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# AN INVESTIGATION OF THE EFFECTIVENESS OF GESTURES TO ENHANCE CONCEPT RETENTION IN CHEMISTRY INSTRUCTION

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## ABSTRACT

The emergence of embodied cognition as a theory of learning has placed new emphasis on the interdependent relationship between what the mind perceives and what the body experiences. Movement and objects in the physical environment take on significant roles in the process of learning within this view and the role of gesturing in cognition has become increasingly interesting. Significant research suggests that the physical process of gesturing is connected to how the mind processes information. Gesturing during the recall of information is a universally known phenomena and one that seems to aid in the process of recall. More recent findings have suggested that the use of gestures may play a helpful role in assisting learners with processing information and particularly with retaining information longer. This study investigates this claim by using intentional gestures at the time of encoding new information to assist a group of first year chemistry students in high school process how to identify and label Lewis acids and bases in reaction schemes. A treatment group received an intervention lesson where key concepts were instantiated with the use of related gestures while the control group received the same lesson without the use of gestures. The intervention lesson involved students using BeSocratic, a web-based, interactive system currently under development. Performance was assessed with a pre-post test and a delayed post-test administered three weeks after the intervention to determine if the treatment group would retain the concepts significantly better than the control group. The results showed that two groups of students with similar backgrounds in the material exhibited similar gains in information from the intervention lesson. However, when given the same assessment three weeks later, the group of students who had received the gesture enhanced lesson significantly outperformed those students who did not. The gains were limited to questions most directly linked to the gestures. The results are part of a small but growing body of evidence that suggests that the use of gestures during the encoding of new information does offer a tool to help learners retain information.

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# CHAPTER ONE

# INTRODUCTION

Challenges abound for many students experiencing chemistry for the first time. Learners are faced with the need to deal with complex abstract concepts, compare unintuitive propositions to empirical data in meaningful ways, and apply nascent problem-solving skills. As if these tasks were not daunting enough for the learner, there is also the necessary expectation that concepts are not only grasped in the short term, but retained, expanded and employed throughout the course and subsequent science courses. Learners struggle with all of these demands, but perhaps most perplexing is the cumulative nature of chemistry and the expectation that prior learning must remain accessible.

Walter R. Tschinkel, a professor of biology, writes about a discussion with his students regarding metaphors of education. Presented with several options for good metaphors of education, his students easily rejected the metaphor of education as that of a teacher filling empty vessels. As Tschinkel predicted, they were particularly agreeable to the metaphor of education as the construction a building, where each concept added another brick to the structure built from cooperative endeavor. Their assent with this model led to the following exchange between Tschinkel and the class (Tschinkel, 2007);

> "Now, this is very interesting," I said, smiling. "You do understand that to build an edifice, every brick you add must remain in place? That is, in your education, you have to remember what you learned before, so that you can build on it in the next phase of education. But we have repeatedly experienced here that you remember little from your previous courses — or, for that matter, from the previous test, or even from last week. Your behavior violates the basic requirement of this metaphor. Some students nodded their understanding; others looked poleaxed."

Tschinkel then argues that the metaphor of education which many learners have unwittingly adopted is that of education as sport. Under this metaphor, concepts are treated as mere means for scoring points during the next game, or rather test. Learners grasp what they must for immediate success and carry nothing forward except for a score which is tallied at the end of the season, or rather the course. This metaphor speaks to a problem experienced daily in math and science classrooms and often dismissed as a cultural deficiency brought about principally by the values that learners bring to the classroom, namely that students lack appropriate motivation to adequately engage the material presented.

While student motivation and attitudes toward learning are relevant issues, classroom educators don't possess any levers large enough to address sweeping social generalizations. While challenging student metaphors and approaches to education is essential work, the question emerges as to whether any classroom practices might provide the means for educators to, at the very least, assist students in elevating their game. Specifically, do teaching methods exist that address student engagement of concepts and enhance learner performance toward retaining concepts for the long term?

While the response to such a question could go in many directions, the direction of this research is to explore one potential teaching method for enhancing learner retention. The method under investigation is the intentional use of gestures at the time of encoding concepts. The purpose of this research is to investigate if the learners' use of gestures during a chemistry lesson promotes retention of the chemical concepts presented with gestural enhancement. The potential use of gestures emerges from the development within educational psychology and the science of cognition termed embodied cognition. Embodied cognition challenges theories of learning which view learning to be primarily focused on brain functions exclusively, by suggesting a radically collaborative effort between mind and body within the process of cognition. Embodied cognition argues for a process of learning that emerges from an interdependent relationship between what the mind perceives and what the body engages, placing a new emphasis on the physical environment and motion present during the process of learning (Barsalou, 1999, 2003; Klein 2006; Tytler 2010). The novelty of embodied cognition is the argument that the physical context of learning does not just fulfill a supportive role for a disembodied process of cognition but that the very act of cognition is integrally bound to and profoundly shaped by the physical context.

Building upon recent developments in embodied cognition and previous research into the enactment effect, recent research suggests a potential role of intentional gesturing by the learner to instantiate concepts at the time of encoding as an instructional approach to help learners as they endeavor to construct and retain knowledge (Cook 2008, 2010). If such a relationship can be firmly established, educators will have a powerful tool to help learners build concepts that endure and can be used to build upon later. The goal of this research is to investigate whether gestures created to represent concepts within a chemical model and introduced to the learner at the time of encoding will significantly enhance the learner's ability to retain the concepts.

In this study, first year high school chemistry students will be presented with a lesson on Lewis acid-base reactions. The objective of the lesson will be for students to develop the concepts and skills necessary to predict the products of simple Lewis acid-base reactions and determine which reactant served as the Lewis acid and which reactant served as the Lewis base. Students will use Lewis structure models of the reactants and products and the concept of arrow pushing to model the role of electrons in chemical reactions to predict the outcome of simple Lewis acid-base reactions. Students will be divided into two groups, one of which will receive the lesson emphasizing the use of gesture to simulate the donation of electrons and subsequent chemical bond formed via the acid-base type reaction. The control group will receive the same lesson using the same technology, but without the use of gestures. The lesson for both the treatment and control groups will use a tablet PC and the Be.Socratic learning environment where Lewis structures of molecules can be manipulated to model the reaction conceptually. Students will be given a pre-test, immediate post-test and a delayed post-test approximately three weeks following the initial instruction. The data from these assessments will be used to analyze the efficacy upon instruction of student-gesturing at the time of encoding.

