

Kennesaw State University  
**DigitalCommons@Kennesaw State University**

---

Master of Science in Chemical Sciences Theses

Department of Chemistry and Biochemistry

---

Summer 7-11-2019

# USE OF POPE ENGAGEMENT INDEX TO MEASURE COGNITIVE LOAD OF PHYSICAL MODELING ACTIVITIES IN ORGANIC CHEMISTRY

Jenifer Calvert

Follow this and additional works at: [https://digitalcommons.kennesaw.edu/mscs\\_etd](https://digitalcommons.kennesaw.edu/mscs_etd)



Part of the [Chemistry Commons](#), and the [Science and Mathematics Education Commons](#)

---

## Recommended Citation

Calvert, Jenifer, "USE OF POPE ENGAGEMENT INDEX TO MEASURE COGNITIVE LOAD OF PHYSICAL MODELING ACTIVITIES IN ORGANIC CHEMISTRY" (2019). *Master of Science in Chemical Sciences Theses*. 25.  
[https://digitalcommons.kennesaw.edu/mscs\\_etd/25](https://digitalcommons.kennesaw.edu/mscs_etd/25)

This Thesis is brought to you for free and open access by the Department of Chemistry and Biochemistry at DigitalCommons@Kennesaw State University. It has been accepted for inclusion in Master of Science in Chemical Sciences Theses by an authorized administrator of DigitalCommons@Kennesaw State University. For more information, please contact [digitalcommons@kennesaw.edu](mailto:digitalcommons@kennesaw.edu).

## ABSTRACT

### USE OF POPE ENGAGEMENT INDEX TO MEASURE COGNITIVE LOAD OF PHYSICAL MODELING ACTIVITIES IN ORGANIC CHEMISTRY

By Jenifer L. Calvert

Understanding how students learn and process information is critical to developing physical modeling activities that facilitate student learning by decreasing cognitive load in the working memory. Optimizing cognitive load during physical modeling activities in organic chemistry is the key to effective and efficient learning. Using EEG (electroencephalogram) and eye tracking technologies, researchers measured and recorded the cognitive processing of participants while they completed a chiral physical modeling activity. Analysis of the data using the Engagement Index developed by Pope *et al* provided information necessary to develop curriculum that does not undermine student learning due to excessive cognitive load.

USE OF POPE ENGAGEMENT INDEX TO MEASURE COGNITIVE LOAD  
OF PHYSICAL MODELING ACTIVITIES IN ORGANIC CHEMISTRY

A Thesis

Submitted to the  
Faculty of Kennesaw State University  
in partial fulfillment of  
the requirement for the degree of  
Master of Science in Chemical Sciences  
Department of Chemistry and Biochemistry

by

Jenifer L. Calvert  
Kennesaw State University  
Kennesaw, GA

2019

Principal Investigator: Kimberly Linenberger Cortes

Committee: Adriane B. Randolph and  
Thomas Leeper

## Table of Contents

Table of Contents.....	iii
List of Tables.....	v
List of Figures.....	vi
Dedication.....	viii
Acknowledgements.....	ix
Chapter One: Introduction.....	1
Purpose of the Study and Research Questions.....	2
Chapter Two: Literature Review.....	4
The Brain: Center of Learning.....	4
Constructivism.....	5
Information Processing Model.....	6
The Working Memory.....	7
Cognitive Load Theory.....	9
Measurement of Cognitive Load.....	10
Physical Modeling and Spatial Ability in Chemistry Education.....	12
Chirality.....	14
Conclusion.....	15
Chapter Three: Methodology.....	17
Research Questions.....	17
Mixed Methods Approach.....	17
Context of the Study.....	18
The Activity.....	18
Participant Selection.....	19
Participants.....	20
Simulated Learning Environment.....	20
Data Analysis.....	22
Electroencephalogram Data.....	23

Eye Tracking Data.....	24
Safety and Ethical Concerns.....	24
Conclusion.....	24
Chapter 4: Results.....	26
Question: How do the tasks associated with the activity impact organic chemistry students' cognitive engagement and performance?.....	26
Activity Question 1.....	26
Activity Question 2.....	31
Activity Question 3.....	34
Spatial Ability Test Scores and Gender.....	37
Question: How do students' spatial abilities impact their task performance and cognitive engagement while completing the organic chemistry modeling activity?.....	39
Chapter 5: Conclusions, Implications and Future Work.....	43
Discussion.....	43
Limitations of Study.....	44
Implications for Educators.....	45
Implications for Future Research.....	46
Next Steps for this Study.....	46
References.....	48
Appendix A.....	52
Appendix B.....	54
Appendix C.....	56
Appendix D.....	60
Appendix E.....	61
Appendix F.....	62
Appendix G.....	66
Appendix H.....	70

### **List of Tables**

Table 1	The Lobes of the Brain, Location and Function.....	5
Table 2	Spatial ability test scores for females and males fall 2017.....	38
Table 3	Spatial ability test scores for females and males spring 2019.....	38
Table 4	Spearman’s Rho correlations between EI and spatial ability test.....	41

## List of Figures

Figure 1	Depiction of the brain and location of the four lobes.....	4
Figure 2	Information Processing Model.....	7
Figure 3	Molecular models displaying R and S configuration.....	14
Figure 4	An example of an item on the PVRot.....	20
Figure 5	An example of an item on the HFT.....	21
Figure 6	Electrode layout used in the study.....	22
Figure 7	Engagement Index (EI) for participants from fall 2017 and molecules associated with each question.....	27
Figure 8	Engagement Index (EI) for participants from spring 2019 and molecules associated with each question.....	28
Figure 9	Number of average fixations of all participants for each molecule for fall 2017.....	29
Figure 10	Number of average fixations of all participants for each molecule for spring 2019.....	30
Figure 11	Fall 2017 and Spring 2019 performance data compared to engagement indices.....	31
Figure 12	Negative Log of Engagement Index (EI) for fall 2017 and spring 2019 participants for activity question 2.....	32
Figure 13	Question 2b from the Spring 2019 physical modeling activity.....	32
Figure 14	Negative Log of Engagement Index (EI) for spring 2019 participants for activity question 2a and 2b.....	33
Figure 15	Preconstructed models for question 3 of chiral modeling activity.....	34
Figure 16	Engagement Index (EI) for fall 2017 participants for activity question 3.....	35
Figure 17	Engagement Index (EI) for spring 2019 participants for activity question 3.....	35
Figure 18	Number of Fixations for activity question 3 for fall 2017 and spring 2019.....	36

Figure 19	The number of fixations for activity 1 question compared to HFT scores.....	40
Figure 20	The number of fixations for each activity 1 question compared to PVRot.....	40



## **Dedication**

This thesis is dedicated to my genetics:

Kathryn, Karissa and Konnor

Their love, support and patience have meant more to me than

I will ever be able to express in words. I love all of you, forever.

And to

Troy

For believing in me even when I did not believe in myself.

## **Acknowledgements**

Two years ago, I changed the course of my life. I knew that starting my masters at Kennesaw State University was an amazing opportunity for my career, but little did I know the lasting impact it would have on my existence. Learning, I believe, is key to a happy, healthy, and successful life. One should never stop learning or setting goals that seem nearly impossible to achieve. You might just surprise yourself and be rewarded beyond belief.

I have had the great privilege of working with Dr. Kimberly Linenberger Cortes and Dr. Adriane Randolph, both of whom are leaders in their respective fields of study. Thank you, Ladies, for everything you have done for me along this journey. I know I was a challenge on more than one occasion, but your patience and guidance will continue to serve as a standard for my own behavior, as I once again become the teacher. Thank you to Dr. Thomas Leeper for agreeing to be a member of my committee. I appreciate your time and helpful suggestions. Thank you to Dr. Cassidy Terrell and Xavier Prat-Resina for your Northern hospitality during my visits.

I would like to thank the KSU professors, my fellow graduate students and members of the BrainLab for sharing of knowledge and time. I recognize that I would have never been able to earn my degree without your support. I would especially like to recognize Ethan Miller, Kim Kammerdiener and Deidre VanDenbos who not only shared office space with me but continue to brighten my life with their friendship.

Finally, to my friends and family, thank you for your unconditional love and support. We did it!!

## Chapter One: Introduction

Alex Johnstone offers the following explanation for why science is often a difficult subject for students, “The difficulties of learning science are related to the nature of science itself and to the methods by which science is customarily taught without regard to what is known about children’s learning” (Johnstone, 1991 p. 75). Teachers struggle with guiding their students to the acquisition of knowledge daily, and what is effective for some students is not for others. Both teachers and students would benefit from having greater insights into individual cognition and learning in the classroom.

The working memory, the bridge between external stimuli and long-term memory, is often over stressed with excessive cognitive load preventing information processing (Sweller, 1994; Baddeley, 1992). Cognitive load is the processing capability of the working memory. The construction of knowledge requires that new information be added to the existing mental framework or that the framework be modified to fit with the new information (Von Glasersfeld, 1984; Bodner, 1986). Using physical models in lessons can help to make abstract connections; however, with improper activity design and varying degrees of spatial ability, cognitive load can actually increase, deterring effective and efficient learning (Chi, 2008; Gentner & Stevens, 1983; Copolo and Hounshell, 1995; Antonoglou *et al*, 2014; Stieff *et al*, 2012; Bodner & Guay, 1997; Sweller, 1994). Therefore, understanding how students process information from the perceived external stimuli to the creation of knowledge in the long-term memory is critical to success for both the teacher and the student (Mayer, 2009).

Fortunately, methods have been developed to assess the cognitive load affecting the working memory. One such method is to utilize brain activity, a physiological method. This study intends to record and process brain activity in order to calculate the engagement index, a

measure of cognitive load, developed and tested by Pope *et al* (1995) to determine the effectiveness of physical modeling in organic chemistry.

### **Purpose of the Study and Research Questions**

The purpose of this study is to further understand learning in organic chemistry using the concept of chirality by measuring brain activity using electroencephalogram (EEG) technology and to determine the level of cognitive load experienced by the participant. Cognitive load will be measured by identifying and assessing theta, alpha, and beta band frequencies while the participant manipulates physical molecular models of various chiral molecules. The study intends to document, analyze and share outcomes in hopes of helping teachers develop techniques that promote student learning of R or S determination of chiral centers effectively and efficiently. As said by David A. Sousa, “Increasing the options that teachers have during the dynamic process of instruction also increases the likelihood that successful learning will occur.” (Sousa, 2011 p. 8)

The following are the research questions used to drive this study:

1. How do the tasks associated with the activity impact organic chemistry students’ cognitive engagement and performance?
2. How do students’ spatial abilities impact their task performance and cognitive engagement while completing the organic chemistry modeling activity?

Ultimately, the goal of this research is to optimize the cognitive load of modeling activities in order to improve learning. Once optimized, the activities will be provided to the organic chemistry educator community along with trainings on what to consider when developing modeling activities to optimize the cognitive load of students. When student learning

can be impacted in such a way as to increase efficiency and effectiveness, long-term knowledge gains will result. Students will be able to apply this knowledge in more advanced chemistry courses necessary to further their education.

## Chapter 2: Literature Review

The purpose of this chapter is to explore the literature relevant to this thesis and to discuss the theoretical framework used for this research project. A discussion of the brain and learning models will also be included. Finally, the importance of physical models as a teaching strategy and the impact of spatial ability on interpreting physical models will be explored.

### The Brain: The Center of Learning

The brain is a complex organ that is responsible for maintaining body functions, perceiving and interpreting information from the environment, and storing that information for future use. It is divided into three specialized areas called the cerebrum, cerebellum and brainstem. The cerebrum is composed primarily of the cortex, which is further sectioned into four lobes: frontal, parietal, temporal and occipital lobes. The frontal lobe is found in the front of the cortex and responsible for thinking and planning. Behind the frontal lobe is the parietal lobe which processes sensory information and is the center for spatial orientation. The temporal lobe is found at the bottom of the cortex and above the ears (see Figure 1). It is responsible for processing sound. Finally, the occipital lobe, found at the back of the cortex, is responsible for processing all visual stimuli (Sousa, 2011). Table 1 below summarizes the location and function of each of these areas of the brain.

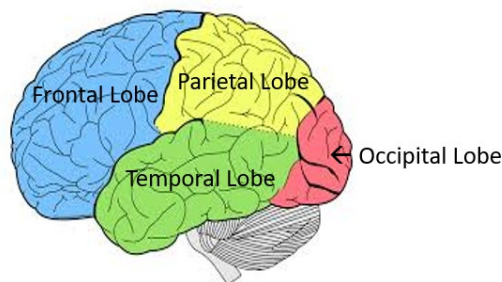


Figure 1. Depiction of the brain and location of the four lobes

Table 1  
*The Lobes of the Brain, Location and Function*

Brain Lobe	General Location (See Figure 1)	Function
Frontal	light blue section	Thinking, problem solving and planning
Parietal	pale yellow section	Interpreting sensory information including touch and taste Spatial orientation
Temporal	Light green section	Processing auditory information
Occipital	pink section	Processing visual information

How the brain perceives, interprets and stores information is an area of study that continues to develop as technology for recording and analyzing brain activity advances. With a deeper understanding of brain mechanics, the concept of learning will be less mysterious. One of the theories for how the brain learns is called Constructivism. This theory serves as the theoretical framework for this research project and is the subject of discussion for the next section of this thesis.

### **Constructivism**

Many in the field of chemistry education research believe that research should inform the practice of chemical education and that research is more useful and powerful if it is theory-based (Abraham, 2008). This research will be based in the Theory of Constructivism; a theory derived from Piaget's Theories of Intellectual Development (Piaget, 1936). Constructivism suggests that students have a framework of knowledge in place that was developed by experiences and information gained over their lifetime (Von Glasersfeld, 1984; Bodner, 1986).

Piaget believed that learners must assimilate and accommodate information that is presented to them in order to learn and organize the new knowledge. The process of assimilation occurs when new information fits and is added into a person's existing knowledge framework. Accommodation requires the modification of a person's mental framework in order for the

information to fit into what the student currently knows and understands. This adjustment of the framework allows for the new information to be added. Constructivism suggests that new knowledge is attained by fitting the information into mental structures the learner currently possesses. In order to understand how the new information is processed so that it can be added to the mental framework, a discussion on the information processing model must occur.

### **Information Processing Model**

The information processing model is used to explain how information perceived through the body's senses travels from the environment and eventually is stored in long-term memory. Environmental stimuli are filtered by the perception filter located in the thalamus. Using stored experiences, the thalamus determines if the data is to be lost or passed on to the cortex for further analysis in the immediate and working memories. For the information to be permanently stored in long term memory, the working memory must determine if the data makes sense and is meaningful (Mayer, 2009; Sousa, 2011). If the criteria are met, the information moves from the cortex to areas distributed across the brain. The memories that were once sensory data are now pieces of information that are stored, retrieved and used to reconstruct current understanding or knowledge (Mayer, 2009). Figure 2, illustrating the information processing model, shows how prior knowledge is integrated into the processing of new information, which leads to the development of new knowledge, as suggested by the theory of Constructivism.



