Em Micer graduated from the University of Memphis in 2021 with a double major in Chemistry and Biology. In 2020, they were awarded the Honors Summer Research Fellowship from the University of Memphis, which led to their continued research, the completion of their honors thesis, and, eventually, this publication. Throughout this research journey, they have presented at multiple conferences, even winning 1st place for 2 of these presentations. Since graduating, Em has begun working in a laboratory while in preparation to take the MCAT and apply to medical school. Outside of education, they enjoy gaming, cross-stitching and volunteering for organizations such as the Ronald McDonald House Charity and the Red Cross.

Em Micer

Exploring Undergraduate Biology and Chemistry Students' Understanding of Enzymes

Faculty Sponsor

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Abstract

When undergraduate students in introductory biology and chemistry courses learn about enzymes, their understanding tends to be superficial, and students tend to struggle with thinking about the functionality of enzymes in a visually representative way. In this study, we created and tested an activity based on Dr. Nathan DeYonker's NSF CAREER grant-funded website, RINRUS, that is intended to increase students' long-term retention and understanding of enzymes. We first ran a pilot study in a class of graduate students to determine assignment accessibility. We then surveyed and interviewed students in introductory biology and chemistry courses to determine what information about enzymes students learn and retain. Results from this study will help to develop student understanding about enzymes and provide ideas and strategies for instructors to support their students in understanding enzyme structure and function.

Introduction

For early biology and chemistry students, typically freshmen and sophomores, developing an intricate network of long-term memory that is parallel to accepted scientific thought is a key to learning the sciences (Gabel, 1999). Students may often have a difficult time understanding scientific concepts, particularly chemistry concepts, because they are unable to relate these concepts to real life (Gabel, 1999). However, undergraduate students are sometimes able to correctly solve problems that graduate students are unable to due to the undergraduate student's ability to think about a problem on a deeper level, without as many restrictions based on prior understanding of a concept (Rickey and Stacy, 2000). Although undergraduate students may be more open to new ideas, teaching science to undergraduate college level students can prove to be difficult for a myriad of reasons. Some of these reasons include, but are not limited to, changing fields, a professor's resistance to change, student fear of new types of instruction, and scarcity of resources in a changing institution (Sunal et al., 2001). Finding new ways to teach scientific concepts that are accessible and beneficial to college students is essential.

According to Stains et al. (2018), a majority of students are being taught chemistry through didactic measures alone, while instructors spend very little time adapting their teaching method to student-centered learning. This occurs in many STEM courses; however, Oludipe and Awokoy (2010) show that this occurs in chemistry courses frequently. Teaching students in this manner often leads to asking questions within the classroom by calling on individual students, which will cause students anxiety (Oludipe and Awokoy, 2010). Oludipe and Awokoy (2010) also suggest that students who have experienced this type of anxiety are more likely to limit their participation when learning. Based on the results found by Oludipe and Awokoy (2010), group assignments can cause stress to individuals if effort is not put in by all parties, but they have also been proven to be useful in fostering ideas and relieving anxiety. Chemistry courses tend to be high stress for many students, since they involve a wealth of new, complex material. The introduction of more group activities involving student-centered learning can increase confidence and success in chemistry courses.

Metacognition is the understanding of one's own cognitive processes (Sabel, Dauer, and Forbes, 2017; Schraw, Crippen, and Hartley, 2006). Rickey and Stacy (2000) state that "whether students' knowledge is coherent or fragmented and context-bound, a keen awareness of their own conceptions should allow students to recognize when their ideas are not productive. One effort made to increase understanding of chemistry concepts is the addition of concept maps, which allow students to construct visual diagrams that show how concepts are related. Another method of chemistry learning is the Predict-Observe-Explain (POE) task, which is often used in beginner chemistry courses when students are just learning concepts. While POE tasks can be useful by allowing students the opportunity to observe actual outcomes and compare them to their initial predictions, Tien, Rickey and Stacy (1999) elaborated on this and created the Model-Observe-Reflect-Explain (MORE) Thinking Frame which "is used to help students think about the inquiry process and their own process of learning about science concepts" (p. 318). By allowing students to interact with material and observe what happens, they are able to challenge their own misconceptions to determine the true answers. Overall, students are often able to best learn about chemistry concepts when they are given the opportunity to evaluate their own understanding.