Chapter Two reviews the literature related to embodied cognition in the science classroom and the potential use of gestures to impact encoding during cognition. Chapter Three presents the design of the lesson intervention including the assessment materials used in this study and the process by which data was obtained. Chapter Four presents the statistical analysis of the data obtained during the study and discussion of those results. Chapter Five presents conclusions drawn from this study and implications for future research.

# CHAPTER TWO

# LITERATURE REVIEW

As researchers in education begin to investigate the claims of embodied cognition, one focus that emerges is that gestures matter. However, it would be incorrect to state that the role of gesture depends upon the ultimate success of a fully embodied view of cognition. Philosophers of cognition and scientists of the brain are actively debating and researching the role that the physical environment and human interaction with it plays in the development of knowledge. Still, the perspective of embodied cognition has been argued to be useful for two reasons when studying gestures; first the embodied view of cognition has much to say about how gestures might be related to active thought and secondly that embodied cognition provides a coherent account from which to explain gestures (Hostetter and Alibali, 2008). Embodied cognition argues for an integral and interdependent role for bodily movement and sensations in the construction of mental concepts, and whether or not the claims are fully realized, there is no doubt that movement, such as gestures, are important aspects of certain types of learning. Gestures are universally used to describe mental images as people speak and are particularly successful at expressing spatial or motor information (Feyereisen & deLannoy, 1991; Alibali, 2005). While it is usually assumed that gestures are an adaptive process meant to help convey concepts to others, it has been noted with keen interest that people gesture even when it is quite clear that no one is watching. This suggests that the use of gestures is for the benefit of the speaker (Iverson & Goldin-Meadow, 1998; Alibali, Heath, & Myers, 2001). Gestures then might represent something far more important than just a complementary mode of communication. They might be directly related to the process of accessing information. Learners who are directed to gesture while attempting to recall information report more details than learners who are directed not to gesture (Stevanoni & Salmon, 2005). Gestures are commonly associated with recalling information that while on the top of the tongue, eludes words. Many seem to perceive that the act of gesturing can move those words from the tip of the tongue into the conversation.

That gestures are helpful during the process of recalling stored information is one direction in which the inquiry between gesture and cognition has delved. Another direction involves how gestures relate to the process of building information. Interestingly, gestures sometimes seem to indicate the comprehension of new knowledge prior to the learner being able to articulate the concept verbally. By monitoring the mismatch between gestures a learner produces and what they are saying as they struggle with a new concept, one study showed that the gestures displayed the construction of the concept prior to the verbal articulation and thus served as an indicator as to whether the learner would master the concept (Pine, Lufkin, & Messer, 2004). The learners' use of self-directed gesturing also seems related to how well one retains information. Learners who gesture spontaneously while processing information outperform those who do not gesture with regards to retaining the information (Alibali & Goldin-Meadow, 1993; Cook & Goldin-Meadow, 2006). What remains unclear is if this implies that the motion of gesturing itself has an important role in cognition, or merely that the more engaged and active learner who encoded the information more successfully was actively gesturing.

The idea that gesturing is not just an indicator of receptiveness to learning but is itself useful to the process of learning is proposed by a study that finds that gesturing assists learning by increasing cognitive resources available for the task of recall. The suggested mechanisms for the effect include decreasing the effort of recall by providing a mental map, by providing links between concepts and words or by promoting greater mental organization of concepts (Goldin-Meadow, Nusbaum, Kelly & Wagner, 2001). An example of this is a study of high school physics course where students used gestures to help process and explain the concepts and materials they experienced in a lab setting during presentation to the class (Roth 2002). The use of gestures in tandem with the objects that had been manipulated during the lab allowed the learners to more easily acquire and present newly attained scientific concepts than was the case when presentation of the concepts required speech alone. Gestures that allowed students to embody difficult, abstract concepts seemed to help them organize and acquire the appropriate language to do so.

More support for the constructive role of gestures can be found in a study where students learning in a context in which the language of instruction differed from their own, displayed significantly enhanced performance of learning mathematical concepts when gestures were employed in the instruction (Church, Ayman-Nolley, & Mahootian, 2004). Another study of students learning mathematical concepts showed that students who were taught a strategy that included gestures during learning outperformed those who did not on a posttest. Interestingly, the students exposed to gesturing during gesturing tended to use those gestures during the process of recall. This was interpreted to suggest that their enhanced performance was related to the use of gestures in instruction (Cook & Goldin-Meadow, 2006).

Another recent study has shown that gestures profoundly shape the mental conception learners store for tasks they relate to the gestures (Beilock and Goldin-Meadow, 2010). Two groups were given a similar task for which they were to create gestures to explain the process and then repeat it. One group had the components of the task secretly changed such that their gestures would oppose completion of the task on the repeated trail. They performed decidedly worse than the group that did not have components switched. Even more interestingly a second trial was conducted where both groups had components switched before repeating the procedure with secretly changed components. One group explained their process with gestures before repeating the process while the other group did not. The group that created gestures to explain their process for the task did not adapt well to the switched disk, while the group that skipped the gestures did. This further shows that gesture does not just reflect concepts already attained, but plays a vital role in constructing thought by directing learners to think with not just their minds, but also with their hands.

Research suggests that cognition and gestures are related, that gestures are helpful with recall, and that gestures are related to the construction of knowledge. A further implication, and the one of primary interest to this research, maintains that gestures not only are helpful in the construction of concepts, but lead to significant enhancement of the learner's retention of concepts. The possibility of a role for gesture in the process of making longer lasting memories is suggested by research into enacted encoding. Research indicates that when learners are presented with a concept that directly involves an action, they will retain this concept more readily if the learning process is coupled with the actual action itself versus just being verbally transmitted. This conclusion is termed the enactment effect and indicates an interdependent relationship between action and cognition under specific circumstances (Engelkamp, 1997; Engelkemp, Seiler and Zimmer, 2005; Masumoto, et al, 2006).