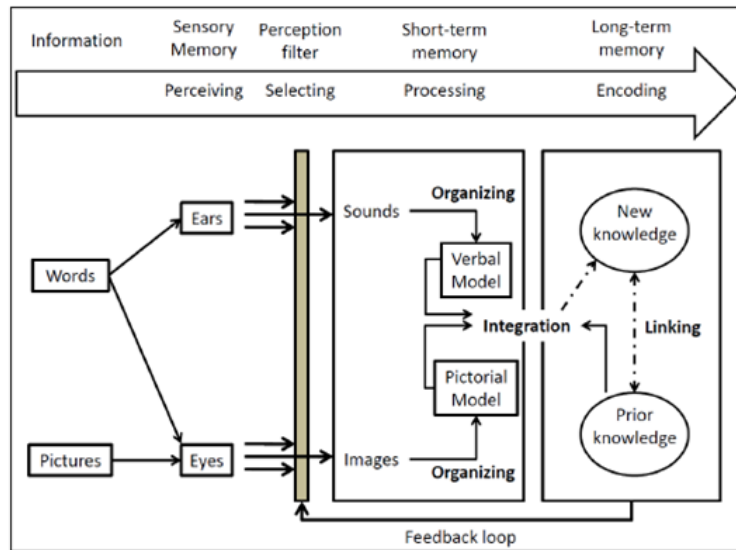


Figure 2. Information Processing Model. Source: Mayer, R. E. (2009). "Multimedia learning 2nd Ed." Cambridge University Press: New York

The information processing model is the key to explaining how external stimuli are processed and eventually linked to the established framework of knowledge in the long-term memory. All of this processing occurs in the working memory which is the processing center between the external stimuli in the environment and the prior knowledge stored in the long-term memory.

### The Working Memory

Once referenced as the short-term memory, the working memory is now considered a part of the short-term memory and often referred to as the central executive (Baddeley, 1992). The working memory is thought to temporarily store and coordinate information that is transmitted to it from the phonological loop and the visuospatial sketchpad, both of which are referred to as the slave systems. The phonological loop is thought to be responsible for processing information attained from speech; whereas, the visuospatial sketchpad is responsible for processing visual and spatial information (Baddeley and Hitch, 1974; Baddeley, 1992; Jaeger, Shipley and

Reynolds, 2017). The objective of the working memory is to complete tasks such as communication, problem solving and learning. In addition, the working memory can pull information from the long-term memory to assist with processing and analysis of external stimuli (McLeod, 2012). The working memory is finite and can only process a limited number of stimuli at once. Research conducted suggests that the working memory can only process 7 plus or minus 2 pieces of information at one time without overloading the working memory and decreasing processing efficiency (Miller, 1956; Johnstone and Kellet, 1980; Cranford *et al* 2014).

The exact location of the working memory is open to debate. Research conducted by Dong Gyu Na *et al* (2000) utilized positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) in an attempt to locate areas of the brain that were activated while using verbal and visual working memory. They determined that various areas of the brain including the prefrontal cortex and parietal cortex were activated depending on the type of stimuli the participant received. If the stimulation tasks were verbal in nature, the phonological loop was activated, and brain activity was noted in the prefrontal cortex as well as areas in the inferior parietal cortex. The prefrontal and parietal cortices were activated when the stimuli were visual in nature due to the probable location of the visuospatial sketchpad. They believed that although the simulations showed various areas of activation in the brain through the use of PET and fMRI, further research is necessary to substantiate these findings (Na *et al*, 2000).

In the working memory, environmental stimuli obtained from the senses is analyzed in conjunction with stored long-term memories and knowledge. As previously stated, learning occurs when new information is accommodated and assimilated into the long-term memory for

storage. This process is most efficient and effective if cognitive load is not interfering in such a way as to inhibit thinking (Baddeley, 1992).

### **Cognitive Load Theory**

Learning, a challenging endeavor influenced by many variables, is achieved when new knowledge is gained and retained for use in the future. Cognitive load, one such variable, is the effort put forth by the working memory to process new information from the environment using stored knowledge from long term memory (Sweller, 1988). Cognitive Load Theory (CLT) suggests that cognitive processes in the working memory interact with learning content and long-term memories and affect the performance of the learner (Sweller, 1994).

There are three types of cognitive processing that can affect cognitive load: extraneous, intrinsic and germane. Extraneous processing is due to curriculum practices or materials that do not support student learning. An example of extraneous processing could be an activity that requires a computer program that is not working as intended or the student has little experience with the computer program. This would require a greater amount of the working memory's capacity even though it is not directly related to the learning objective; therefore, extraneous load should always be kept to a minimum. Intrinsic processing is related to the degree of difficulty of the content being learned. Some learning objectives are inherently more difficult than others. As a result, intrinsic load should be managed. Germane processing is the learning capabilities of the learner and relies on his motivation and prior knowledge. Because germane is connected to the efficiency of the learner's working memory, it should be maximized to ensure optimum cognitive load (DeLeeuw and Mayer, 2008).

Although it is critical that the learner engage in cognitive processes to gain knowledge, it is important to remember that the working memory is finite and has a limited load capacity (Miller, 1956; Johnstone and Kellet, 1980). When designing learning activities, it is important that the tasks designed for students not only hold relevance but also be sensitive to cognitive load (Mayer and Moreno, 2003). Next, measurement of cognitive load is examined.

### **Measurement of Cognitive Load**

There are various methods for attempting to measure cognitive load during a learning activity. One method for measuring cognitive load is through the use of subjective questions, which ask participants to rank the mental difficulty of the task they performed using a Likert scale (Schmeck et al, 2015). This method used by Pass and van Merriënboer in 1994, asked participants to determine the amount of effort required for the given task by rating the difficulty of the task performed using a scale of 1 (very easy) to 9 (very difficult). Because analysis of the cognitive load occurs posthoc and is completely subjective, there are some disadvantages to using this method (Cranford *et al*, 2014).

The learner's performance on the task when distracted by a meaningless request can also be used to assess the level of cognitive load experienced. (Pouw et al, 2016a; Skulmowski and Rey, 2017) Operating on the assumption that the working memory is finite, but able to work on multiple tasks at once, participants working on a primary learning objective can be asked to perform a secondary task. One such task, the Stroop task, requests participants to read the name of a color printed in a color that does not match its name. For example, the word red might be printed in yellow ink. The response time of the secondary task is measured and used as a way

for determining the amount of cognitive load associated with the primary task (Gwizdke, 2010; Cranford *et al*, 2014).

Physiological methods can also be used to determine cognitive load including brain activity, heart rate, pupil dilation and galvanic skin response (sweating) (Skulmowski and Rey, 2017; Cranford *et al*, 2014; Karch, García Valles and Sevian, 2019). Very little research has been conducted for teaching and learning chemistry in regard to the measurement of cognitive load using physiological methods. One such study conducted used heart rate as a means for measuring cognitive load in organic chemistry (Cranford *et al*, 2014). In this study, the researchers designed cognitive load progression activities (CLPA) using the concept of chirality. These activities were designed to elicit an increase in cognitive load with each subsequent question. The heart rates of the participants were monitored as they completed the activity questions. In addition, researchers compared the heart rates of students (novices) and instructors (experts) as each completed the CLPA. Researchers found that heart rate increased as cognitive load of the CLPA problems increased and that novices showed a greater increase in heart rate while answering questions than experts did answering the same questions (Cranford *et. al*, 2014).

In another study, pupil dilation was used to determine the cognitive load experienced by general chemistry students while answering questions from the Chemical Concepts Inventory (CCI). This was accomplished by gaze and pupillometric data from eye-tracking equipment and the study found that pupil dilation fluctuated as participants answered questions. In addition, researchers noted that pupil signals were different for those participants that answered questions correctly as compared to participants who did not (Karch, García Valles and Sevian, 2019).

Brain activity, another physiological method for measuring cognitive load can be collected using Electroencephalogram (EEG), technology. Unlike other physiological methods, EEG is a direct measure of information processing by the brain (Potter and Bolls, 2012; Cortes, Kammerdiener and Randolph, 2018). Electrodes are used to capture the biopotentials or electrical signals that may be detected at the skin's surface due to a neuron transferring an impulse. Electroencephalography has been used in educational research, but not to assess the cognitive load of chemistry students. To determine the cognitive load influencing the working memory from brain activity, an engagement index using beta, alpha and theta frequencies can be used. This engagement index was developed and tested by Alan T. Pope and team in 1995. In a pilot study conducted by Charland *et al*, EEG and Pope's engagement index was used to access the cognitive load of problem solving in physics. Researchers found the "EEG data and implicit arousal significantly predict problem-solving performance" (Charland *et al*, 2016).

### **Physical Modeling and Spatial Ability in Chemistry Education**

Because of the nature of chemistry, models are often used to connect difficult abstract ideas. A student will never be able to hold an individual molecule in his hand for inspection and observation; therefore, models are used to give the student a sense of what that molecule looks like and how it may behave when interacting with other molecules. The use of a physical model may improve the efficiency of the working memory by helping the student to organize information as it is processed (Copolo and Hounshell, 1995). Modeling activities can help students to develop accurate mental models that assist in comprehending difficult concepts which facilitates the new knowledge being stored in long-term memory for future recall (Chi, 2008; Gentner & Stevens, 1983; Copolo and Hounshell, 1995).

Research shows that using physical and virtual models in chemistry can serve as a means for helping students create and use mental models which in turn help students translate representations of compounds and identify structural differences between the compounds (Wu, Krajcik and Soloway, 2000; Copolo and Hounshell, 1995). However, using models successfully is often dependent on the spatial ability and the conceptual knowledge of chemistry of the student (Harle and Towns, 2010). Because students differ on spatial abilities, making mental manipulations of 2D representations of molecules could prove to be difficult and the use of 3D models as a learning aid is beneficial to make the necessary connections (Copolo and Hounshell, 1995).

Research suggests that a student's spatial ability, a type of intelligence that allows a person to manipulate or rotate an image in his mind, influences how information from the model is processed. The spatial ability to mentally create and recognize drawings of molecules and explain conceptual information about the molecule is called visuospatial ability (Harle and Towns, 2010). Due to the nature of chemistry and its use of models, spatial ability is considered a valuable skill and a primary factor in a student's success in learning the content (Antonoglou *et al*, 2014; Stieff *et al*, 2012; Bodner & Guay, 1997). As stated in 2014 by Antonoglou *et al* after conducting a study on spatial ability and its connection to 2D representations, "Fluency with Chemistry representations is closely related to molecular visualization ability and particularly the recognition of diagrammatic or graphic conventions, the perception of spatial information and the manipulation of spatial relations in molecular representations." For this reason, students cannot be expected to naturally have the skills necessary to look at a 2D representation of a molecule and understand its movement in space. In an earlier study regarding spatial ability and performance by Pribyl and Bodner in 1987, researchers found that students with high spatial

ability were more likely to draw figures before attempting to answer questions and that these students scored higher on questions that required problem solving skills. Students with low spatial abilities were more likely to draw figures that were incorrect, out of proportion and non-symmetric. The next section of this chapter gives a brief explanation of chirality, difficulties students have with chirality and how research suggests chirality is best taught.

### Chirality: R or S Configuration

Some molecules have the same chemical formula, but their atoms are chemically arranged in such a way as to form molecules that produce mirror images. These mirror images, called enantiomers, are non-superimposable meaning they cannot be placed on top of one another and therefore, are not the same molecule. When four different substituents are connected to a stereocenter, R or S configuration for that molecule can be determined. Most often, these chiral centers have a tetrahedral arrangement of bonds. In order to determine R or S configuration, each substituent is given a priority based on atomic number. The lowest priority substituent is rotated to the back of the molecule and the remaining are used to determine the direction of configuration, clockwise (R) or counterclockwise (S) (McMurry, 2004). Figure 3 below is an example of enantiomers and labels each as an R or S configuration.

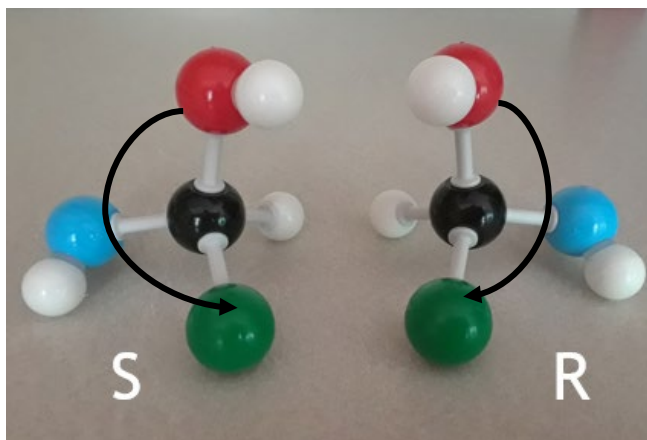


Figure 3. Molecular models displaying R and S configuration



There are many methods and debate as to which teaching strategy is best for instruction of this concept. Traditionally, this is accomplished by drawing representations of the molecule usually including a wedge and dash approach (Wintner, 1983; Abraham, Varghese and Tang, 2010; Kramer and Griesbeck, 2008). As technology improves, computer simulations and the development of apps are becoming popular teaching methods (Jones, Spichkova and Spencer, 2018; Abraham, Varghese and Tang, 2010). A study conducted by Chapman and Russell in 1992, suggested the use of nuclear magnetic resonance spectroscopy (NMR) as an experimental approach for introducing and teaching students about chirality. Although these researchers are all creative and unified in a common goal, not all students have access to these differing levels of technology. How then are students with various spatial abilities and limited access to technology able to make the connections necessary to learn chirality? The answer could be simple: molecular 3D models (Abraham, Varghese and Tang, 2010; Chapman and Russell, 1992).

### **Conclusion**

This chapter discussed the current research applicable to this study and showed where further research is needed. Knowledge, according to Constructivism, is obtained when new information is processed by the working memory and assimilated or accommodated into the framework of the long-term memory. In order to assist learners in chemistry, physical models can be used to connect abstract concepts; however, the effectiveness of the activity can be influenced by the learner's spatial ability. Cognitive load interferes with the processing of the working memory and can be measured subjectively, by performance or by physiological means. Heart rate and pupil dilation have been used in chemistry education research, but to date, no research has been conducted using brain activity. To fill this gap, brain activity was used to

measure cognitive load in this research study and chapter 3 gives a detailed explanation of the methodology used.

### **Chapter 3: Methodology**

This study was designed to conduct research and collect EEG and eye-tracking data to answer questions about cognitive load during the performance of a physical modeling activity in organic chemistry. In this chapter, a description and explanation are given in regard to the methodology used for this research project.

#### **Research Questions**

This study uses the Engagement Index (EI) to answer questions related to cognitive load and to determine any correlations between cognitive load and other variables. The research goal was to design a physical modeling organic chemistry activity that optimizes the cognitive load of students while completing the activity. The following are the research questions associated with this goal:

1. How do the tasks associated with the activity impact organic chemistry students' cognitive engagement and performance?
2. How do students' spatial abilities impact their task performance and cognitive engagement while completing the organic chemistry modeling activity?

#### **A Mixed Methods Approach**

To answer the presented research questions, a mixed methods approach, the use of qualitative and quantitative methods of data collection and analysis, was used during the study. A mixed methods design allows researchers to balance the strengths and the weakness of each individual methodology, as well as, provide a more interpretable and valid outcome than either methodology could alone (Townes, 2008). This study will collect qualitative and quantitative data concurrently giving both types of data equal priority. By using a mixed methods approach,

the findings generated using each methodology will potentially confirm and corroborate one another (Towns, 2008).

### **Context of the Study**

Beginning in Fall of 2017 and again in the Spring of 2019, research was conducted in collaboration with a small Midwestern metropolitan campus. This university is 75% female and has only one degree, a Bachelor of Science in Health Sciences. Data was collected in the content area of organic chemistry. Fall 2017 participants were first semester, first year college students enrolled in an organic chemistry first curriculum which means organic chemistry is taught before general chemistry. The course was considered the equivalent to organic chemistry I.

