty. To better understand underlying cognitive processes, researchers can observe how students' focus their attention while completing online chemistry word problems in real time with eye-tracking glasses. The Tobii Pro eye-tracking system allows researchers to better understand students' behavioral responses to instructional assignments in an online environment. Researchers typically analyze eye movements in terms of fixations (pauses over informative regions of interest) and saccades (rapid movements between fixations).

Eye movements are typically the result of cognitive activities. Specifically, the duration of eye fixation indicates the cognitive complexity of the material visually considered. The total number of fixations in an area of interest (AOI) can be considered an indicator of how important the information in that region is and how efficiently it is transferred to long-term memory. Fixation duration and total number of fixations in certain areas of interest, reveals strategies of processing information or solving problems including the final organization of information in long-term memory.

## **Research Methodology**

This study was designed to answer the following research question: *What is the impact of blended instruction on students' chemistry problem-solving skills?* Students responded to chemistry nomenclature word problems. Researchers used eye-tracking hardware and software to observe students' cognitive processes when solving chemistry nomenclature word problems in an online environment.

## **Research Participants**

Nine students enrolled in a general chemistry course at an open access historically black college and university (HBCU) participated in this study. Students were divided into two groups. They were randomly assigned to two treatment groups—experimental (blended learning class) and control (traditional lecture-based course). There were four students in the experimental group and five students in the control group.

All students, prior to the teaching of chemistry nomenclature, were asked to respond to a nomenclature pre-test. At the end of the unit, students were asked to respond to the same questions. All students responded to test questions while wearing eye-tracking glasses.

## **Data Analysis**

A Tobii T120 eye tracker was used to collect eye movement data while students completed online word problems. The eye-tracking variables analyzed were fixation duration and total time spent in specific areas of interest. Fixation count and duration are important metrics for revealing the cognitive load and attention of users and the perceived importance of interface elements. Total fixation duration reports the total time spent in an appropriate area of interest. A fixation occurs when the fovea centralis (located in the retina) is stable on an object and was defined as an eye movement with less than 30 degrees/second of movement.

The area of interest (AOI) analyzed in this study included the entire periodic table. This AOI was hypothesized as important for understanding students' visual interaction and learning behavior patterns during the problem-solving task.

Pre- and post-test eye-tracking data were analyzed for statistical significance. SPSS was used to analyze data. A time (pre vs. post)-by-condition (experiment vs. control) mixed measures ANOVA was conducted on students' average fixation duration. Data were analyzed to determine whether there was a difference in the average fixation duration between the pre-test and post-test; a difference in average fixation duration between experiment and control condition and difference in average fixation duration were different for those in experiment condition and those in control condition. Descriptive and inferential statistical data of each student's response to the pre-and post-test (matched paired analysis) are reported. Tobii Pro lab software was used to analyze students' eye-movement. Data visuals in the form of heat maps and gaze plots were generated.

## Results

Students in the experimental group scored higher on the post-test than those in the control group. Table 1 below shows the average scores, based on the percent of correct responses for students in each condition. Students in the experimental condition scored higher on the nomenclature post-test ( $M=72.2$ ) than on the pre-test ( $M=43.3$ ). Students in the control condition scored higher on the post-test ( $M=33.0$ ) than on the pre-test ( $22.2$ ). The post-test scores for students in the experimental group were higher than the post-test scores for students in the control group. There was a 39.2 percent difference in the mean score between the experimental and control group on the post-test.

Table 1: Average test scores (percent correct) by Condition and Time

Condition	Pre-test		Post-test	
	<i>M</i>	<i>N</i>	<i>M</i>	<i>N</i>
Experimental	43.3	4	72.2	4
Control	22.3	5	33.0	5

Table 2 shows that there was a significant interaction between time and condition on the time, in seconds, students spent looking at the periodic table,  $F(1,7)=7.97$ ,  $p=0.03$ . Students in the experimental condition spent longer looking at the periodic table in the post-test ( $M=28.26$ ,  $S.D. = 21.88$ ) than in the pre-test ( $M=0.02$ ,  $S.D. = 0.00$ ), but students in the control condition spent the same amount of time looking at the periodic table in the post-test ( $M = 13.04$ ,  $S.D. = 12.55$ ) and the pre-test ( $M=16.80$ ,  $S.D. = 8.35$ ).