While the enactment effect is relevant, in chemistry education where learners are presented with abstract models to describe phenomena, the essential question is whether or not gestures at the time of encoding can enhance retention of concepts that are not embedded in the actual physical movement at the macroscale of human physical context. In other words, if the gestures are intentionally coupled with interpretations of an abstract model rather than emerge from actual tactile reality, will the gestures still function to enhance retention of the concepts they are coupled with during the act of encoding?

Evidence of a potentially broader relationship between concepts and encoding enhanced by gesture has been presented in the literature (Cook, Mitchell, & Goldin-Meadow, 2008). In this study, elementary school students were presented with a lesson in a problem-solving strategy in math. The students either received a lesson where they were directed to verbally repeat the strategy, to repeat the strategy using only gestures, or to repeat the strategy using both gesture and speech. While all three groups showed significant gain from pre-test to post-test, on a follow-up test administered four weeks later the learners who had been exposed to either the gesture or the gesture plus speech strategy showed very significant gains over students who were directed to verbally repeat the procedure only. This suggests that gesturing may have a profound influence on retention over time. A second report consisting of three separate studies found similar conclusions (Cook, KuangYi Yip, and Goldin-Meadow, 2010). Each of these studies concluded that gesturing during encoding led to significantly greater recall both immediately and after a period of three weeks. Perhaps more interestingly, this latter study showed that gesturing can help encode information from speech for a longer duration. This is interesting because while it may quickly become evident that gesturing plays a significant role in assisting learners in retaining information, the work to conclude what information can be enhanced by this methods and under what conditions and restrictions this effect is observed will take some time to establish.

CHAPTER THREE

INTERVENTION DESIGN AND ASSESSMENT

**Methods**

This study was conducted at a small, public high school with students in a first year honors chemistry course. Permission was granted by the institution to conduct the study. The material was presented as part of a unit of acids and bases. The specific topic involved in this study, the Lewis acid-base model, is not typically covered in a first year, high school chemistry course. The material was included as a logical next topic following the usual presentation of the Brønsted-Lowry acid-base model. The material was presented as any other lesson, but students were informed that the Lewis acid-base model material would not be included in their course grade so that no students would be disadvantaged by alternative approaches to the material.

A pre-post experimental design was used with a second, delayed post-test administered three weeks after the initial lesson to measure potential difference in the retention of concepts over time. Students were not randomly assigned to this project. The treatment and control groups were created from existing classes with students paired into control and treatment groups based on comparable PSAT scores. Students from four classes were divided into 5 groups where one group met during an alternate class time to even up the distribution of students. Three groups comprised the control population of 28 students and the two remaining groups comprised the treatment population of 28 students. All students had the same pre-treatment conditions, and all instruction prior to and during the study was carried out by the researcher.

**Intervention**

The intervention took place during a regular 90-minute class period. Students began the class by completing the pre-test. This was followed by a lesson on the Lewis acid-base model that typically lasted about 55 minutes and concluded with a discussion of how vital Lewis acid-base interactions are to the chemical evolution of life. Students from both the treatment and control group received the same lesson with the only difference being that all examples and practice problems for the treatment group involved the students using gestures. The post-test was administered immediately following the lesson.

The intervention lesson for both the treatment and control groups was conducted using the BeSocratic web-based system (http://besocratic.clemson.edu/) that allows for interactive lessons in a free-form environment. The BeSocratic system is an interdisciplinary project being developed at Clemson University and builds upon previous work to develop OrganicPad (Cooper, 2009). The purpose of this system is to provide a software environment where students can enter free-form representational data, such as graphs or chemical structures. One potential use of this platform is that student work can be analyzed by a researcher for the purposes of investigating how students achieve representational competency in STEM disciplines. Another purpose is to provide an interactive environment where students can practice and receive instant feedback on tasks requiring representational competency. In this project, the purpose of the BeSocratic system was to allow students to practice drawing a curved arrow from the Lewis base to the Lewis acid. This practice allowed for the use of a repeated gesture, the sweeping motion of the finger intentionally from one atom of interest to another, promoting the embodiment of the concept of a Lewis bases donating electron to a Lewis acid. Students used tablet computers with enabled touch screens to interact with the BeSocratic system. While the primary purpose of using the touch enabled tablets was to enable electronically monitored gesturing throughout the lesson, the tablets were also used with the control group to make the treatment and control conditions as similar as possible and avoid the possibility of a multimedia effect confounding measurement of the any potential treatment effect.

The lesson was presented to both groups using a Powerpoint presentation on a Smartboard that allowed the instructor to interactively present and model the examples and practice problems that the students experienced on the tablets using BeSocratic. Eleven interactive slides were produced for the students to use. Figure 1 shows one of the interactive slides in the BeSocratic environment used with the treatment group. The slide requested that the student place a finger on the atom in the Lewis base with electrons to donate and with that finger directly on the touch screen, draw a curved arrow that ended with the atom on the Lewis acid that would accept the electron pair to form the coordinate covalent bond. For the treatment group, on all eleven slides, the exercise required the student to produce this curved arrow with their finger, thus producing a repeated gesture that related the Lewis base to the Lewis acid and inferred the donating-accepting relationship by the direction of the drawn arrow.