Participants in spring of 2019 were second semester, first year chemistry students enrolled in CHEM II. Due to a curriculum change in the sequence of chemistry courses offered at the institution, the course currently called CHEM II is similar to organic chemistry I. Before enrolling in CHEM II, students are required to successfully complete CHEM I, which is similar to general chemistry I. Chirality, the topic of investigation for this study, is a concept being introduced for the first time to the participants for both the fall 2017 and spring 2019 semesters.

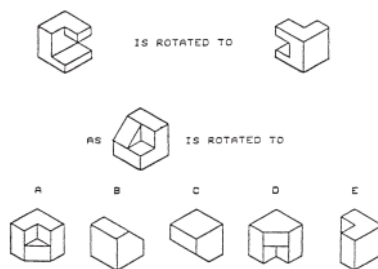
### **The Activity**

The chirality physical modeling activity used in the study was designed as an actual activity in the curriculum for the course. The physical modeling activity consisted of three different questions with each question having sub questions. For question 1 of the activity, participants were to construct a 3D model from a 2D drawing. Using the model, students were to identify the priorities of the substituents and determine if the molecule had an R or S configuration. There was a total of 6 molecules included in this question to which the degree of

difficulty varied between the molecules. Question 2 asked participants to identify which molecules from question 1 when paired were mirror images. In the spring of 2019, a second question was added asking participants to identify the characteristics of the enantiomers (mirror images) identified. Finally, in question 3, participants were given three different preconstructed models for which they were to draw and assign R or S configuration for the chiral center. A copy of the physical modeling activity for both years can be found in the appendix A and B.

### **Participant Selection**

At the beginning of the course for both fall 2017 and spring 2019, students were informed of the research study by the collaborating university professors. If the students were willing to participate and met the study criteria of right-handedness, they were invited to take a spatial abilities test. Because research has determined that spatial ability is a skill that is needed when performing 3D modeling tasks (Wong *et. al*, 2018; Antonoglou *et. al*, 2014; Stieff, 2007), the Purdue Visual Rotations Test (PVRot) was utilized to achieve a stratified sample. The PVRot consists of 20 items that require the participant to determine how a block was rotated and then perform the same rotation on the test item choosing the appropriate matching answer from the responses (See Figure 4). The goal for the number of participants in each of the case studies was 12 with representation in each of the ranges for rotational spatial ability (low, medium and high). Once these individuals were identified, they were invited to participate in the study and encouraged to sign up for sessions. Invitations were sent by the collaborating professors until all twelve participants were identified.



*Figure 4.* An example of an item on the PVRot, the spatial ability test used for selection (Bodner & Guay, 1997)

## Participants

There was a total of 8 participants for the fall 2017 data collection. Of the 8 participants, 2 were male. The spring 2019 sample also had 8 participants; of which, 3 were male. In 2017, the ethnicity of the participants was as follows: 3 White, 4 Hispanic or Latino and 1 Asian or Pacific Islander. In 2019, the ethnicity of the participants was as follows: 4 White, 2 Hispanic or Latino, 1 Asian or Pacific Islander and 1 other. All participants, for both data collections, were right-handed, traditional college freshmen with an age of either 18 or 19.

## Simulated Learning Environment

The sessions were conducted outside of class and during the participant's free time. Twenty-five-dollar Amazon gift cards were given to the participants as an incentive for participation upon completion of their data collection. Each participant was placed individually in a simulated learning environment meant to emulate the experience they would have in their classroom on the subsequent class period. An instructor was present to answer questions the participant may have had during the physical modeling activity. During the session, participants were connected to the EEG to monitor brain wave activity and eye-tracking glasses to document their completion of the activity and record eye fixations during the activity.

All sessions took place in a group study room that had space for two small tables. One of the tables was the participant workspace and the other was used for EEG and eye tracking equipment. The allotted time for each session was 75 minutes, which included time for a demographic survey, an additional spatial ability test, completion of the activity, and equipment set-up and removal. Fall 2017 participants completed the survey and spatial ability test before equipment set up; whereas, spring 2019 participants completed the survey and spatial ability test after the completion of the activity and the removal of equipment.

The Hidden Figures Test (HFT) was an additional spatial ability test utilized to measure field dependence, a student's ability to distinguish detail from the surrounding context (Bodner, G.M. & Guay, R.B., 1997). This test consisted of 16 items that required the participant to determine which of the 5 simple figures was embedded in a more complex figure. Participants were given 12 minutes to complete the Hidden Figures Test (See Figure 5).

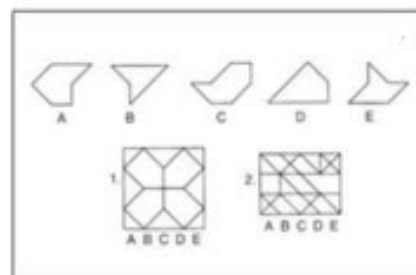


Figure 5. An example of an item on the HFT, the spatial ability test used to determine field dependence (Bodner & Guay, 1997)

Participants were connected to the EEG equipment to monitor brain activity as they completed the required modeling tasks. These files were a continuous data collection of EEG so that the participant was not interrupted while performing the activity. Using a 16-channel BioSemi ActiveTwo system with Ag/AgCl, pin type active electrodes, biopotentials were monitored and recorded from the scalp of the participant. These biopotentials are generated by

neural activity in the various lobes of the brain. Electrodes are labelled with a letter and number or letter combination using the international standard 10-20 system. The 16 channels that were monitored are highlighted in both yellow and green in Figure 6. For this thesis study, only the electrodes highlighted in green (Cz, P3, Pz and P4) are used in data analyses.



*Figure 6.* Electrode layout used in the study, where yellow and green represent all sixteen electrodes used to record signals and green represents the four electrodes used for data analysis. Letters represent the brain lobe the electrode monitors such that FP represents pre-frontal, F represents frontal, C represents cortex, T represents temporal, P represents parietal and O represents occipital. Odd numbers refer to left of midline, z is midline and even numbers are right of midline.

Once it was determined that all electrodes were generating a clear EEG signal, the eye tracking glasses were fitted to the participant. The Tobii Glasses 2 Eye Tracker was calibrated to each participant to ensure that eye tracking data was accurate. Researchers were interested in how often participants referenced the model when answering the activity questions. As an added benefit, the eye tracking glasses recorded visual and audio for the entire session, which were used for further observational review.

### **Data Analysis**

Analysis of the data was completed using several different software programs: EEGLAB, MATLAB, Tobii Pro and the Statistical Package for the Social Sciences (SPSS). The



ActiveTwo software was used to reduce, decimate and crop the EEG files. MATLAB and EEGLAB were used to clean the EEG files and identify and calculate theta, alpha, and beta brain wave frequency bands so that the Engagement Index could be determined for each participant during the physical modelling activity using the following equation:

$$Engagement\ Index = \frac{\sum \beta\ power}{\sum \alpha\ power + \sum \theta\ power} \quad \text{Equation 1}$$

Tobii Pro was used to analyze data from the eye-tracking glasses to determine fixations between 2D and 3D representations of the molecule in question. To complete statistical analysis on data obtained during the study, researchers used SPSS. Spearman's Rho was utilized to investigate and identify significant associations between variables.

### **Electroencephalogram Data**

Because all sessions had continuous EEG recorded and sampled at a rate of 2048 Hz, files were extremely large; therefore, the initial step for researchers was to reduce and down sample (decimate) the data files. All files were reduced to just the 16 channels of interest as some sessions had captured additional channels possible with the equipment. Then the data was decimated to a sampling rate of 256 Hz to increase the efficiency of analysis (Kostilek and Stastny, 2012). Using the videos from the eye tracker, beginning and ending times for each activity question were determined and used to crop the EEG files so that Engagement Index values could be determined for each question. At this point, each file was imported into EEGLAB for filtering. A common average reference (CAR) was used to isolate the brain activity across all electrodes. Following the CAR, a notch filter capturing data between 0.1 Hz and 50 Hz and an artifact subspace reconstruction (ASR) were applied to further clean and remove artifacts from the data such as eye blinks and electrical noise from the environment

(Charland et al, 2016). To find the band power values for theta (4 – 7 Hz), alpha (8 – 12 Hz) and beta (13 – 30 Hz), the cleaned files were imported into MATLAB. For this research project, only data collected from electrode sites Cz, P3, Pz and P4 were analyzed in MATLAB. Using the band power values from these sites, the Engagement Index was determined for each activity question.

### **Eye Tracking Data**

The video recordings from the eye tracking glasses were used to explain trends between the engagement index values. In addition to these observations, transitions between 2D and 3D representations of each molecule were counted to further understand the participants' use of the model when completing the activity. Audio from the video recordings provided additional insight into the thought process of the participant as activity questions were answered.

### **Safety and Ethical Concerns**

Due to the use of human subjects, this study has been approved by the University of Minnesota Institutional Review Board (IRB) and Kennesaw State University. In accordance with the IRB, additional training in ethics and minimal risk research were completed by researchers to ensure the appropriate and proper treatment of participants and data. Copies of consent forms can be found in appendix C and IRB approvals can be found in appendix D and E.

### **Conclusion**

This chapter described the methodology used for this research project. In chapter 4, the research questions posed will be answered using the data collected and the analysis of that data using the various software programs described. Observational data from the videos will be used

to corroborate and confirm findings to further substantiate the conclusions determined by researchers.

## Chapter 4: Results

The findings from the research project are presented in this chapter in an attempt to answer the following research questions:

1. How do the tasks associated with the activity impact organic chemistry students' cognitive engagement and performance?
2. How do students' spatial abilities impact their task performance and cognitive engagement while completing the organic chemistry modeling activity?

**Question: How do the tasks associated with the activity impact organic chemistry students' cognitive engagement and performance?**

### Activity Question 1

The first question of the physical modeling activity asked participants to build the 3D representation of a 2D drawing for six different molecules. After building the molecule, participants were to identify if the molecule's chiral center had an R or S configuration. Figure 7 shows the distribution of cognitive engagement (along the y-axis) by molecule for fall 2017 participants. As previously stated, the engagement index values were used as the method for determining the cognitive load of the participant during the activity, as there is a direct relationship between the engagement index and cognitive load experienced by the participant (Pope, Bogart and Bartolome, 1995; Charland et al, 2016). Overall, there does not seem to be any observable trend for the group as a whole.

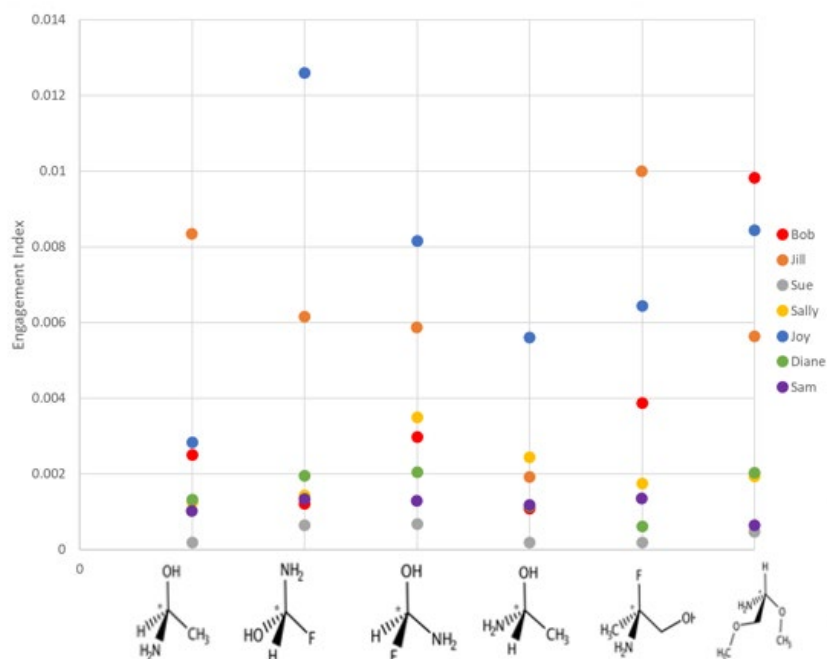


Figure 7. Engagement Index (EI) for participants from fall 2017 and molecules associated with each question

However, for the spring 2019 sample, a definite trend can be observed. It is hypothesized that adjustments made to the activity after analysis of the fall 2017 eye tracking data allowed for more effective and efficient scaffolding of questions which optimized cognitive load as seen through the Engagement Index (EI) values. In Figure 8, the EI for molecules 1 through 4 display a steady decrease in engagement, suggesting that students were better prepared to answer the next question based on the experience of answering the previous. For molecules 5 and 6 of the activity, the size of substituent groups on the molecule increases which researchers believe challenged the participant's field dependency and in turn increased the EI. It is also important to note that the overall engagement of the spring 2019 sample is lower than the spring 2017 sample.

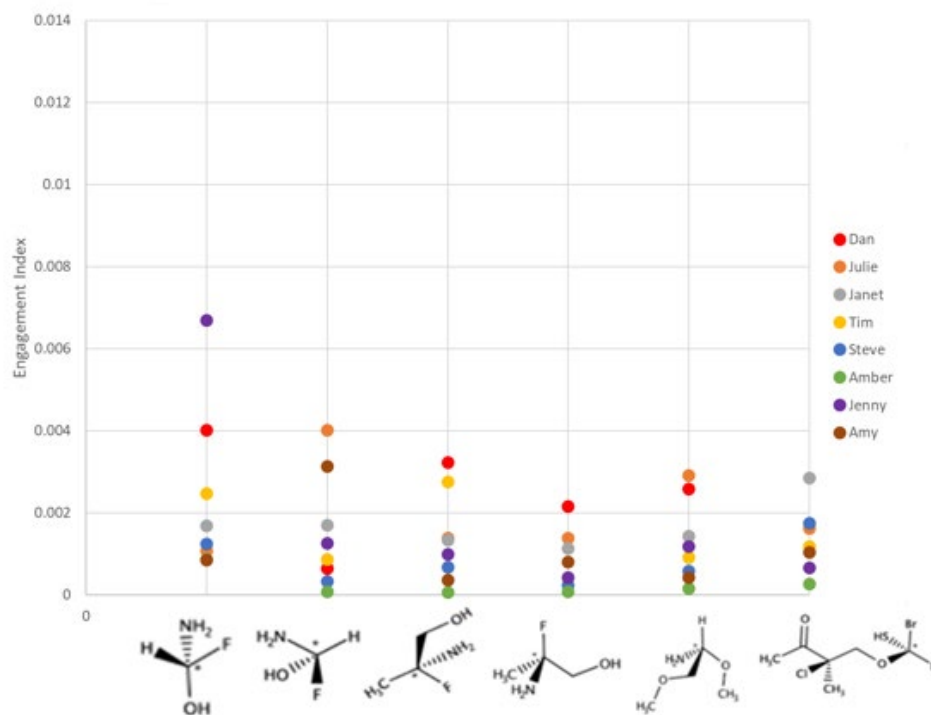


Figure 8. Engagement Index (EI) for participants from spring 2019 and molecules associated with each question

Because of the nature of chemistry, using models to connect abstract concepts to concrete physical experiences can be the difference between long term knowledge and information discarded by the working memory. However, to be effective, models must be used appropriately, or student misconceptions can derail the learning objective (Coll, France and Taylor, 2005; Oh and Oh, 2011; Gilbert and Osborne, 2007). The next few paragraphs are a discussion of how participants used the models to answer the questions about chirality during the physical modeling activity.