Table 2: Fixation duration on periodic table (in seconds) by Condition and Time

Condition	Pre-test			Post-test		
	<i>M</i>	<i>S.D.</i>	<i>N</i>	<i>M</i>	<i>S.D.</i>	<i>N</i>
Experiment	0.02	0.00	4	28.26	21.88	4
Control	16.80	8.35	5	13.04	12.55	5

Figure 1 is a graph showing the fixation duration, in seconds, on the periodic table by condition and time.

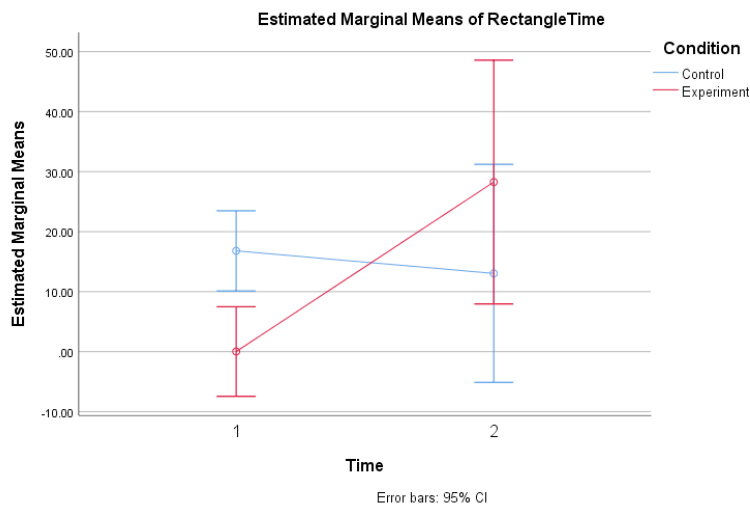


Figure 1: Fixation duration on periodic table by condition and time

Figure 2 shows the heat maps showing the students visual attention to the periodic table during the posttest. In naming ionic compounds, students should use the periodic table to see if an element is a metal, transition metal or non-metal. Students should use the periodic table to determine whether an element as a metal, transition metal or non-metal. Next, they use the element determination to determine the charge on the element based on the location of the element on the periodic table.