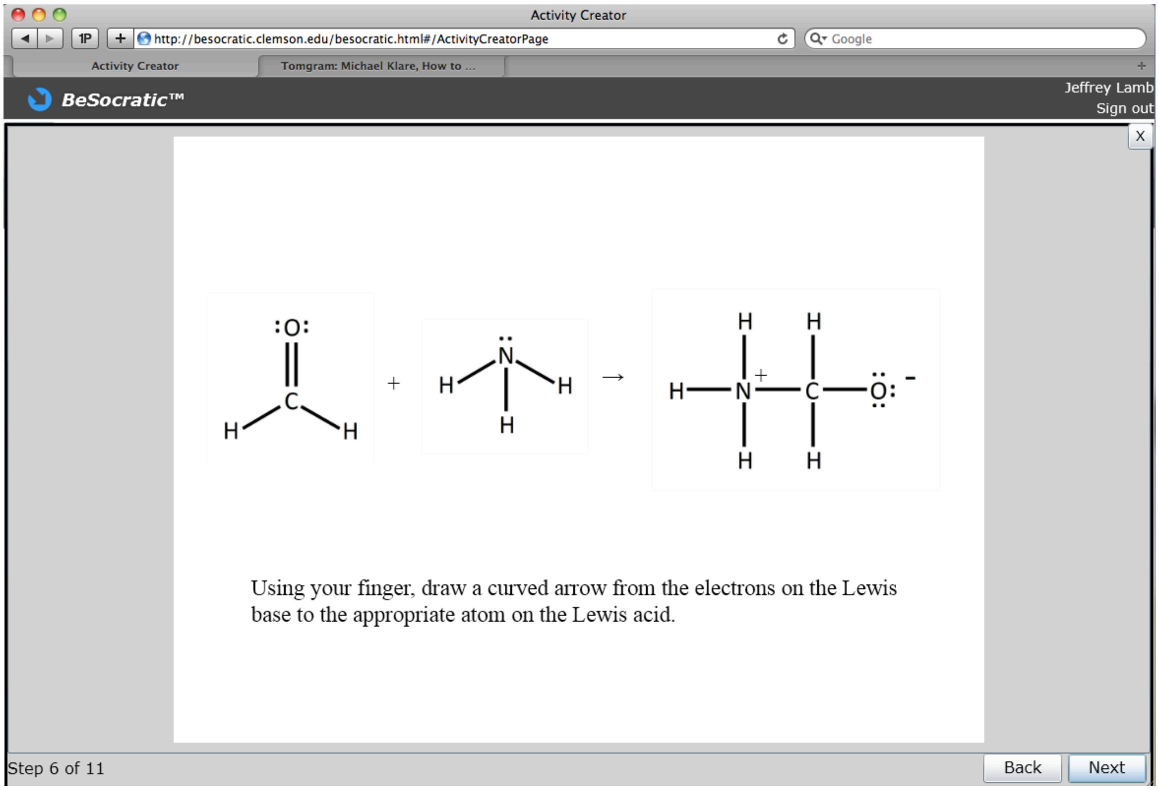


**Figure 3.1: Example Question in BeSocratic System**

If the student began the arrow drawing gesture on the correct atom and ended on the correct atom, the BeSocratic system responded with the message, "good job," as shown in Figure 2. If the student paired the incorrect atoms or went in the wrong direction, the BeSocratic system sent a message to "try again," and allowed unlimited attempts.

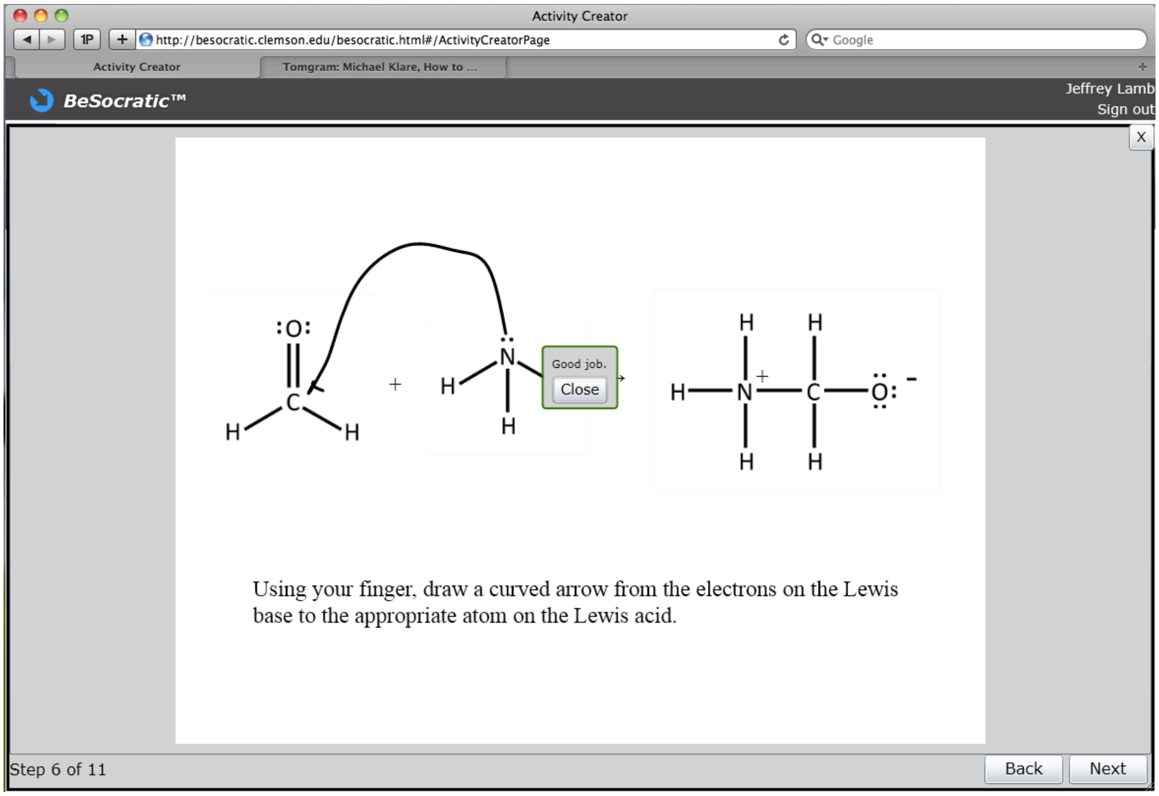


**Figure 3.2: Example Question in BeSocratic System with Student Response**

Students in the control group were presented with the same lesson and eleven interactive slides, but instead of being shown and prompted to trace the movement of electrons with a curved arrow on the tablet screen using their fingers, the students were instructed to select the correct atom by tapping on that atom on the base followed by selecting the correct atom on the acid by tapping on that atom. Both groups were exposed to the same material in the same order and with the same examples. The only intentional difference between the groups was the use of the arrow drawing gesture on the touch screen with their fingers versus just tapping on the atoms.