Question 1 of the activity asked participants to build the 3D model that represented the 2D drawing for six different molecules. Once the model was built, the number of transitions between the model and the 2D drawing were counted using the Tobii eye tracking videos. Using the Tobii software, fixations between the model and the 2D drawing while the participant was

determining the R or S configuration of the chiral center could be identified. Figure 9 represents the average number of times all participants from fall 2017 referenced each of the models while answering the question. It should be noted that the first, third and fifth molecule were drawn with the lowest priority substituent in the back and as such some of the participants were able to answer the question without building the model.

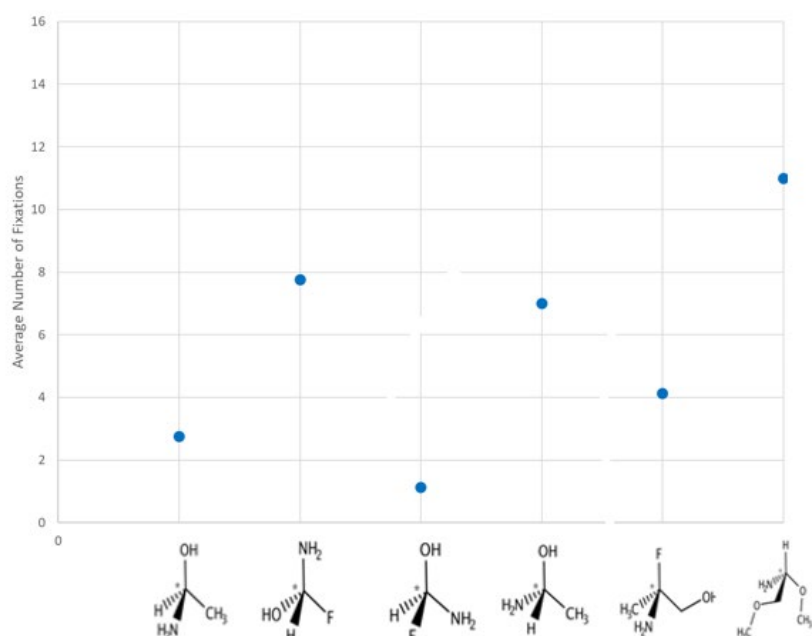


Figure 9. Number of average fixations of all participants for each molecule for fall 2017

After modifications to the activity were made for the spring 2019 sample, only one of the 2D drawings had the lowest priority substituent in back. This molecule happened to be molecule d (fourth molecule from the left), which also has the lowest number of fixations as shown by Figure 10.

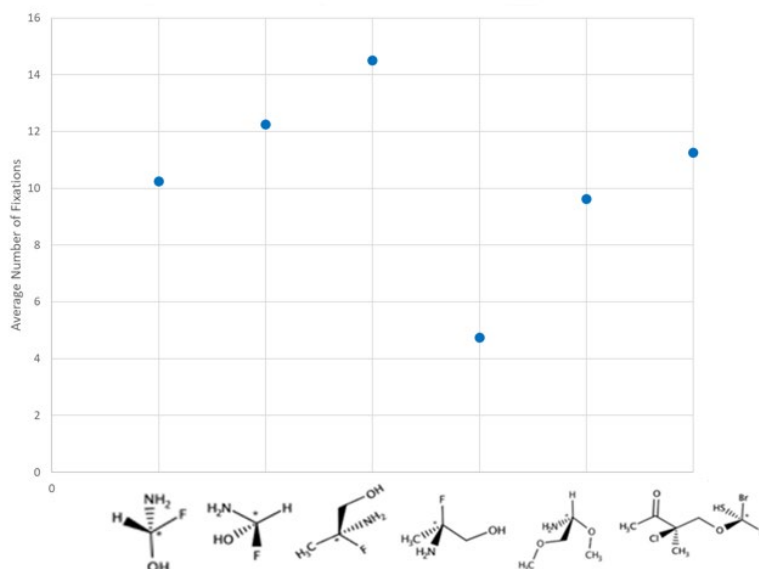


Figure 10. Number of average fixations of all participants for each molecule for spring 2019

Figure 11 represents the average engagement index compared to the average percent correct for each part of question one. From the graph, it should be noted that although fall 2017 participants scored better on the questions than spring 2019 participants, their overall engagement index is greater. In addition, the spring 2019 participants' engagement index decreases as their percent correct increases, an indirect relationship. As the average performance on the question improves, the engagement level decreases suggesting the cognitive load is less. It should be noted that performances on questions 2 and 3 were comparable between the two samples.



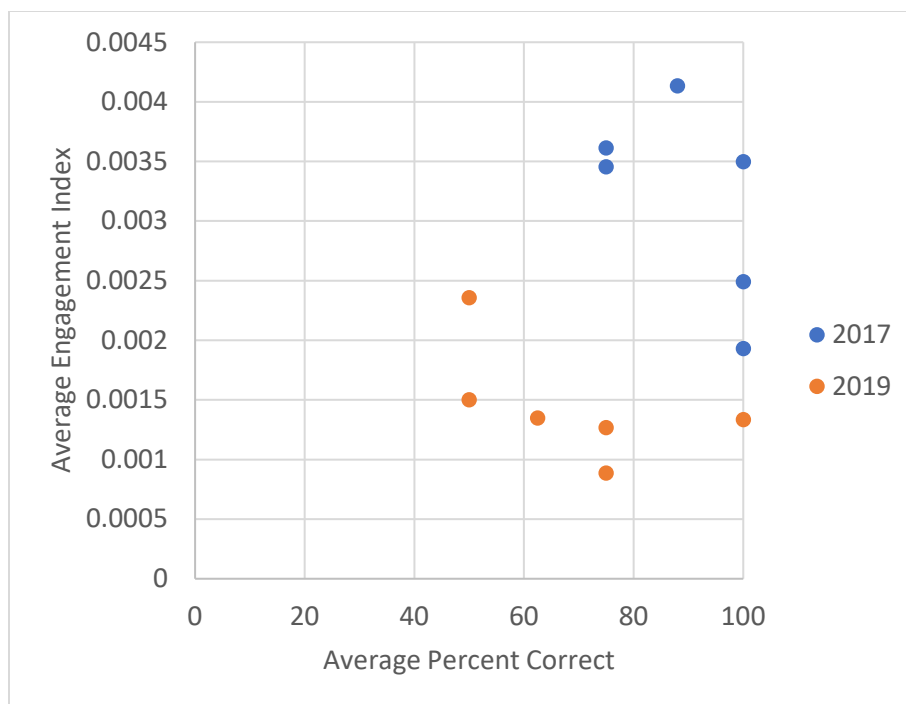


Figure 11. Fall 2017 and Spring 2019 performance data compared to engagement indices

### Activity Question 2

For question 2 of the modeling activity, participants were asked to identify which of the molecules from question one, when paired, would form enantiomers or mirror images. It should be noted that due to time constraints, Dan was not able to complete the modeling activity beyond question 1 and therefore is not included in the analysis of questions 2 and 3. Figure 12 displays the distribution of negative log EI values for the fall 2017 and spring 2019 participants. Because the EI values are on a negative log scale, the higher the value the lower the cognitive load. The engagement range of both years is essentially the same and relatively low for this question. The 2017 (question 2) activity required participants to identify two pairs of enantiomers; whereas the 2019 (question 2a) activity required only one. This change in the activity resulted from suggestions made by researchers after reviewing the fall 2017 eye tracking data, where it was

determined that 75% of the participants only identified one pair of enantiomers correctly and only 25% identified both pairs. Of the 2019 participants, only 57% identified the single pair of enantiomers correctly.

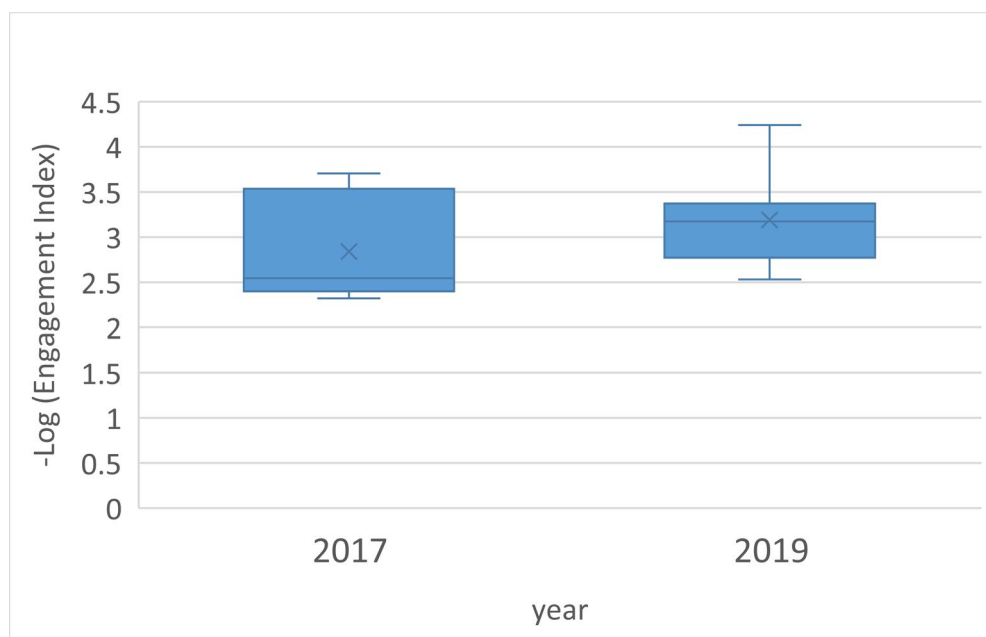


Figure 12. Negative Log of Engagement Index (EI) for fall 2017 and spring 2019 participants for activity question 2

For the spring 2019 activity, researchers added part b to question 2 (Figure 13) which required the participant to identify which chemical phenomena would be the same between the enantiomers; essentially testing the participant's chemical conceptual knowledge.

**b) For the two molecules in part a, circle all the following that would be the same between the two molecules.**

<b>i. Hybridization</b>	<b>ii. Polarity</b>	<b>iii. Reactivity</b>	<b>iv. Relative boiling point</b>
<b>v. Intermolecular forces (non-covalent interactions)</b>	<b>vi. Relative melting point</b>		
<b>vii. Acidity/basicity</b>	<b>viii. Optical rotation</b>		

Figure 13. Question 2b from the Spring 2019 physical modeling activity

Per the rubric (appendix F), participants who identified all 7 phenomena correctly were granted 3 points, participants who missed 1 to 3 of the seven were granted 2 points and participants who

missed 4 to 6 of the seven were granted 1 point. Sixty-three percent of the participants scored 2 points on this question while the remaining scored 1. As shown by Figure 14, there is very little difference in the negative Log of EI values between question 2a and 2b for the 2019 sample, except for Amber. From the Tobii video recording, it was observed that Amber was the only participant who constructed models for all of the potential molecules that could be enantiomers. Other participants constructed a pair of molecules or none at all. Amber made 4 separate molecules representing molecules a, b, c and d and the engagement index data suggests she was able to utilize the models to decrease her cognitive load (see Appendix B). However, her engagement index for question 2b is possibly higher because she was unable to use the models to answer that question.

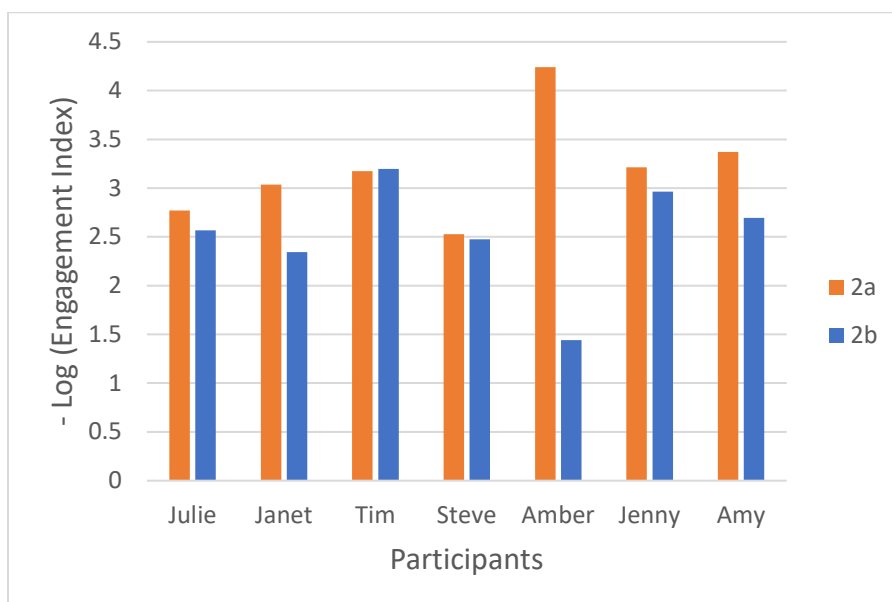


Figure 14. Negative Log of Engagement Index (EI) for spring 2019 participants for activity question 2a and 2b

Question 2 of the activity required participants to determine which pair of molecules were mirror images. None of the participants from fall of 2017 used the models to answer this question. One of the participants, Diane, rebuilt models but did not reference them when

answering the question. Seventy-five percent of the participants from spring 2019 rebuilt or used models they had not taken apart and referenced the models when determining which of the molecule pairs were enantiomers. Of the remaining participants, only one constructed a model but did not use it to answer the question. As expected, due to the recall nature of question 2b, none of the participants from spring 2019 used the models when answering the question.

### Activity Question 3

Question 3 of the physical modeling activity required participants to draw a 2D representation of a preconstructed 3D model, see Figures 15. The same molecules were used for both studies and were labeled a, b and c. After completing the drawing, participants identified the chiral center and determined R or S configuration.

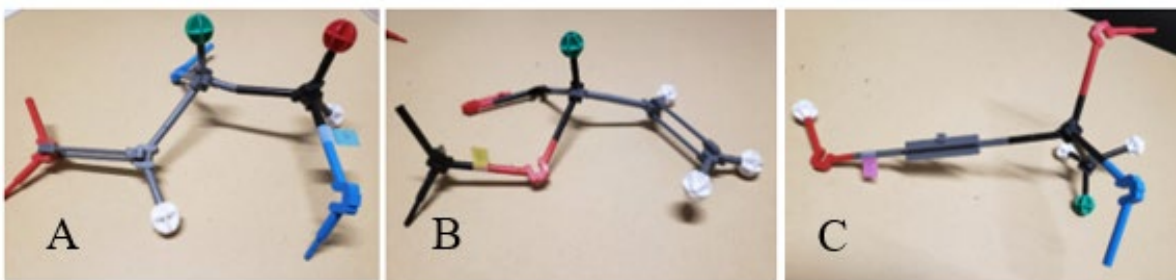


Figure 15. Preconstructed models for question 3 of chiral modeling activity

Although no modifications were made to question three between the studies (Appendix A and B), the same trends regarding EI values noted in question one was also observed in question three. Figure 16 represents the EI values for the fall 2017 participants and Figure 17 represents the participants for spring 2019. With the exception of Sam and Jill, the EI for the participants of fall 2017 remained the same or decreased slightly as they worked through activity question 3.