Oftentimes when undergraduate students begin progressing into upper-level biology and chemistry courses, they have difficulties piecing together information from earlier classes. One topic that students find particularly difficult is specific information regarding enzymes. To combat this gap in enzyme understanding in undergraduate biology students, an assignment was created by adopting portions of the Residue Interaction Network-based ResidUe Selector (RINRUS). RINRUS was created by Dr. Nathan DeYonker. RINRUS was created by Dr. Nathan DeYonker and his research group (see Summers et al. 2019 for another project using this program). It is a computational biochemistry research software package with a user-friendly web interface. RINRUS functions to create models of enzyme-substrate complexes at different levels of specificity that are able to be visualized through software such as the Molecular Operating Environment (MOE) or online through several web-based viewers.

The Multiple Intelligence Theory shows that humans all have 8 different types of intelligence, and each of these types of intelligences interact in a different way within the world (Gardner, 2011). Gardner (2011) lists the intelligences as the following: linguistic, logical-mathematical, musical, spatial, bodily-kinesthetic, interpersonal, intrapersonal, and naturalistic. In one study by Yalmanci and Gözüm (2013), students were taught about enzymes using eight different activities that aligned with each type of intelligence. Results from this study showed that students retained enzyme information to a greater extent than students in a control group (Yalmanci and Gözüm, 2013). Although the visual-spatial mode of intelligence is often thought to be of use in architects and others who work with their hands, the basis behind it is the ability to perceive information and create visual images from this information (Gardner, 2011). In the study completed by Yalmanci and Gözüm (2013), the visual-spatial category of intelligence was placed into an activity by use of visual presentations such as PowerPoint. However, we propose that by extending the visual-spatial area of intelligence to allow students to create three-dimensional models of enzyme-ligand complexes, students will have the ability to understand these complexes to a greater degree. Construction and manipulation of protein models will help students develop a more concrete understanding of what happens in these complexes, rather than simply being taught this concept through a PowerPoint lecture.

To begin with, we created an assignment based on the RINRUS website previously mentioned. To understand the effectiveness and accessibility of the RINRUS assignment, we ran a pilot study in a class of chemistry graduate students. To better understand the current level of content that introductory undergraduate students were taught and the extent of their enzyme knowledge, we evaluated class materials that focused on enzymes and asked students to complete surveys and interviews within General Biology I, General Chemistry I, and General Chemistry II courses. Our overarching goal was to enrich General Biology I student understanding of enzymes, as this is a required course for all students in the Biology and Chemistry majors. Students in General Biology I also have course material already dedicated to learning about enzymes. The purpose of this study was to explore the results of the following research questions:

1. How do graduate chemistry students perceive the RINRUS assignment as it pertains to understanding enzymes?
2. What information about enzymes are beginner undergraduate biology and chemistry students obtaining and retaining from their courses?

Methods

Participants and Context

To create the RINRUS assignment, we viewed class materials and typical textbooks that are used in General Biology I to see what students are usually taught regarding enzymes through this course. Once we evaluated and compiled all lecture material, we began creating the RINRUS assignment. At the beginning of the assignment, we provided an overview of enzymes, including a review of what students are taught during class. Additionally, we added some more specific information that would be necessary to the assignment, including topics such as chemical mechanisms and arrow pushing, which is a way to show the movement of electrons and the formation and breaking of bonds within a mechanism. In addition, we included information about x-ray crystallography and why computational chemistry is important. Following this background material, we tasked students with finding a peer-reviewed article about a specific enzyme in the Protein Data Bank (PDB) repository. The function of requiring an article was to bridge any gaps that might not be clear with visualization of the enzyme alone. Students then viewed the enzyme through the PDB Ligand Interaction viewer, allowing them to visualize the connections between the enzyme and ligand. Students were then tasked with inserting PDB information into the RINRUS website, and from the website students would receive a zip file. Finally, students would open this zip file using the program MOE, which would allow the students to visualize the enzyme-ligand complexes in a variety of ways. We obtained IRB approval from the University of Memphis (protocol #PRO-FY2021-241) before we began testing the assignment with students.

All 11 students from a graduate level chemistry class, CHEM 8711: Approximate Chemical Modeling Methods, were recruited to participate in the pilot run of the RINRUS assignment over 2 class meetings during the Fall 2019 semester. All students were graduate students in the Department of Chemistry. This class consisted of three 50-minute meetings per week, and students learned about classical and quantum mechanical techniques for modeling chemical systems and molecular mechanics. Eight of these students participated in interviews lasting approximately 25 minutes long to understand what alterations to the RINRUS assignment might be needed for introduce it to beginner chemistry and biology students. Each student who participated in an interview was given a $10 gift card.