For both groups, the treatment and the control, there was an emphasis on looking at the Lewis structure of the product to assist in deducing where the new coordinate covalent bond was formed. Given the level of experience of the students in this study, there was no expectation that students could discern, on their own, the products of Lewis acid-base reactions and the range of types of Lewis acid-base reactions was limited to three. Students were first presented with a typical Brønsted-Lowry acid-base reaction and shown how this reaction could also be explained within the Lewis acid-base model. In a previous unit a discussion of the electron deficient compounds formed by boron and aluminum had been presented and so Lewis acid-base reactions involving these types of compounds were included as students could understand why these atoms would accept electrons. In addition to acidic hydrogens, and boron or aluminum compounds, compounds with carbonyl groups were also presented as Lewis acids.

The chemistry of carbonyl containing compounds is definitely not a typical first year chemistry topic in high school, but a secondary goal of the lesson was to present Lewis acid-base chemistry in a larger context of the chemical story of evolution. As a conclusion to the lesson, research into abiogenesis and the prebiotic chemistry of amino acids was briefly presented. Keys steps in the synthesis of amino acids from small molecules were shown as additional examples of Lewis acid-base interactions essential to the evolution of life. In previous lessons, students had investigated electronegativity, bond polarity and molecular polarity as well as basic structures of organic compounds. After a brief review of electronegativity, students were presented with the concept of carbons in a carbonyl group as being electron deficient and thus behaving as a Lewis acid. The Lewis structure of the intermediate was shown and no time was spent discussing any carbonyl chemistry beyond the ability of a carbonyl carbon to act as a Lewis acid.

**Assessment**

The assessment used for the pre-post test was written by the researcher and had not been previously used in prior lessons or research. It consisted of five questions and the first four questions closely resembled the examples and practice problems that the students experienced throughout the intervention lesson. The fifth question asked the students to explain the role of the acid and the base in Lewis acid-base reactions in words. Unlike the intervention lesson, the assessment was conducted on paper meaning that students were required to transfer skills they learned on the touch screen to paper and pencil.

The first four questions, Figures 3-6, asked the students to label the Lewis acid and the Lewis base and circle on each specifically the atom involved in the acid-base interaction. The instructions on the assessment were not varied between the treatment and control group. Because the relationship of primary interest here was the role of gesture at the time of encoding information, students were not instructed to produce the gesture on the post-test which could invoke an effect of gesturing at the time of recall. Some students in the treatment group naturally drew a curved arrow in their responses on their own and this was not prohibited.

**Problem 1**
Label the Lewis acid and the Lewis base in the following reaction. Circle the atom on both that is primarily involved in the acid-base interaction.

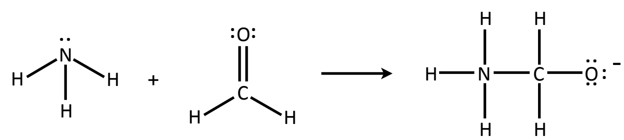

**Figure 3.3: Pre-Post Test Question 1**

The first assessment question, Figure 3, involved a carbonyl containing compound as the Lewis acid and ammonia as the Lewis base. This question was very similar to a reaction presented during the lesson, but the acid and base were presented in reverse order in an attempt to make sure the students were analyzing which compound was the acid and which the base rather than get into a pattern which seems common in text books where the acid is presented first and the base second.

**Problem 2**
Label the Lewis acid and the Lewis base in the following reaction. Circle the atom on both that is primarily involved in the acid-base interaction.

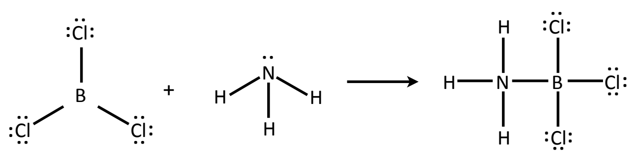

**Figure 3.4: Pre-Post Test Question 2**

**Problem 3**
Label the Lewis acid and the Lewis base in the following reaction. Circle the atom on both that is primarily involved in the acid-base interaction.

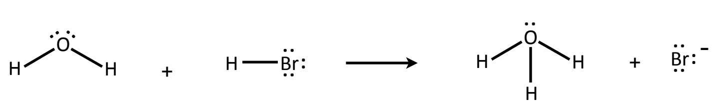

**Figure 3.5: Pre-Post Test Question 3**

The second assessment question, Figure 4, presented an electron deficient boron compound as the Lewis acid, which was very similar to two examples in the lesson. The third assessment question, Figure 5, presented a binary inorganic acid that should have been familiar to the student as an acid in the reaction that could be explained using either the Lewis or the Brønsted-Lowry acid-base model.

**Problem 4**
Label the Lewis acid and the Lewis base in the following reaction. Circle the atom on both that is primarily involved in the acid-base interaction.

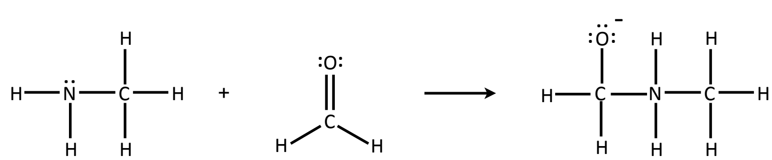

**Figure 3.6: Pre-Post Test Question 4**

The fourth assessment question, Figure 6, also involved a carbonyl compound as the Lewis acid, but included a much larger compound as the base.

In three out of the four questions, the base involved a nitrogen with an non-bonded pair of electrons and this question expected that students could look beyond a few extra atoms and recognize the pattern of a nitrogen atom donating a pair of electrons to form a coordinate covalent bond with a suitable Lewis acid.

The final question, Figure 7, was different than the previous four questions. Instead of asking the students to repeat the process of identifying and labeling the Lewis acids and bases, students were asked to define a Lewis acid and a Lewis base. The purpose of this question was to probe whether or not students could transfer the process of identifying Lewis acids and bases into explaining them and for the delayed post-test, whether there might be a significant difference between performance on questions where the action involved in the gestures was relevant versus the question that required recall of the definitions.