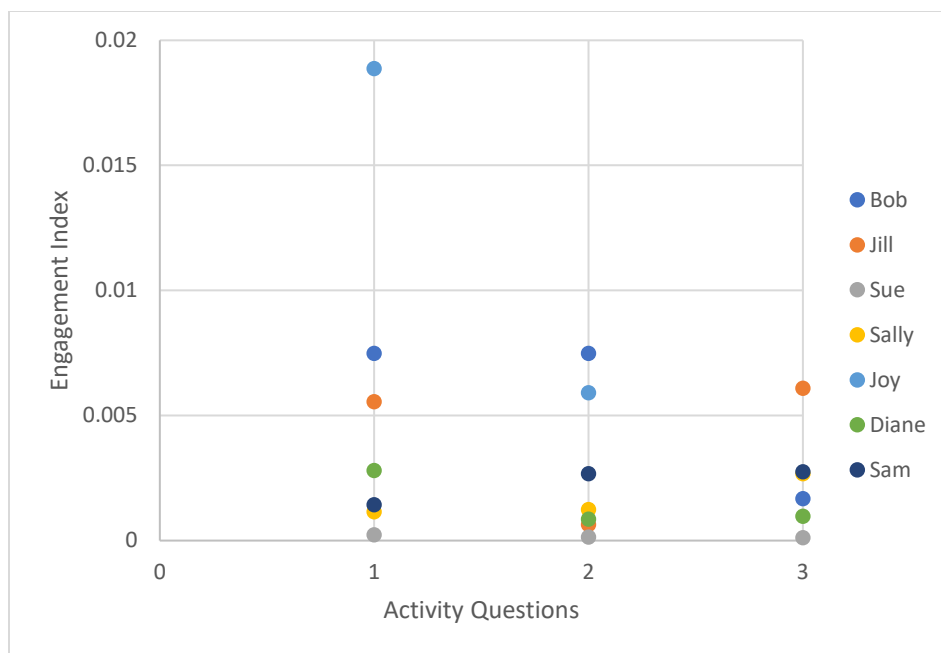


Figure 16. Engagement Index (EI) for fall 2017 participants for activity question 3

In Figure 17, researchers observed that EI values of spring 2019 participants had very little difference between the three molecules and were much smaller in value when compared to 2017 participants.

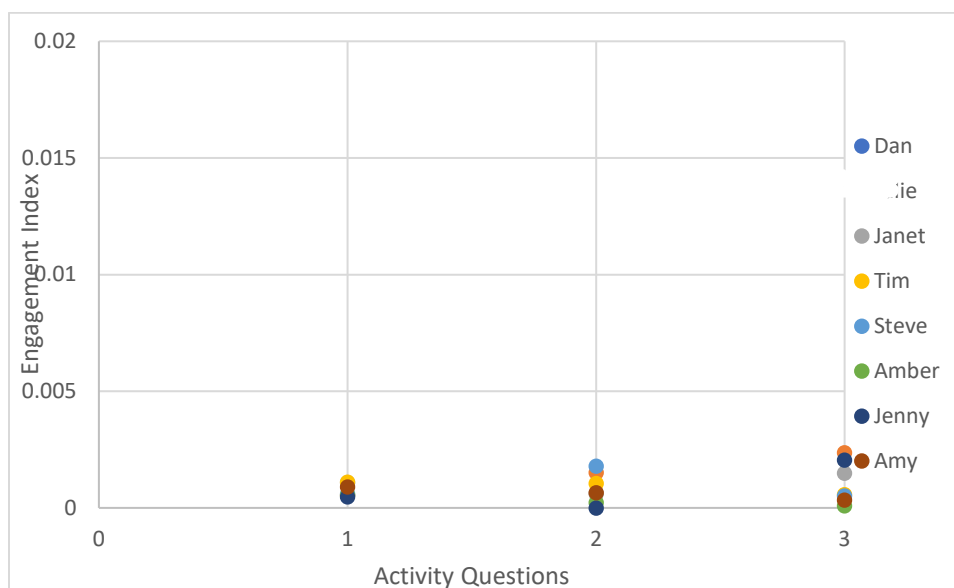


Figure 17. Engagement Index (EI) for spring 2019 participants for activity question 3

For question 3, participants were required to draw the preconstructed molecule before the chiral center could be identified and labeled as R or S configuration. Because the question could not be answered before the molecule was drawn, Figure 18 includes fixation counts that occurred during the translation of the 3D model to the 2D drawing (noted with “T”) and during the time the participant referenced the 3D model to answer the question (noted with an “R”). According to Figure 18, a much higher number of fixations occurred during the transition between 3D and 2D representations of the molecule. Primarily, participants used the models to create the 2D drawing, but then relied mostly on that drawing to determine R or S configuration. In the videos, it was observed that participants, when answering the question would utilize the 3D model to verify their drawing was correct. Also, it should be noted that 50% of the participants took 2 to 3 minutes to study the model before they began drawing.

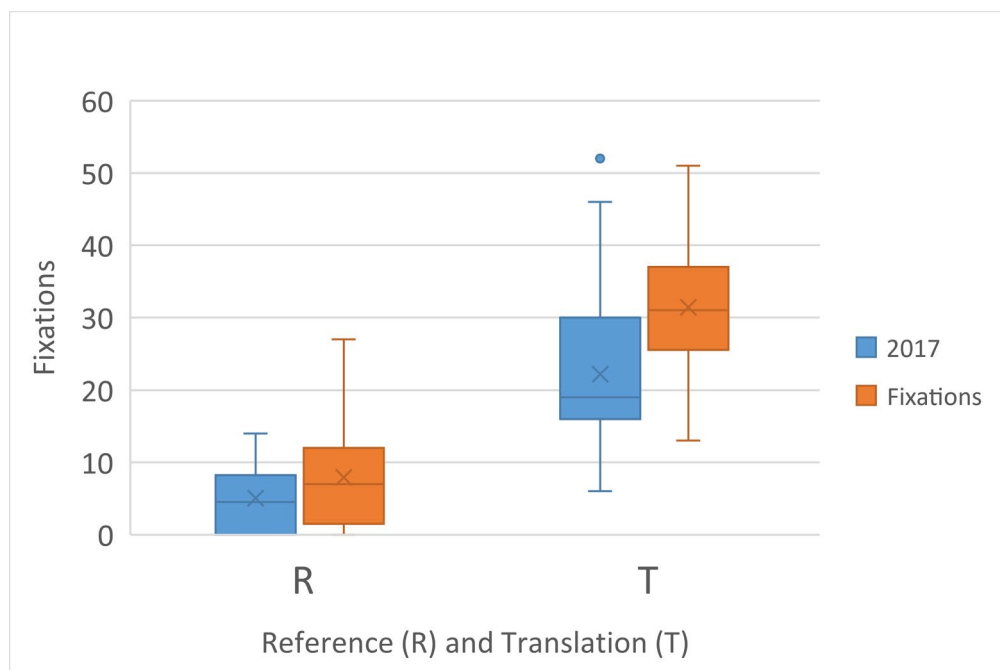


Figure 18. Number of Fixations for activity question 3 for fall 2017 and spring 2019

This entire activity was designed for participants to use models to reinforce the concept of chirality in organic chemistry. Participants were required to translate from 2D drawings to 3D models and also the reverse. It is clear from figures 9 and 10 that some participants utilize models a great deal, especially, when the molecule is larger, more complicated and lowest priority substituent is not already located in the back of the drawing. Understanding how the participants used the models and more importantly, if they were beneficial is the goal of this paper. In the next section of chapter 4, spatial ability and cognitive load will be explored.

### **Spatial Ability Test Scores and Gender**

Because the population was limited, it was the goal of researchers to achieve a range of students with different spatial abilities with as much variation in demographics as could be achieved. Due to time constraints, each sample finished with 8 participants. Scores for both spatial ability tests were broken into three ranges: low, medium and high. Test score ranges were based on the total number of test questions for each test type. For the Purdue Visual Rotation Test (PVRot), a participant's score was considered low if he/she answered up to 6 questions correct, considered medium if 7 to 13 questions were answered correctly and high if the participant answered 14 or more questions correctly. In the fall of 2017, six females and 2 males participated in the study. Of those that participated, 1 female fell in the low range, 1 female fell in the medium range and 4 females and 2 males fell in the high range. Before completing the activity on the day of the session, participants were tested on their field dependency using the Hidden Figures Test (HFT). Participants' scores were considered low if they answered 5 or less correctly, medium if they answered 6 to 11 correctly and high if they answered 12 or more test questions correctly. The HFT scores for the fall 2017 participants were

as follows: 2 females and 1 male in the low range and 4 female and 1 male in the medium range. (See Table 2).

Table 2.

*Spatial Ability Test Scores for Females and Males Fall 2017*

		Purdue Visual Rotation Test (PVRot)		
		Low (0 – 6)	Middle (7 – 13)	High (14 – 20)
		Female/Male	Female/Male	Female/Male
Hidden	Low (0 – 5)	-	1/0	1/1
Figures	Medium (6 – 11)	1/0	-	3/1
Test	High (12 – 16)	-	-	-
(HFT)				

In the spring of 2019, 5 of the 8 participants were female. In regard to the PVRot scores, all participants fell into the medium or high range: medium range included 3 females and 1 male, and the high range included 2 females and 2 males. The HFT for this study was completed during the session after the modeling activity. The participants' scores in this sample were as follows: 2 females and 1 male in the low range, 2 females and 2 males in the medium range and 1 female in the high range. (See Table 3).

Table 3.

*Spatial Ability Test Scores for Females and Males Spring 2019*

		Purdue Visual Rotation Test (PVRot)		
		Low (0 – 6)	Middle (7 – 13)	High (14 – 20)
		Female/Male	Female/Male	Female/Male
Hidden	Low (0 – 5)	-	1/0	1/1
Figures	Medium (6 – 11)	-	1/1	1/1
Test	High (12 – 16)	-	1/0	-
(HFT)				



**Question: How do students' spatial abilities impact their task performance and cognitive engagement while completing the organic chemistry modeling activity?**

Research suggests that spatial reasoning is a contributing factor to success in organic chemistry classes. Having a low spatial ability may contribute to cognitive load and cause students to misunderstand important spatial concepts or fail to problem solve using spatial strategies (Stieff et al, 2012; DeSutter and Stieff, 2014; Pribyl and Bodner, 1987). This section of chapter four discusses spatial ability and how it affected the engagement index. The previous section of this chapter included figures that considered average and total fixations per activity question. This section considers the number of fixations that occurred and compares it to each of the participants' spatial ability. In addition, the researchers investigate how the engagement index is influenced by the participant's spatial ability.

Figure 19 below displays the number of fixations for question one for both samples compared to the HFT score. Figure 20 displays the number of fixations for question one for both samples compared to the PVRot score. These fixations occurred while the participant was deciding if the chiral center had an R or S configuration. Consistent with other fixations figures, sample 2019 used the models more often. Researchers believe this is in response to the modifications made to the activity between studies. In addition, figure 19 shows that participants in the medium range had more average fixations than participants in the low range. Whereas in figure 20, participants with high spatial ability score had fewer average fixations than participants with a medium spatial ability score.

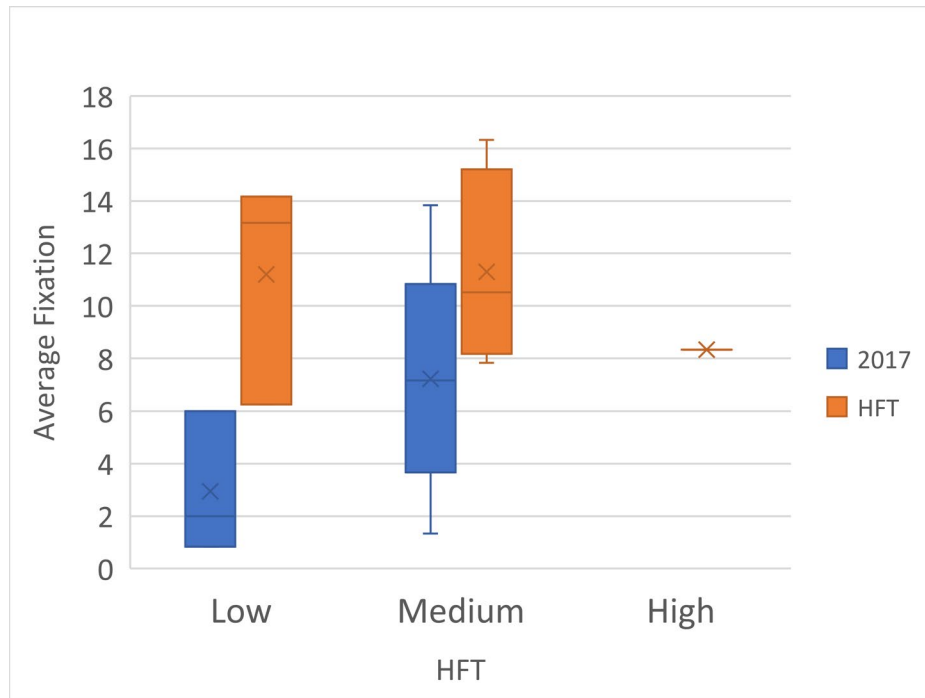


Figure 19. The number of fixations for activity 1 question compared to HFT scores

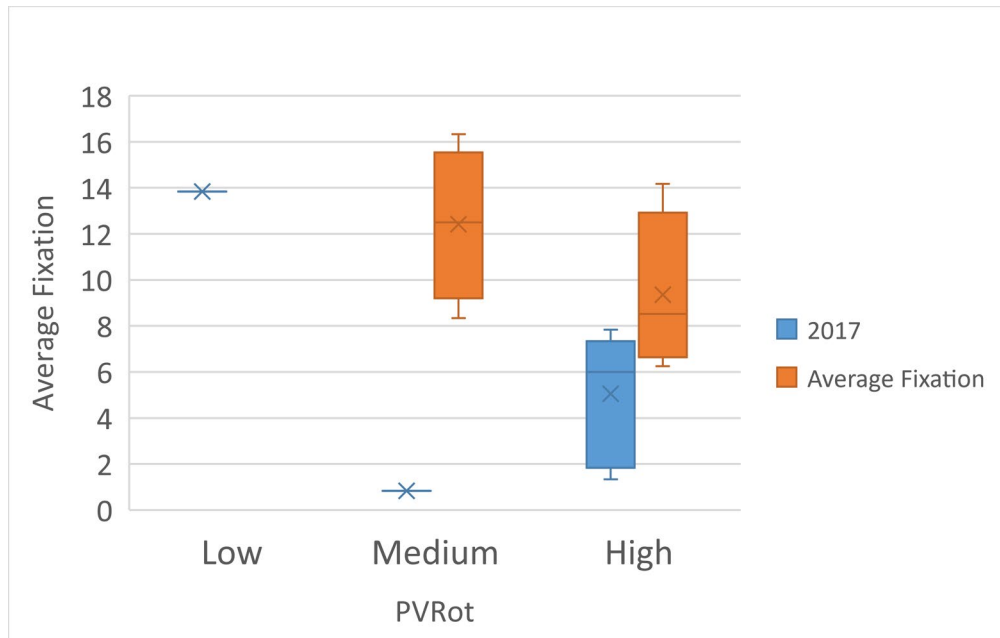


Figure 20. The number of fixations for each activity 1 question compared to PVRot

Spearman's Rho was used to determine if there was an association between variables. Researchers wanted to examine the strength of the relationship between the engagement index and the two spatial ability tests. Because of the large number of trials tested, 11 and 10 respectively, the Bonferroni Correction was used to adjust the alpha value from 0.05 to 0.005 (see Table 4). With this correction, no significant correlation between engagement index and spatial ability was found. The n values differ due to participant completion of activity questions. All graphs generated from this data can be found in appendix G and H.

Table 4.