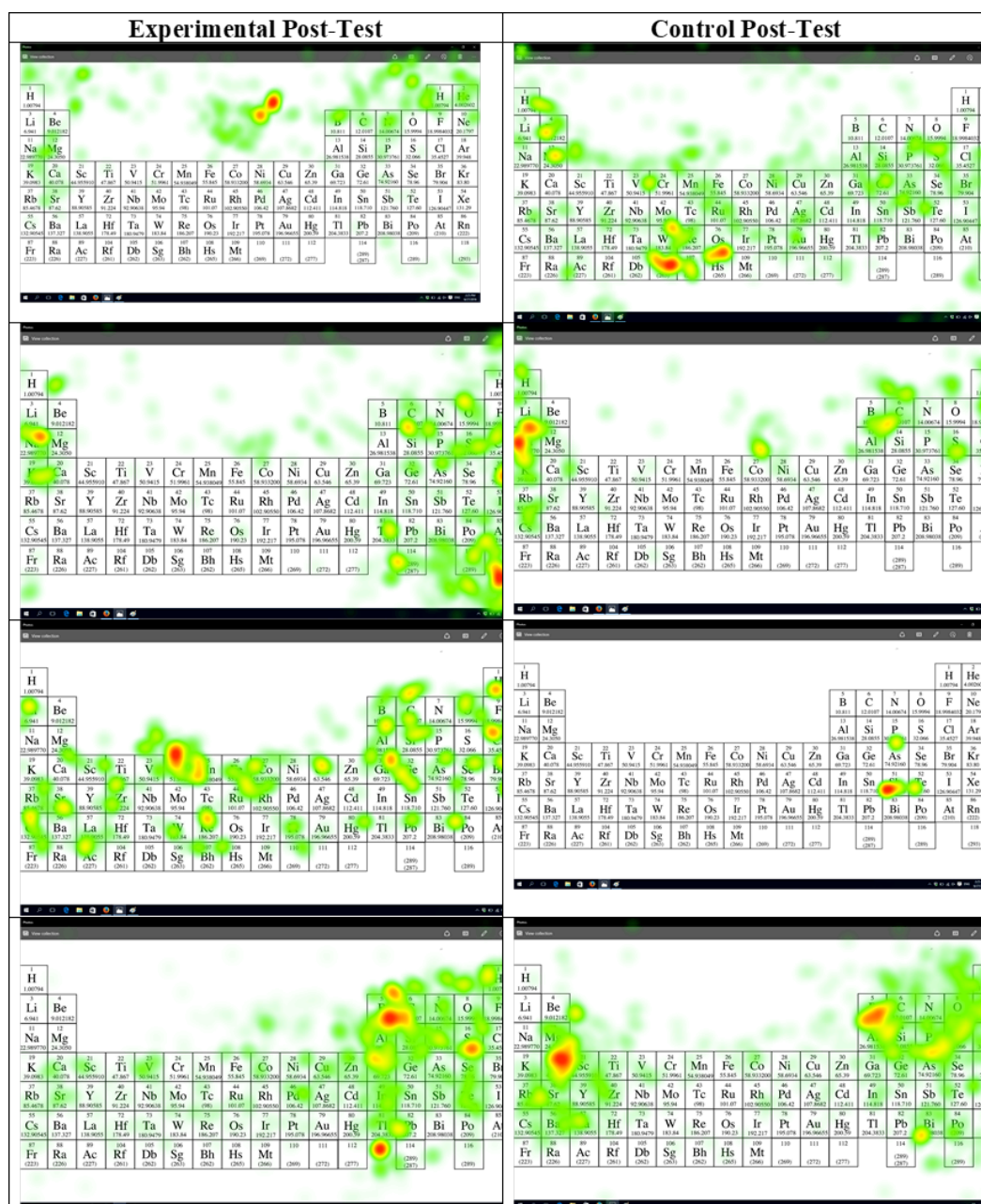


Figure 2: Heat maps on posttest by condition

## Conclusion

Data from this research study suggest that students in the experimental group spent more time looking at the periodic table during the post-test than students in the control group. Students in the experimental group received instruction that included small peer led groups where students more familiar with nomenclature concepts

provided instructional support to students who were struggling. Additionally, in the blended learning environment, the instructor moved around the classroom working with small groups and providing feedback on concepts.

Conversely, students in the control group were taught using a traditional lecture based instructional approach. The professor primarily stood in front of the class and lectured. The instructor wrote formulas on the board to demonstrate how to solve nomenclature word problems.

Findings reveal objective measures of students' attentional focus in an online environment and on test performance based on certain instructional conditions. This research revealed that students in the blended learning environment were more focused and engaged and demonstrated an ability to use what was learned to solve chemistry word problems. Students in the blended learning environment scored better on the post quiz and spent more time during the post-test looking at the periodic table.

These findings have implications. This study demonstrates with objective data that increases in learning occurs in the ability to help students increase their focus in specific areas of interest. An analysis of eye-tracking data revealed that on average, students in the control group did not focus on the periodic table to solve nomenclature word problems. An analysis of fixation duration confirmed students' cognitive behavior recorded with the eye-tracking system. Their post-test scores were reflective of their fixation behavior.

These findings inform chemistry faculty on the importance of introducing instructional strategies that increase students' engagement, thus increasing their ability to focus on important instructional resources necessary to answer chemistry word problems.

Future analysis includes an assessment of students' focus in targeted areas of interest (AOIs) to include three sections of the periodic table; metals, transition metals and non-metals. These AOIs are hypothesized as important for understanding students' visual interaction and learning behavior patterns during the problem-solving task. As such, if we can increase students' focus immediately in the appropriate area of interest while learning chemistry nomenclature, we can increase their performance on chemistry nomenclature word problems. It is likely that this type of small incremental focus is applicable to helping students perform better on more difficult and challenging chemistry concepts like rates of reactions, stoichiometry, and oxidation reduction concepts to name a few.

There are several inferences from this study. Data from this study could be used in designing online courses that are adaptive to students' learning, specifically related to cognitive focusing and problem solving. This research provides high school and university chemistry faculty with an understanding of how blended learning environments increase students' cognitive focus while learning to name chemicals. This increased focus improves performance on chemistry assessments.

In the future, researchers anticipate using data from this study and others to enhance and scaffold students' online or distance learning experiences to improve their critical

thinking and chemistry word problem solving skills through embedded online auditory strategies that increase students' focus in appropriate areas of interest.

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