**Problem 5**
In each of the previous problems, you labeled one species as the Lewis acid and one Lewis base and circled the atom for each that was primarily involved in the acid-base interaction.

Explain briefly the role of the atom you circled on the Lewis acid.

Explain briefly the role of the atom you circled on the Lewis base.

**Figure 3.7: Pre-Post Test Question 5**

The assessment was scored out of 20 points and converted to percentages for statistical analysis. Each of the five questions were scored for up to 4 points each. The first four questions had the same scoring scheme; one point for labeling the Lewis acid, one point for labeling the Lewis base, one point for circling the correct atom that accepted the non-bonded electron pair and one point for circling the atom that donated the non-bonded electron pair. The final question also was scored out of four points; one point for associating acid with accepting, one point for associating base with donating and two points for including that what was donated and accepted was a pair of electrons.

The last phase of the study was the delayed post-test. This was administered approximately three weeks after the students received the intervention lesson. During the three weeks between the immediate and delayed post-test, the material was not reviewed or further discussed. Students were not told at any time that the assessment would be given again. All students in the study took the delayed post-test during regular class time and were instructed not to discuss or warn any other students about the assessment so that the delayed post-test would be as accurate an assessment of what was retained as possible in this setting.

# CHAPTER FOUR

# DATA ANALYSIS AND DISCUSSION

## Data Analysis

Data collected from the pre-test, immediate post-test and delayed post-test were collected for all 56 students and subjected to statistical analysis to look for significant differences between the treatment and control groups. Most students improved dramatically from the pre-test to the immediate post-test showing that the instruction in either form had some immediate benefit for most students. Like a previous study on the role of gesturing at the time of encoding (Cook, 2008) and current work within the Cooper research group (manuscript in progress), the significant finding is that there was clearly a difference in the performance between the treatment and control group on the delayed post-test.

| | *Z* | *p* | *r* |
|---|---|---|---|
| Pre-Test | -1.579 | .114 | - |
| Immediate Post-Test | -1.228 | .219 | - |
| Delayed Post-Test | -2.728 | .006 | .36 |

**Table 4.1: Summary of Statistical Analysis of Pre-Post Test Results**

The data gathered from the pre-posts tests were subjected to the Wilcoxon-Mann-Whitney (WMW) test, also known as the rank sum test. Unlike the t-test, this is a non-parametric test that provides valid results whether or not population distributions are normal. The purpose of the Wilcoxon-Mann-Whitney test is to allow for the evaluation of the null hypothesis which states that the median of the groups compared are not significantly different. The *Z* value is a measure of the difference between the results and the mean of the ranked data. The data were analyzed as non-directional, or two tailed, meaning that for a .05 level of significance, z must be greater than +1.96 or less than -1.96.

Based on the data in Figure 8, the Z value of -1.579 did not indicate a substantial difference between the control and treatment groups for the pre-test. This data suggests that all of the students in this study began this research with approximately the same prior knowledge of the subject.

The immediate post-test data also revealed no significant difference between the group with the embodied lesson and the control group. The *Z* value of -1.228 indicates that the treatment and control groups made similar gains due to the intervention.

However, the data shows that the null hypothesis is rejected for the delayed post-test. The Z score of ±2.4 is considered high,even for a two-tailed test, therefore the result of -2.728 shows a significant difference between the groups. The level of significance for this result is $p = .006$, which is well below $p = .05$ threshold meaning there is a very small chance of falsely rejecting the null hypothesis. The data supports the hypothesis that students exposed to a gesture-enhanced lesson would show significant difference on retaining the Lewis acid-base concepts on a delayed post-test than the group that received the same lesson but without the gestures. Since the difference between the control and treatment groups was significant, an effect size calculated. The effect size, r = 0.36, is a medium to large effect. On Cohen's effect scale, the effect size of $d = 0.79$ was just below what constitutes a large effect, $d = 0.80$. The large Z result along with the size effect suggests a very sizable impact by the treatment on the outcome for learners who were asked to instantiate the concept of electrons being transferred and donated with a gesture compared to students who were shown how to point and click on the correct answers.

The performance gap on the delayed post-test was further analyzed by examining the difference between the treatment and control groups on the five individual questions on the assessment.

| | Question 1 | | Question 2 | | Question 3 | | Question 4 | | Question 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **N** | **T** | **C** | **T** | **C** | **T** | **C** | **T** | **C** | **T** | **C** |
| 1 | 25 | 75 | 0 | 100 | 0 | 25 | 0 | 50 | 0 | 0 |
| 2 | 50 | 25 | 100 | 25 | 100 | 25 | 100 | 25 | 0 | 0 |
| 3 | 25 | 0 | 50 | 25 | 100 | 0 | 50 | 0 | 0 | 0 |
| 4 | 100 | 25 | 100 | 50 | 100 | 0 | 100 | 25 | 100 | 0 |
| 5 | 50 | 25 | 100 | 25 | 25 | 0 | 75 | 25 | 0 | 0 |
| 6 | 25 | 0 | 50 | 25 | 25 | 0 | 25 | 0 | 0 | 0 |
| 7 | 100 | 25 | 100 | 50 | 100 | 25 | 100 | 25 | 0 | 0 |
| 8 | 25 | 50 | 50 | 50 | 25 | 50 | 25 | 50 | 0 | 0 |
| 9 | 50 | 0 | 50 | 0 | 0 | 0 | 50 | 0 | 0 | 50 |
| 10 | 50 | 50 | 50 | 50 | 50 | 0 | 100 | 0 | 50 | 0 |
| 11 | 75 | 25 | 100 | 50 | 75 | 50 | 75 | 25 | 50 | 0 |
| 12 | 50 | 0 | 50 | 25 | 50 | 0 | 50 | 0 | 0 | 0 |
| 13 | 50 | 50 | 0 | 50 | 0 | 25 | 0 | 50 | 0 | 0 |
| 14 | 100 | 25 | 100 | 50 | 100 | 25 | 100 | 25 | 100 | 0 |
| 15 | 50 | 25 | 50 | 100 | 50 | 25 | 50 | 50 | 0 | 50 |
| 16 | 50 | 100 | 100 | 100 | 75 | 75 | 100 | 75 | 0 | 100 |
| 17 | 100 | 50 | 100 | 50 | 25 | 50 | 100 | 50 | 100 | 0 |
| 18 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 100 | 100 | 100 | 100 | 100 | 0 | 100 | 100 | 0 | 100 |
| 20 | 100 | 100 | 100 | 100 | 100 | 75 | 100 | 50 | 100 | 100 |
| 21 | 100 | 25 | 100 | 25 | 75 | 25 | 100 | 25 | 0 | 0 |
| 22 | 75 | 0 | 75 | 0 | 75 | 0 | 75 | 25 | 100 | 0 |
| 23 | 50 | 75 | 0 | 0 | 0 | 0 | 50 | 25 | 0 | 0 |