*Spearman's Rho Correlations Between EI and Spatial Ability Test*

	HFT (2017)				PVRot (2017)			
	n	r	p	r <sup>2</sup>	n	r	p	r <sup>2</sup>
1a	7	-0.473	0.284	0.224	7	0.074	0.875	0.005
1b	7	0.018	0.969	0.000	7	0.259	0.574	0.067
1c	7	-0.382	0.398	0.146	7	-0.111	0.812	0.012
1d	7	-0.145	0.756	0.021	7	-0.185	0.691	0.034
1e	7	-0.691	0.086	0.478	7	-0.296	0.518	0.088
1f	7	-0.546	0.205	0.298	7	0.074	0.875	0.005
2a	7	-0.764	0.046	0.584	7	-0.259	0.574	0.067
3a	6	-0.493	0.321	0.243	6	0.174	0.742	0.030
3b	7	-0.491	0.263	0.241	7	-0.148	0.751	0.022
3c	6	-0.618	0.191	0.382	6	-0.638	0.173	0.407

	HFT (2019)				PVRot (2019)			
	n	r	p	r <sup>2</sup>	n	r	p	r <sup>2</sup>
1a	8	-0.216	0.608	0.046	8	0.331	0.423	0.110
1b	8	0.862	0.006	0.743	8	-0.049	0.908	0.002
1c	8	0.299	0.471	0.090	8	0.258	0.538	0.066
1d	7	0.667	0.102	0.444	7	0.073	0.877	0.005
1e	8	0.431	0.286	0.186	8	0.503	0.204	0.253
1f	7	0.360	0.427	0.130	7	0.318	0.487	0.101
2a	7	0.090	0.848	0.008	7	0.730	0.063	0.533
2b	7	-0.324	0.478	0.105	7	0.056	0.905	0.003
3a	7	0.487	0.268	0.237	7	-0.430	0.335	0.185
3b	7	-0.09	0.848	0.008	7	0.692	0.085	0.479
3c	7	0.324	0.478	0.105	7	0.561	0.19	0.315

Chapter 4 discussed the data that was collected and analyzed from the fall 2017 and spring 2019 organic chemistry chirality physical modeling activity. Researchers were interested in determining the cognitive load of learning activities by calculating the engagement index. This index was compared to spatial ability, model usage and performance. Chapter 5 will further discuss this data, will express the implications of this research for teaching this concept in the future and provide the future implications of this research.

## **Chapter 5: Conclusions, Implications and Future Work**

The purpose of this chapter is to summarize and reflect on the findings of the research from this study, and to state the implications of this research to current organic chemistry teachers and to chemistry education researchers. Finally, the potential for future research from these findings will be discussed.

### **Discussion**

The goal of this research study was to determine the amount of cognitive load associated with physical modeling activities in organic chemistry. The goal of education should be to optimize cognitive load for students by creating activities that improve the effectiveness and efficiency of learning (Mayer and Moreno, 2003; Copolo and Hounshell, 1995). Researchers in this study hypothesize that as cognitive load increases, learning decreases. Constructivism, the theoretical framework for this research study, assumes that all students have a learned framework in place and that learning occurs if new information can be added to that framework (Von Glasersfeld, 1984; Bodner, 1986). If cognitive load interferes with this process, meaningful learning will not take place.

This study was able to collect data from two different groups with an activity modification occurring between the collections. The graphs generated from both sets of data for question 1 look quite different. The fall 2017 graph (Figure 7) comparing the engagement indices for each part of question 1 shows no trend as the engagement index is scattered; however, the spring 2019 graph (Figure 8) for engagement indices per question shows a distinct trend. As participants completed the activity, the engagement level decreased suggesting that the questions of the activity were scaffolded to optimize cognitive load. Questions 2 and 3 from the modeling activity were not modified and results from both years were similar.

The study also found that model use varied based on the difficulty of the question. Molecules that were drawn with the lowest priority substituent in the back had a lower average frequency of model usage. Researchers determined that these types of questions had low level of engagement and discouraged the use of models to answer the questions; therefore, one of the modifications made between the studies was to change questions of this type from 3 in the fall 2017 activity to 1 in the spring 2019. The result was a much higher frequency of fixation between the 2D drawing and 3D model representations for the spring 2019 study as compared to fall 2019 (see Figure 9 and 10).

Spatial ability and its effect on engagement was inconclusive for this study. The results obtained did not support what was expected by the researchers and cannot be logically justified. A collection of more data and increased sample sizes could provide further insight into these findings.

### **Limitations of Study**

The goal of this research project was to have a total of 12 participants for each study. Although 12 participants had signed up to complete sessions, due to various circumstances, each sample finished with 8 participants. This is not uncommon for this type of research and several other studies have had similar n values. The engagement index used for this study originates from a study completed by Pope, Bogart and Bartolome, 1995 and this study had only 6 participants. Another study interested in engagement and learning tasks using EEG data and in the content area of physics utilized 10 male participants (Charland et al, 2016).

Another limitation of the sample is that the population from which the sample was taken is relatively homogeneous in regard to ethnicity and major (pre-med). In addition, there was a

chemistry curriculum change between the fall 2017 and spring 2019 collections. Although all participants were considered first year college freshman, the fall participants were first semester and the spring participants were second semester.

### **Implications for Educators**

Using models to help students understand and learn difficult abstract chemical concepts is a strategy used by many educators at all levels of chemistry education (Chi, 2008; Gentner & Stevens, 1983; Copolo and Hounshell, 1995). Research of this type gives insight to not only the benefits of physical modeling activities, but also, ways to improve the activity to ensure that cognitive load is optimized for the learner. The most important lesson from this research project was the need for a carefully designed activity. The differences in the engagement index values between the fall and spring studies was evident in the graphs generated from the data (Figure 7 and 8). In addition, an increase in the number of fixations during 2D and 3D translations occurred between fall 2017 and spring 2019 data collections (Figures 9, 10, 18 – 21). It is hypothesized that the changes in the graphs could be a result of the modifications made to the activity; however, more data collection is needed to corroborate this hypothesis. Research suggests that if the cognitive load is optimized, learning can occur (Mayer and Moreno, 2003). Therefore, an educator designing modeling activities, needs to consider the questions being asked. Guiding the student through the learning objective with scaffolding and carefully placed questions seems to be beneficial for the learning experience.

In addition, the engagement index generated from the data gives insight to the cognitive load of the participant for each question during the activity. Giving information of this type to the educator could prove to be a useful tool in recognizing students that need enrichment (low engagement indices) or remediation (high engagement indices). For validation, students could

possibly self-assess their cognitive load subjectively and then compare it to their calculated engagement index.

### **Implications for Future Research**

There is an abundance of research available regarding spatial ability, specifically rotational, and its necessity for success in chemistry classes (Antonoglou *et al*, 2014; Stieff *et al*, 2012; Pribyl and Bodner, 1987; Harle and Towns, 2010). Data from this research study, however, seems to be inconclusive regarding the importance of spatial ability for this physical modeling activity. In addition, only field dependency as tested by the HFT showed strong correlations between EI (table 4). Rotational spatial ability did not seem to be associated with the engagement level of the participants in either study regardless of the modifications made to the activity. For this reason, different types of spatial ability (rotational and field dependency) and its connection to cognitive load should be investigated to see if additional correlations can be determined or if the association is only in regard to previous reports of performance.

### **Next Steps for this Study**

To calculate the engagement index, this paper utilized data from the midline cortex and parietal lobe. However, research conducted using PET and fMRI suggest that the frontal lobe could also be an area of interest when cognitive processing is occurring (Na *et al*, 2000). Therefore, data from the frontal cortex could potentially yield different engagement index values. One such study is using data from electrode sites F3, F4, O1 and O2 and exploring cognitive load problem solving performance in physics (Charland *et al*, 2016). The frontal lobe is the part of the brain responsible for thinking and problem solving, and the occipital lobe translates all visual sensory information.



As research continues for this project, all potential combinations of electrodes sites located in the frontal, parietal and occipital lobe should be investigated to determine if the same results and trends are generated regardless of the electrode signals chosen to complete data analysis. The following are the specific combinations proposed for investigation: frontal lobe only, occipital lobe only, frontal and parietal lobe, frontal and occipital lobe and finally frontal, parietal and occipital lobes.

In addition, the activity should be tested again without additional modifications to see if the participants in the next study have similar EI values as the spring 2019 study. This would provide stronger evidence that the differences in the EI values between fall 2017 and spring 2019 were indeed from the activity and not some other variable. Researchers predict that similar trends to the 2019 sample would be seen in the next sample group.

Ultimately, the goal of this research is to increase learning for all students. As EEG technologies and the methods for determining cognitive load improve, an understanding of how the brain learns will improve teaching methods and promote student learning. Educating students should always be as efficient and effective as possible.

## References

- Abraham, M.R. (2008). Importance of a Theoretical Framework for Research. *Nuts and Bolts of Chemical Education Research*; American Chemical Society: Washington, DC; ACS Symposium Series 976, pp 47–66.
- Abraham, M., V. Varghese and H. Tang. (2010). Using molecular representations to aid student understanding of stereochemical concepts. *Journal of Chemical Education*. 87(12), 1425-1429.
- Antonoglou, L. D. *et al.* (2014). Investigating chemistry students' skills to mentally manipulate (rotation & reflection) 2D symbolic molecular representations. *Procedia – Social and behavioral Sciences*. 152, 517 - 522.
- Baddeley, A. (1992). Working Memory. *Science*, 255, 556 – 559.
- Baddeley, A. D and G. J. Hitch (1974). The Psychology of Learning and Motivation, G. A. Bower, Ed. Academic Press, New York, vol. 8, pp. 47-89.
- Bodner, G.M. (1986). Constructivism: a theory of knowledge. *Journal of Chemical Education*, 63, 873-878.
- Bodner, G.M., & Guay, R.B. (1997). The Purdue visualization of rotations test. *The Chemical Educator*, 2(4), 1-17.
- Chapman, O. L and A. A. Russell. (1992). Structure and chirality and FT-NMR in sophomore organic chemistry. A modern approach to teaching. *Journal of Chemistry Education*. 69(10), 779.
- Charland, P. *et al.* (2016). Measuring implicit cognitive and emotional engagement to better understand learners' performance in problem solving. *Zeitschrift fu Psychologie*. 224(4), 294 – 296.
- Chi, M. T. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. *International handbook of research on conceptual change*, 61-82.
- Coll, R. K., B. France and I. Taylor. (2011). The role of models/and analogies in science education: implications from research. *International Journal of Science Education*. 27(2), 183-198.
- Copolo, C. F. and P. B. Hounshell (1995). Using Three-Dimensional Models to Teach Molecular Structures in High School Chemistry. *Journal of Science Education and Technology*, 4(4), 295-305.

- Cortes, Kimberly J., Kammerdiener, Kimberly, and Randolph, Adriane B., "Using Multiple Psychophysiological Techniques to Triangulate the Results of Eye-Tracking Data," VandenPlas, Jessica R., et al., eds. *Eye Tracking for the Chemistry Education Researcher*, American Chemical Society, Volume 1292, pp 119-143, September 19, 2018.
- Cranford, K. N., Tiettmeyer, J. M., Chuprinko, B. C., Jordan, S., & Grove, N. P. (2014). Measuring load on working memory: the use of heart rate as a means of measuring chemistry students' cognitive load. *Journal of Chemical Education*, 91(5), 641-647.
- DeLeeuw, K.E. and R.E. Mayer. (2008). A Comparison of Three Measures of Cognitive Load: Evidence for Separable Measures of Intrinsic, Extraneous, and Germane Load. *Journal of Educational Psychology*, 100, 223 – 234.
- DeSutter, D. and M. Stieff (2014). Taking a New Perspective on Spatial Representations in STEM. ICLS 2014 Proceedings, 1599 – 1600.
- Gentner, D., & Stevens, A. L. (1983) *Mental models*. Hills-dale: NJ: Lawrence Erlbaum.
- Gilbert, J.K. and Osborne, R.J. (1980). The use of models in science and science teaching. *European Journal of Science Education*, 1(2), 3-13.
- Gwizdkle, J. Using Stroop Task to Assess Cognitive Load. Proceedings of the European Conference on Cognitive Ergonomics; Delft: The Netherlands, 2010.
- Harle, M and M. Towns. (2011). A Review of Spatial Ability Literature, Its Connection to Chemistry, and Implications for Instruction. *Journal of Chemical Education*. 88(3)351-360.
- Jaeger, A. J., T. F. Shipley and S. J. Reynolds. (2017). The roles of working memory and cognitive load in geoscience learning. *Journal of Geoscience Education* 65, 506–518
- Johnstone, A. H., & Kellett, N. C. (1980). Learning difficulties in school science-toward a working hypothesis. *International Journal of Science Education* 2: 171–181.
- Johnston, J.H., S.M. Fiore, C. Paris and C.A.P. Smith. (2013) Application of Cognitive Load Theory to Develop a Measure of Team Cognitive Efficiency. *Military Psychology*, 25, no. 3, 252 – 265.
- Johnstone, A.H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7(2), 75-83.
- Jones, A. H., M. Spichkova and M. J. S. Spencer. (2018). Chirality – 2: Development of a multilevel mobile gaming app to support the teaching of introductory undergraduate-level organic chemistry. *Journal of Chemistry Education*, 95(7), 1216-1220.

Karch, J. M., J. C. García Valles, and H. Sevian. (2019). Looking into the black box: using gaze and pupillometric data to probe how cognitive load changes with mental tasks. *Journal of Chemical Education*. 96, 830–840.

Kostilek, M. and J. Stastny. (2012). EEG biometric identification: repeatability and influence of movement -related EEG. *IEEE Xplore 2012 Proceedings*.

Kramer, W. H. and A. G. Griesbeck. (2008). The same and not the same: chirality, topicity and memory of chirality. *Journal of Chemistry Education* 85(5), 701

Mayer, R. E. (2009). *Multimedia learning 2nd Ed.* Cambridge University Press: New York.

Mayer, R. E. and R. Moreno. (2003). Nine Ways to Reduce Cognitive Load in Multimedia Learning. *Educational Psychologist*. 38(1), 43 – 52.

McLeod, S. A. (2012). Working Memory. Retrieved June 25, 2019, from simplypsychology.org: [http://www.simplypsychology.org/ working%20memory.html](http://www.simplypsychology.org/working%20memory.html)

McMurry, J. (2004). *Organic Chemistry*. Belmont, CA: Thomson Learning.

Miller, G.A. (1956) The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychol. Rev.* 63, 81–97

Na, Dong Gyu *et al* (2000). Functional MR Imaging of Working Memory in the Human Brain. *The Korean Radiological Society*. 1(1):19-24.

Oh, Phil Seok and Oh, Sung Jin. (2011) What teachers of science need to know about models: an overview. *International Journal of Science Education*, 8(33), 1109-1130.

Piaget, J. (1936). *Origins of intelligence in the child*. London: Routledge & Kegan Paul.

Pope, A. T., E. H. Bogart and D. S. Bartolome. (1995). Biocybernetic system evaluates indices of operator engagement in automated task. *Biological Psychology*. 40, 187 – 195.

Potter, R.F. and P.D. Bolls. (2012). *Psychophysiological Measurement and Meaning: Cognitive and Emotional Processing of Media*. New York, NY: Routledge.

Pribyl, J. R. and G. M. Bodner. (1987). Spatial ability and its role in organic chemistry: a study of four organic courses. *Journal of Research in Science Teaching*. 24(3), 229 – 240.