| | Question 1 | | Question 2 | | Question 3 | | Question 4 | | Question 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 50 | 50 | 100 | 50 | 50 | 50 | 50 | 25 | 0 | 0 |
| 25 | 0 | 50 | 25 | 50 | 0 | 0 | 25 | 0 | 0 | 0 |
| 26 | 50 | 100 | 100 | 100 | 25 | 100 | 100 | 100 | 50 | 100 |
| 27 | 50 | 75 | 100 | 50 | 0 | 0 | 0 | 25 | 0 | 0 |
| 28 | 75 | 25 | 100 | 0 | 100 | 0 | 100 | 0 | 100 | 0 |

**Table 3.2: Students Performance Per Question on Delayed Post-Test**

T = treatment group, C= control group, scores are reported as percentages

| **Question** | ***Z*** | ***p*** | ***r*** |
|---|---|---|---|
| 1 | -2.050 | .040 | .28 |
| 2 | -2.476 | .013 | .33 |
| 3 | -2.728 | .006 | .37 |
| 4 | -3.314 | .001 | .44 |
| 5 | -0.888 | .375 | - |

**Table 3.3: Summary of Statistical Analysis of Delayed Post-Test Results**

On the four questions that asked the students to apply the concepts of the Lewis acid-base model by labeling the acid, the base and identifying which atoms were directly involved in forming the coordinate covalent bond, the students in the treatment group significantly outperformed the control group. All four *Z* values for the first four questions indicate a significant difference between the control and treatment groups. The first question, which involved ammonia as the Lewis base and a carbonyl compound as the Lewis acid showed the least difference, but still a significant one where $Z = -2.050$. The next three questions showed large $Z$ values and correspondingly large effect sizes. On the fifth question, where students were asked to define a Lewis acid and base, both the treatment and control groups performed poorly. There was no significant difference in performance as indicated by $Z = -0.888$.

**Discussion**

Why do some students retain information so much better than others? Why do students retain certain things better than others? Clearly, personal interest plays a role. Some students have disciplined themselves to execute a variety of tricks, from note-taking techniques to mnemonics to help retain information. How is it that students who were asked to instantiate a concept recall it weeks later with a much higher degree of success than a group that received the same information and demonstrated the same proficiency for it immediately after instruction? Cook and Goldin-Meadows have suggested there are three ways that gesturing might lead to sustained memory of concepts (Cook 2008). The first is that using a more representational format reduces the burden that new information presents to the mind and that this information can be engaged more meaningfully in the absence of a more cognitively demanding way of receiving the information (Goldin-Meadow 2004, Brünken 2002, Mayer 1998). A second possibility is that gesturing accesses processes in the brain that produce more vibrant memories. This argument says that just by including an action along with verbal content, that how the brain processes this dual information will lead to memories that will be retained longer. This might be the effect produced by studies that show that when children enact a story they will remember the story better than when the story is just read (Glenberg 2004). Lastly, Cook suggests that gesturing might produce better memory by relating concepts to the real environment of the student. This follows the logic of embodied cognition which argues that the external environment is a vital part of the learning process, and when concepts are related to real objects that learning is enhanced. The results of this study could easily be explained by either the first or the second proposed mechanism, but not so easily by the third. The instantiation of the donating and accepting electrons occurred on a small view screen that was a common element between both the control and treatment groups. Both were dealing with unfamiliar objects and new concepts. The difference was a repeated gesture made with the finger to represent the concept. Whatever the mechanism, whether by reducing the cognitive load or by tapping into more robust memory processes of the brain, the suggestion that is emerging from this study and this area of research into embodied cognition is that there might be a simple, yet effective lever which classroom teachers can employ that allows many more students to retain abstract conceptual information.

The analysis of student performance by question is interesting because the results of the data are seemingly divided by the type of question presented. The first four questions asked the student to look at a Lewis acid-base reaction where all reactants and products were written in Lewis structure form. Non-bonded pairs of electrons were shown on atoms that possessed them and the product(s) if correctly read indicated where a new bond had formed. These first four questions were of the same type as the example and practice questions presented during the intervention lesson where the gesturing was introduced and more importantly, were the questions that directly involved the embodied gesturing. This suggests that the gesturing at the time of encoding has a benefit, but that this benefit likely has some specific parameters. The enactment effect is well documented showing that performing an action as one is learning the concepts associated with that action has a significant impact on how well the concept itself is assimilated (Cohen, 1989; Engelkamp, 1998; Nilsson, 2000; Masumoto, et al, 2006). The current study involves the role of an action, gesturing, that is related to an abstract concept where the action embedded in the process is not readily accessible to human experience. We anthropomorphize the behavior of electrons so that we may use words to describe a reality we cannot see. Therefore, the gesture represents the conventions of a theoretical model and involves action that has no direct relationship to the action of the actual physical process. Cook showed that gestures could help middle school students retain a problem solving strategy for a mathematics process (Cook 2008). But aside from that study, there is no specific data about what types of information might be enhanced by instantiation of the concept with gestures. How far can the concept stray from an activity related to it for a gesture to be effective? Are some types of gestures more beneficial than others, or will any form of motion assist in assimilating the information for the long term?