- Skulmowski, A. and G.D. Rey. (2017). Measuring Cognitive Load in Embodied Learning Settings.
- Stieff, M (2007). Mental rotation and diagrammatic reasoning in science. *Learning and Instruction* 17, 219-234.
- Stieff, M. et al. (2012). The Role of Spatial Ability and Strategy Preference for Spatial Problem Solving in Organic Chemistry. *Journal of Chemical Education*, 89, 854-859.
- Sousa, D. (2011). *How the Brain Learns*, 4<sup>th</sup> ed.; Corwin: Thousand Oaks.
- Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12, 257 – 285.
- Sweller, J. (1994). Cognitive load theory, learning difficulty and instructional. *Learning and Instruction*, 4, 293-312
- Towns, M.H. (2008). Mixed Methods Designs in Chemical Education Research. *Nuts and Bolts of Chemical Education Research*; American Chemical Society: Washington, DC; ACS Symposium Series 976, pp 135-148.
- von Glasersfeld, E. (1984). An introduction to radical constructivism. In P. Watzlawick (Ed.), *The invented reality* (pp. 17-40). New York: Norton.
- Wintner, C. E. (1983). Two-dimensional chirality in three-dimensional chemistry. *Journal of Chemistry Education*. 60(7), 550
- Wong, M *et. al.* (2018). Investigating gender and spatial measurements in instructional animation research. *Computers in Human Behavior*. doi: 10.1016/j.chb.2018.02.017
- Wu, H., Krajcik, J. S. and E. Soloway. (2000). Using Technology to Support the Development of Conceptual Understanding of Chemical Representations. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 121-128). Mahwah, NJ: Erlbaum.

## Appendix

### Appendix A – Fall 2017 Physical Modeling Activity

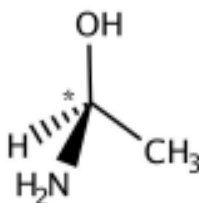
Organic Chemistry I, Fall 2017  
Chirality Activity  
ModEL-C Interviews

Name	
------	--

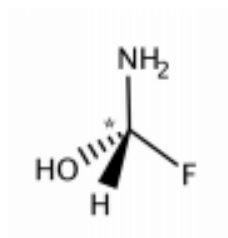
1. For each molecule shown:

1. Build the molecule shown using your modeling kit.
2. Assign R or S configuration to the chiral center (indicated with the \*)

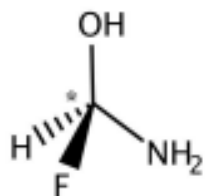
A)



B)



C)



3. Using the 3D physical models:
1. Draw the representation on paper
  2. Assign R or S configuration to the chiral center

A)

B)

C)

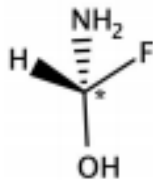
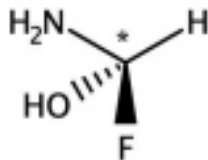
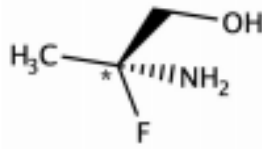
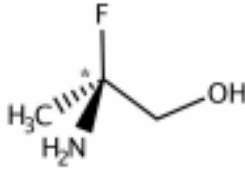
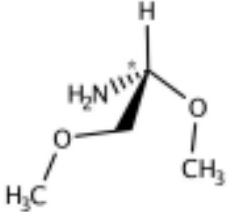
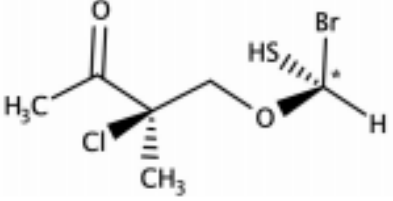
Appendix B – Spring 2019 Physical Modeling Activity

CHEM2, Fall 2019  
Chirality Activity  
ModEL-C Session

Name	
------	--

1. For each molecule shown:

- Build** the molecule shown using your modeling kit.
- Assign** R or S configuration to the chiral center (indicated with the \*)

<p><b>A</b></p>  <p>Circle one: <i>R</i> or <i>S</i> configuration?</p>	<p><b>B</b></p>  <p>Circle one: <i>R</i> or <i>S</i> configuration?</p>
<p><b>C</b></p>  <p>Circle one: <i>R</i> or <i>S</i> configuration?</p>	<p><b>D</b></p>  <p>Circle one: <i>R</i> or <i>S</i> configuration?</p>
<p><b>E</b></p>  <p>Circle one: <i>R</i> or <i>S</i> configuration?</p>	<p><b>F</b></p>  <p>Circle one: <i>R</i> or <i>S</i> configuration?</p>



2. a) Which of the above molecules in question 1 are mirror images:

b) For the two molecules in part a, **circle** all the following that would be the same between the two molecules.

- i. Hybridization    ii. Polarity    iii. Reactivity    iv. Relative boiling point*  
*v. Intermolecular forces (non-covalent interactions)    vi. Relative melting point*  
*vii. Acidity/basicity    viii. Optical rotation*

3. Using the 3D physical models:

1. Draw the representation on paper
2. Assign R or S configuration to the chiral center

A)

B)

C)

## Appendix C – Consent Form

**Title of Research Study:** NSF proposal 1711402/1711425: Collaborative Research: Modeling for the Enhancement of Learning Chemistry (ModEL-C): Measuring cognitive load & impact of modeling activities across the chemistry curriculum

**Researcher:** Cassidy R. Terrell

**Supported By:** This research is supported by NSF pending approval.

### Why am I being asked to take part in this research study?

You are being invited to take part in a research study conducted by Cassidy Terrell, Ph.D. at University of Minnesota, Rochester and Kimberly Cortes, Ph.D. of Kennesaw State University. Before you decide to participate in this study, you should read this form and ask questions about anything that you do not understand. To participate in this study you must be enrolled as a student at University of Minnesota, Rochester and enrolled in Organic Chemistry I, Organic Chemistry II, General Chemistry I, General Chemistry II, and Biochemistry course as a student. You must be at least 18 years of age, English speaker, right handed, and not pregnant.

### What should I know about a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

### Who can I talk to?

For questions about research appointments, the research study, research results, or other concerns, call the study team at:

Researcher Name: Cassidy Terrell Phone Number: 952-334-8167 Email Address: terre031@r.umn.edu	Research Name: Kimberly Cortes Phone Number: 470-578-6278 Email Address: klinenbe@kennesaw.edu
---	--

This research has been reviewed and approved by an Institutional Review Board (IRB) within the Human Research Protections Program (HRPP). To share feedback privately with the HRPP about your research experience, call the Research Participants' Advocate Line at [612-625-1650](tel:612-625-1650) or go to [www.irb.umn.edu/report.html](http://www.irb.umn.edu/report.html). You are encouraged to contact the HRPP if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research.

### Why is this research being done?

This project is a collaboration between faculty at University of Minnesota, Rochester (UMR) and at Kennesaw State University (KSU). The goal of this project is to increase biochemistry and chemistry students' understanding of structure function relationships using 3D modeling activities. First, this we hope to determine the cognitive load of the 3D modeling activities used in chemistry courses. Second, this proposal aims to characterize the impact of 3D modeling on undergraduate student's misconception of structure-function relationships. With this research, we could better design and execute 3D modeling activities that deepen students' ability to understand chemistry.

### How long will the research last?

We expect that you will be in this research study for minimum of one semester and up to six semesters

### How many people will be studied?

We expect about 900 people here will be in this research study.

### What happens if I say "Yes, I want to be in this research"?

You will be presented with several models in a mock teaching environment. The data collection will consist of taking measurements of your eye movement with a remote eye tracker while you are using three-dimensional virtual or physical models. The initial process will require a calibration of your eyes to the eye tracking system. In addition to the eye tracking data, brain activity data will also be collected. Brain activity will be measured by an electroencephalogram (EEG) which is an instrument that reads scalp electrical activity that allows measurements of brain activity. This will be accomplished by placing a non-invasive head cap with 16 electrodes that are placed at strategic points. A small amount of gel will be injected into each electrode to ensure a secure connection. Once the eye tracking system and the EEG monitoring system have been calibrated, you will begin the respective modeling activity that you will be using in your class this semester. In addition, the mock-teaching session will be audio and video recorded to ensure that all interactions with the model and the instructor are recorded.

The activity will take approximately 75 to 90 minutes. During this activity you will interact with the researchers to set up the eye tracker and the EEG and then you will interact with your professor in a mock teaching environment to answer any questions pertaining to the activity itself. The activity will be conducted in a conference room that do not have windows to ensure quality of data. The activity will be conducted towards the beginning of the semester. You will have the opportunity to participate in a second activity session if you would like at a later time. You may be asked upon analysis of the data for additional clarification of the findings from your participation in the study.

### What happens if I do not want to be in this research?

You can leave the research at any time and it will not be held against you.

### What happens if I say “Yes”, but I change my mind later?

You can leave the research at any time and it will not be held against you.

If you decide to leave the research, prior to the completion of the interview you will not be compensated with the \$25 gift card. Each interview completed, however, will result in compensation of a \$25 gift card per interview. You may participate in up to two interviews per semester of the study. If you decide to leave the research after completion of any interview, contact the investigator so that the investigator can know whether or not you would like to include your previous data in the study.

### Will being in this study help me in any way?

There may be no direct benefit to you or others from your taking part in this research. However, possible benefits include additional one-on-one instruction with your professor on topics covered in your course during the mock learning environments. In addition, the researchers will learn more about how students think about models in order to better prepare teachers to teach this material in the future. There may be an inherent sense of satisfaction by participating in academic research using novel technology.

### What happens to the information collected for the research?

Efforts will be made to limit the use and disclosure of your personal information, including research study and medical records, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this institution, the National Science Foundation, and the collaborators at Kennesaw State University.

All data will be stored on a secured computer with access limited to the members of the staff and the principal investigator conducting the study. The password protected computer will be kept in a locked and secure room located in the KSU Science building or in the UMR Usq building. All data on written paper and signed consent forms will be stored in a locked filing cabinet in the research laboratory at Kennesaw State University. These data sets will be kept indefinitely for analysis. If the results are published, your identity will remain confidential.

### Will I have a chance to provide feedback after the study is over?

After the study, you might be asked to complete a survey about your experience as a research participant. You do not have to complete the survey if you do not want to. If you do choose to complete the survey, your responses will be anonymous.

If you are not asked to complete a survey after the study is over, but you would like to share feedback, please contact the study team or the Human Research Protection Program (HRPP). See the “Who Can I Talk To?” section of this form for study team and HRPP contact information.

### What else do I need to know?

All results of this research will be updated on the project website. Feel free to check back to see the results of the study.

The results of this study may also be used for teaching, publications, or for presentation at scientific meetings.

**Signature Block for Capable Adult**

Your signature documents your permission to take part in this research.

---

Signature of participant

---

Date

---

Printed name of participant

---

Signature of person obtaining consent

---

Date

---

Printed name of person obtaining consent

## Appendix D – IRB Approval

### UNIVERSITY OF MINNESOTA

Twin Cities Campus

Human Research Protection Program  
Office of the Vice President for Research

1552 Mayo Memorial Building  
420 Delaware Street S.E.  
MMC 420  
Minneapolis, MN 55455  
Phone: 612-626-5454  
Fax: 612-626-6061  
Email: [hrp@umn.edu](mailto:hrp@umn.edu)  
<http://www.research.umn.edu/subjects/>

#### APPROVAL OF SUBMISSION

May 15, 2017

Cassidy Terrell

952-334-8167  
[terre031@umn.edu](mailto:terre031@umn.edu)

Dear Cassidy Terrell:

On 5/15/2017, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	NSF proposal 1711402/1711425: Collaborative Research: Modeling for the Enhancement of Learning Chemistry (Model-C): Measuring cognitive load & impact of modeling activities across the chemistry curriculum
Investigator:	Cassidy Terrell
IRB ID:	STUDY00000266
Funding:	Sponsor Name: THE NATIONAL SCIENCE FOUNDATION, Grant Title: Modelling for the Enhancement of Learning Chemistry (Mod
Grant ID/Con Number:	CON000000064459;
IND, IDE, or HDE:	None
Documents Reviewed:	<ul style="list-style-type: none"><li>• Hidden Figures Test, Category: Other;</li><li>• ModelC Participant Pre-Survey, Category: Recruitment Materials;</li><li>• ESIC1, Category: Other;</li><li>• IILSI, Category: Other;</li><li>• Purdue Visual Rotation Test, Category: Other;</li><li>• Recruitment Materials, Category: Recruitment Materials;</li><li>• SOCIAL TEMPLATE, Category: IRB Protocol;</li><li>• Interview Consent form, Category: Consent Form;</li></ul>

**Driven to Discover™**

The IRB approved the study from 5/15/2017 to 5/14/2018 inclusive.

To document consent, use the consent documents that were approved and stamped by the IRB. Go to the Documents tab to download them.

For grant certification purposes you will need these dates and the Assurance of Compliance number which is FWA00000312 (Fairview Health Systems Research FWA00000325, Gillette Children's Specialty Healthcare FWA00004003).

The HIPAA Authorization was also approved.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within ETHOS.

Sincerely,

Andrew Allen, CIP

IRB Analyst

## Appendix E – IRB Letter of Support



June 19, 2017

Dr. Kimberly Cortes  
Assistant Professor of Chemistry Education  
Department of Chemistry and Biochemistry  
SC431, MD#1203  
Kennesaw State University

RE: NSF proposal 1711402/1711425: *Collaborative Research: Modeling for the Enhancement of Learning Chemistry (ModEL-C): Measuring cognitive load & impact of modeling activities across the chemistry curriculum*

Dr. Cortes,

This letter is to provide support and clarification regarding IRB oversight of your collaboration with Dr. Terrell on the above referenced project at the University of Minnesota, Rochester (UMR). Because there will be no human subjects data collection from Kennesaw State University (KSU) students, KSU's Institutional Review Board (IRB) will not be providing oversight nor is there a need for us to provide a review/approval of this project.

Furthermore, we have reviewed the UMR IRB approval letter and application documents for STUDY00000266 and can confirm that their IRB will provide oversight for this project.

Please advise if you need additional clarification or information from us to allow you to move forward with this project.

Respectfully,



Christine Ziegler, Ph.D.  
Professor of Psychology  
Director and Chair, KSU Institutional Review Board

## Appendix F – Grading Rubric for Fall 2017 and Spring 2019

Scoring rubrics  
Fall 2017

<b>Question 1A</b>	For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center
	<div> <div>Mastering (1)</div> <div>Not Demonstrated (0 pts)</div> <div>Score</div> <div>Comments</div> </div> <div> <div>S configuration</div> <div>R configuration</div> </div>
<b>Question 1B</b>	For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center
	<div> <div>Mastering (1)</div> <div>Not Demonstrated (0 pts)</div> <div>Score</div> <div>Comments</div> </div> <div> <div>S configuration</div> <div>R configuration</div> </div>
<b>Question 1C</b>	For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center
	<div> <div>Mastering (1)</div> <div>Not Demonstrated (0 pts)</div> <div>Score</div> <div>Comments</div> </div> <div> <div>R configuration</div> <div>S configuration</div> </div>
<b>Question 1D</b>	For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center
	<div> <div>Mastering (1)</div> <div>Not Demonstrated (0 pts)</div> <div>Score</div> <div>Comments</div> </div> <div> <div>R configuration</div> <div>S configuration</div> </div>
<b>Question 1E</b>	For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center
	<div> <div>Mastering (1)</div> <div>Not Demonstrated (0 pts)</div> <div>Score</div> <div>Comments</div> </div>



		S configuration	R configuration		
<b>Question 1F</b>	For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		R configuration	S configuration		
<b>Question 2</b>	Which of the above molecules in question 1 are mirror images				
		<i>Mastering (2 pts)</i>	<i>Emerging (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i> <i>Comments</i>
		B+C, A+D	Missing/incorrect 1 of 2	Missing/incorrect 2 of 2	
<b>Question 3A</b>	Using the 3D physical models: Draw the representation on paper. 2. Assign R or S configuration to the chiral center				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		R configuration	S configuration		
<b>Question 3B</b>	Using the 3D physical models: Draw the representation on paper. 2. Assign R or S configuration to the chiral center				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		R configuration	S configuration		
<b>Question 3C</b>	Using the 3D physical models: Draw the representation on paper. 2. Assign R or S configuration to the chiral center				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		S configuration	R configuration		

Spring 2019

**Question 1A**

For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center

<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
S configuration	R configuration		

**Question 1B**

For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center

<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
R configuration	S configuration		

**Question 1C**

For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center

<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
S configuration	R configuration		

**Question 1D**

For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center

<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
S configuration	R configuration		

**Question 1E**

For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center

<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
R configuration	S configuration		

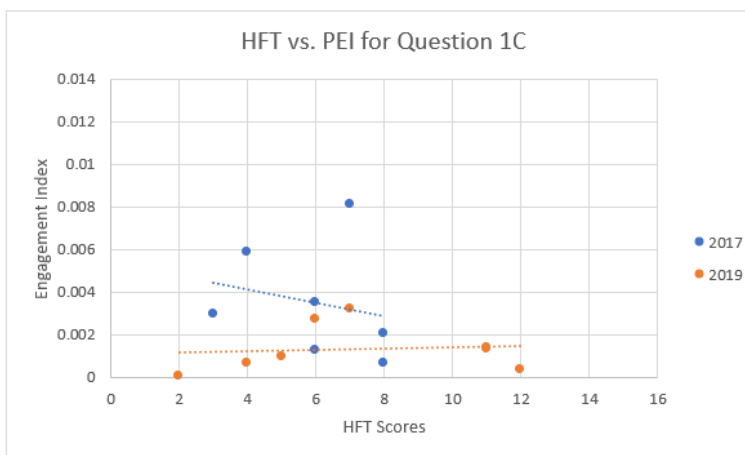
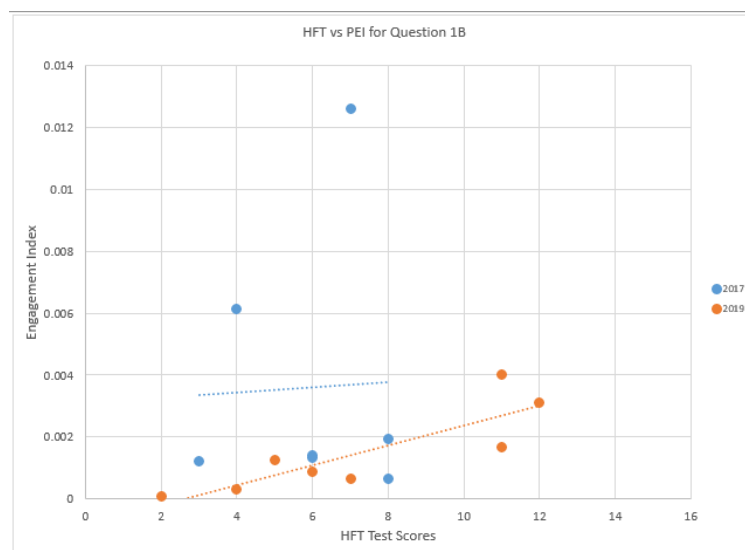
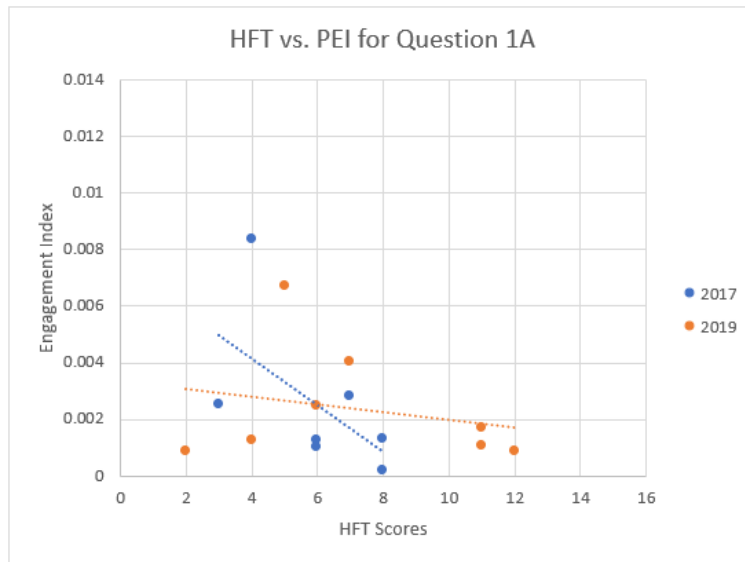
**Question 1F**

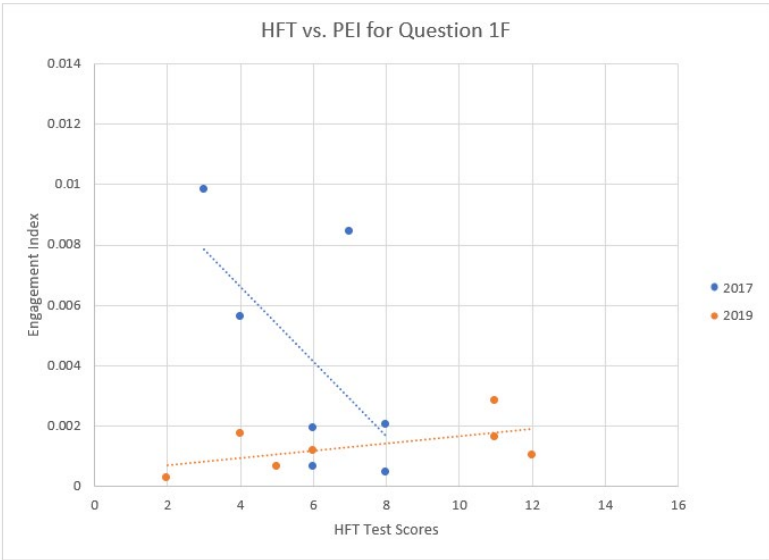
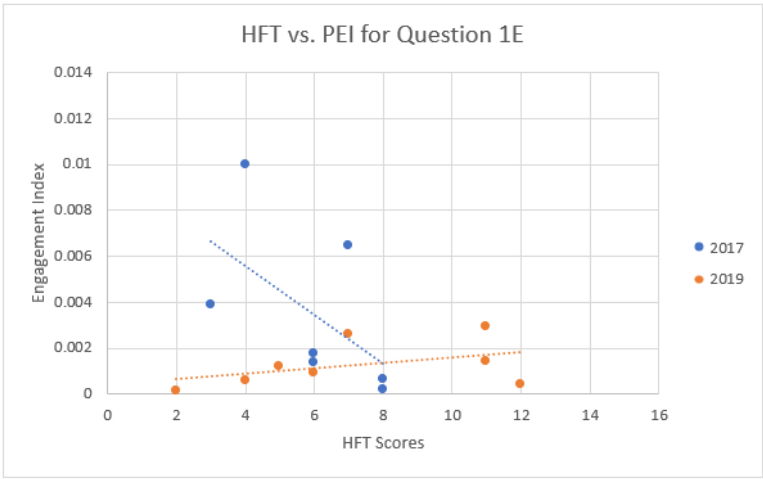
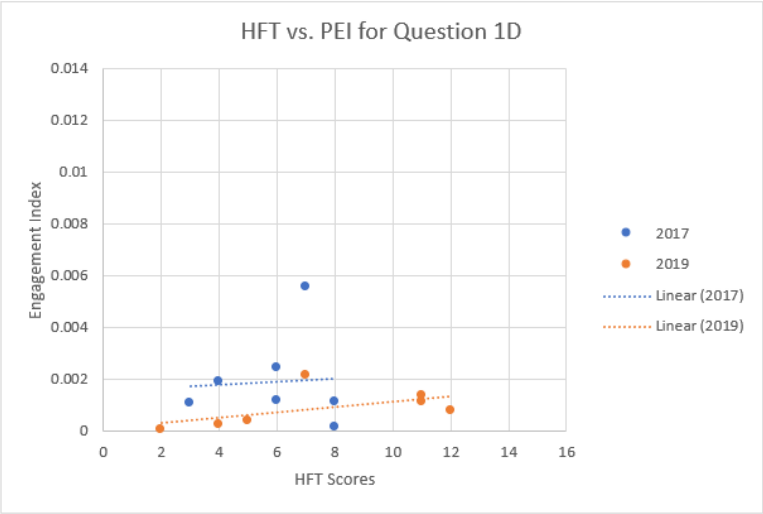
For each molecule shown below: 1. Build the molecule shown using your model kit. 2. Assign R or S configuration to the chiral center

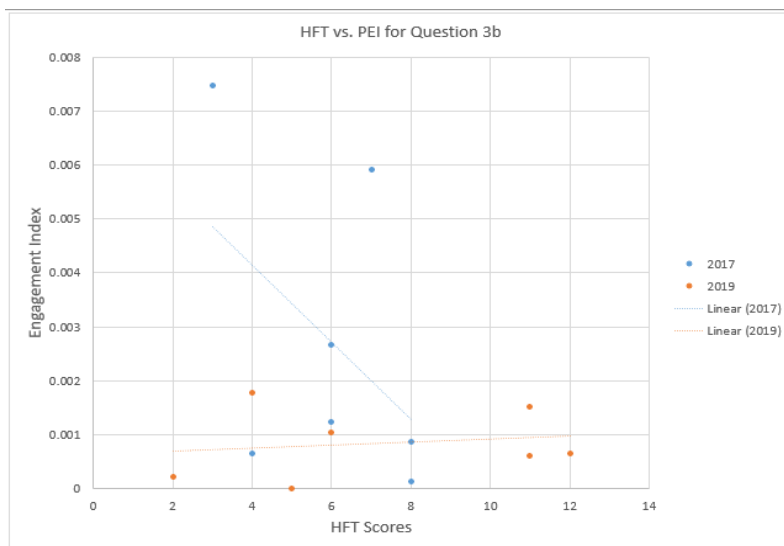
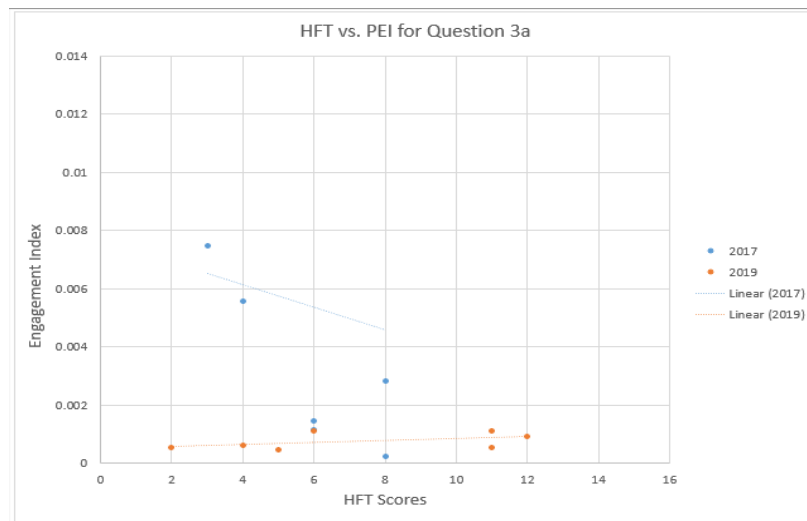
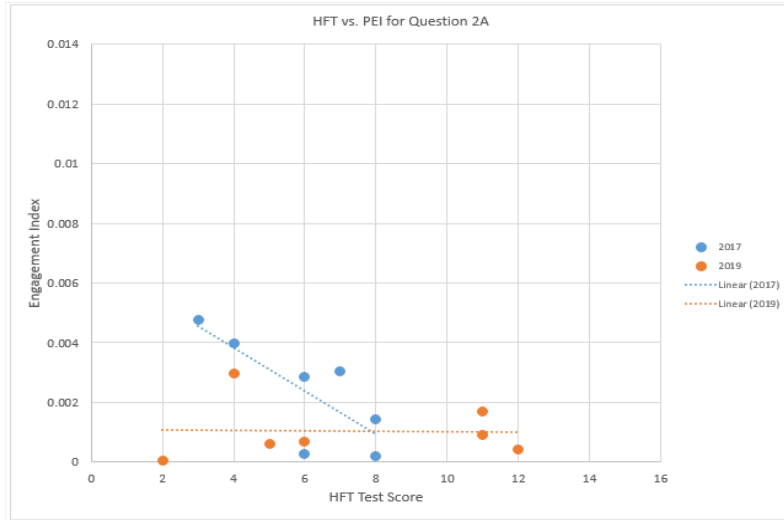
<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>

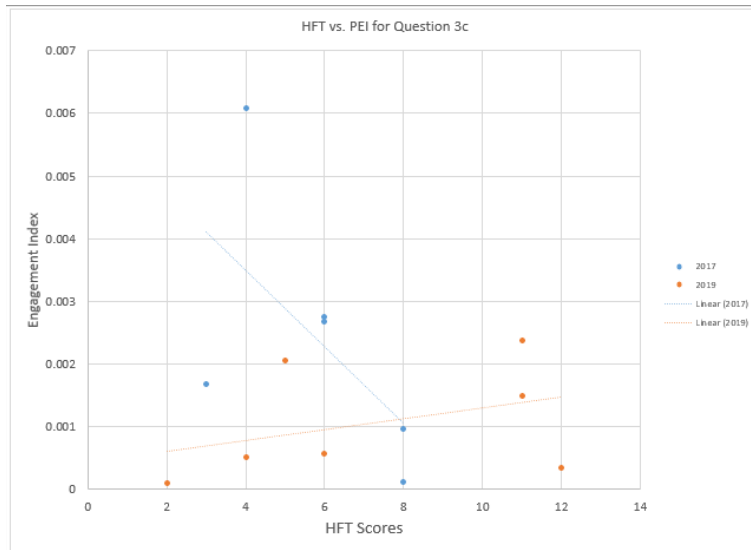
		S configuration	R configuration		
<b>Question 2A</b>	Which of the above molecules in question 1 are mirror images				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		A+B	Incorrect/missing		
<b>Question 2B</b>	For the molecular in part a, circle all the following that would be the same between the two molecules				
		<i>Mastering (3 pts)</i>	<i>Satisfactory (2 pts)</i>	<i>Emerging (1)</i>	<i>Not Demonstrated (0 pts)</i>
		Circles all seven: i,ii,iii,iv,v,vi,vii	Missing/incorrect 1-3 of seven	Missing/incorrect 4-6 of seven	Missing/incorrect 7 of 7
<b>Question 3A</b>	Using the 3D physical models: Draw the representation on paper. 2. Assign R or S configuration to the chiral center				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		R configuration	S configuration		
<b>Question 3B</b>	Using the 3D physical model: Draw the representation on paper. 2. Assign R or S configuration to the chiral center				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		R configuration	S configuration		
<b>Question 3C</b>	Using the 3D physical models: Draw the representation on paper. 2. Assign R or S configuration to the chiral center				
		<i>Mastering (1)</i>	<i>Not Demonstrated (0 pts)</i>	<i>Score</i>	<i>Comments</i>
		S configuration	R configuration		

## Appendix G – Engagement Indices vs. Hidden Figures Test Scores









## Appendix H – Engagement Indices vs. Purdue Visual Rotation Test