The data here suggests that embodied cognition in the form of intentional gesturing can influence the encoding of information, but with limits to what types of information can be carried by this process. The results are not surprising in that students did better on questions that more directly resembled the repeated practice provided during the lesson and did more poorly on the definitional question. And yet, the clear fact is that the students who were exposed to the gesturing treatment retained the ability to solve these problems to a much greater extent that those who did not. So while the students did perform better on questions that most resembled the problems they repeated throughout the lesson, students who repeated those problems with the embodied gesture retained the information significantly better than students who just practiced selecting the acids and bases by tapping on their choices.

The effect of the embodied gesturing did not appear in the data presented for the fifth question. This question was designed to investigate if knowledge about how to appropriately label the Lewis acid and base would transfer to the task of writing an appropriate definition of each. The data shows that this transfer did not occur. Both the treatment and control groups performed poorly on this question and there was no significant difference between them.

The conclusion that can be inferred from this is that information that can be encoded for greater retention is information that is more directly related to the action of the concept. In other words, the gesture can help learners retain a process of an action-oriented concept, but may not have any direct effect on the retention of facts.

In this case, the definition was closely related to the action itself. The gesture involved starting with the electron donated by the Lewis base and drawing a curved arrow to the atom on the Lewis acid that would accept the electron pair. Interestingly students in the treatment group did significantly better at choosing the Lewis acid and base and the correct atoms of interest on each scheme, but this skill did not transfer to understanding in terms of a written definition of what was transpiring.

It would be of significant interest to repeat this study and interview successful students to determine how they answered the first four questions, observe if the students implicate the role of the gesture in their process, and what questions they asked themselves as they answered the fifth, definitional question. But absent that sort of data, the only conclusion which can tentatively be drawn is that the gesturing effect upon encoding information is closely associated with information where the action of the gesture has some very direct relationship, even abstractly, to the actual process or concept encoded.

Though not formally analyzed statistically because of the small number of students involved, another issue of importance is the role of the gesture at the time of recall. Gestures clearly have a role in the recall of information and while this study was very intentional about the use of gesture at the time of encoding, students in the treatment group were neither encouraged nor discouraged from gesturing at the time of recall. Interestingly, on the delayed post-test, only six out of twenty-eight students drew curved arrows on their responses. Of the six students who reproduced the gestures with paper and pencil on the assessment; two had perfect scores, one scored perfect on the application questions 1-4 missing only the definitional question, two identified the correct atoms and drew the arrow in the correct direction but confused the labels, and one drew a series of incorrect arrows and labeled nothing correctly. This could be seen as 5 of the 6 who reproduced the gesture on paper remembered the essential information encoded directly by the gesturing. Of course, the absence of arrows drawn on the assessment does not indicate that other students in the treatment group did not recall the gesture and use it informally. A well developed interview would be necessary to determine this. Still, only four students achieved a perfect score on the delayed post-test. Two of these students were in the treatment group and reproduced the gestures at the time of recall. One was in the treatment group but provided no evidence that the gesture was used at the time of recall and one was in the control group. Further studies to determine if the effect of gesturing at the time of encoding is enhanced by intentional use of gestures at the time of recall might be of interest. It may turn out to be that the instructional technique that could be suggested from this work for classroom teachers is that gestures be used for certain activities and that students be taught to use those gestures as a helpful prompt for remembering previous concepts.

Both the overall data and the per question data strongly suggests a positive role for gesture at the time of encoding for the purpose of helping learners retain certain information.  Given that the differences between the groups only appear after time is elapsed and not on the immediate post-test, it would be difficult to conclude that there was any significant difference in the information relayed to the treatment and control groups during the intervention lesson. Students who used the arrow pushing gesture to instantiate the donation and accepting of electrons significantly outperformed students who did not on the delayed post-test given three weeks after the initial lesson. The data needs to be assessed with the knowledge that the results are from a small sample and that for a more conclusive determination, the study needs to be reproduced. Still, the data supports a small, but growing list of studies that support the strong possibility that the intentional use of gesture at the time of encoding information substantially enhances the ability of the learner to retain information.

# CHAPTER FIVE

# CONCLUSION

> Memory is a net; one finds it full of fish when he takes it from the brook; but a dozen miles of water have run through it without sticking.
>
> Oliver Wendell Holmes

For too many students in science and other STEM discipline courses, so much of the material presented passes through the consciousness like so much water through a net. While many students successfully navigate new concepts and thrive in the short-term, retaining knowledge so that foundations are set that can built upon later is a serious challenge.  This work began with the question, "do teaching methods exist that address student engagement of concepts and enhance learner performance toward retaining concepts for the long term?" A small, but growing body of research, including this study, suggests that one possible answer lies with the careful, intentional use of gestures.

The chemistry classroom offers several obvious examples of lessons that might benefit from the use of gestures to encode physical processes; the gas law relationships, the effect of changes on equilibrium, or the flow of electrons through a voltaic cell. In chemistry, nature is everywhere at work reducing gradients and this dynamic process seems ripe for many gestures to help students grasp and retain the fundamentals of the material universe.

The mechanism for how gestures help students encode information for the long-term is not clear, and the boundaries of exactly what types of information benefit the most from the enhancement with gestures is not established. Several studies, including this one, seem to suggest that gestures are most effective when they contain an action directly related to the concept. In the case of this study, that action was the movement of electrons as they are donated from the Lewis base to the Lewis acid to form a new coordinate covalent bond being encoded with the motion of the traditional curved arrow symbolism in chemical reaction mechanisms seemed to help students retain the basic information of identifying Lewis acids and bases. The Cooper Research group has found that organic chemistry students have benefitted from the use of gestures and while arrows have been traditionally used as common practice in organic courses, it is clear that students who learn to track the movement of electrons with gesture enhanced lessons are taking much more away from the lessons than has been the case traditionally (Manuscript in Progress).

The results of research into the relationship between gesturing and retention of information should encourage further study. More studies need to be conducted to further establish the relationship proposed between gestures and encoding as well as to further tease out what techniques and combinations lead to the greatest gains in learner achievement. The promise of the approach is that relatively simple interventions could allow learners to wield more efficient nets that assist them in retaining key concepts.

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