At the University of Memphis, students following biology and chemistry degree paths are required to enroll in and pass General Chemistry I before they are able to take General Biology I. This often leads to students being enrolled in General Biology I and General Chemistry II simultaneously, however students do not always follow this exact path. Following interviews with the graduate-level class, students enrolled in General Biology I and General Chemistry I were asked to complete surveys and interviews following the Spring 2020 semester to determine the difference in understanding between these courses, with General Chemistry I acting as a baseline. Students enrolled in General Biology I learned about cell structure and function, heredity, and evolution, and the class consisted of two 85-minute meetings per week. Of the 158 students enrolled in General Biology I, 12 students participated in the survey during the summer, and 3 students participated in interviews. Students enrolled in different sections of General Chemistry I were taught about the following: laws of chemistry, atomic theory and bonding, molecular geometry, states of matter, the periodic table and chemical periodicity, and many other topics. Of the 352 students enrolled in General Chemistry I in the spring semester, 17 students participated in the survey during the summer, and four students participated in the interviews. The surveys consisted of 20 questions and lasted approximately 25-30 minutes, and the interviews lasted 20-25 minutes. Each student who participated in the surveys was placed into a drawing for a $50 gift card, and all students who participated in the interviews were given $10 gift cards for their time. Participation in these surveys was quite low due to quarantine and online schooling brought on by COVID-19.

During the Fall 2020 semester, students enrolled in General Biology I and General Chemistry II were recruited to complete pre and post surveys as well as interviews detailing their understanding of enzymes. General Biology I was structured similarly to the class during the Spring 2020 semester, albeit entirely online. Of the 164 students enrolled in General Biology I, 24 students participated in the pre-survey, six participated in the post-survey, and five participated in an interview. Students enrolled in General Chemistry II were taught of the physical properties of solutions, chemical kinetics and equilibrium, thermodynamics, electrochemistry, and acid-base reactions. This course consisted of two 85-minute meetings per week. Of the 91 students enrolled in this section of General Chemistry II, 12 students participated in the pre-survey, five participated in the post-survey, and two participated in an interview. Each student who participated in the pre-survey was entered into a drawing for a $50 gift card, and a separate drawing was done for each student who completed the post-survey for a $50 gift card. In addition to this, each student who participated in an interview was given a $10 gift card for their time.

Data Collection

A total of 57 students engaged in either interviews or a survey, as described in Table 1. Eleven students from the graduate class completed the RINRUS assignment over the course of two days. Throughout these two class periods, we observed the students, providing guidance as needed throughout the assignment. Any issues students had were noted, whether they be technical or general confusion on the subject matter. In the two weeks after the assignment, 8 graduate students participated in semi-structured interviews, and were asked several questions about their experience with the assignment. The interview questions can be found in Appendix A.

Students in General Biology I and General Chemistry I in the 2020 Spring semester and General Biology I and General Chemistry II in the 2020 Fall semester were given surveys to determine multiple aspects of their learning throughout the semesters. Students who participated in these surveys that were enrolled in the Spring 2020 semester were asked extra questions about how the shift to online/remote schooling had affected them. Students enrolled in these classes in the Fall of 2020 were given pre- and post-surveys, with the only variations between questions being a tense change, questions about their overall experience, and the insertion of reflection questions. The full list of survey questions regarding enzymes can be found in Appendix B.

Each of the 14 students who participated in semi-structured interviews from this group were asked 15 questions about their demographics, study methods, and enzyme knowledge. The interview question list can be viewed in Appendix C. Each of these interviews were audio-recorded and transcribed to assist with analysis. Students were given randomly generated numbers to serve as IDs to protect their privacy. All data were saved with these numbers rather than names.

	Undergraduate Students	Graduate Students
Fall 2019	0	8
Spring 2020	30	0
Fall 2020	29	0

Table 1. Graduate and Undergraduate Student Participation by Semester. This table shows the number of undergraduate and graduate students who participated in surveys and interviews during each semester.

Data Analysis

For each group of students, graduate and undergraduate, the data obtained from the interviews and surveys were qualitatively analyzed. The graduate student interviews were analyzed to determine the changes that would need to be made to the RINRUS assignment to make it most accessible for undergraduate students. To analyze these interviews, we searched through the responses to see the most common ideas expressed to determine what most graduate students thought would benefit the assignment. For example, every answer to *"What revisions would you suggest to make this assignment more accessible to beginning undergraduate students?"* was categorized based on the response. The categories fell under "literature search revision," "modeling revisions (MOE or another modeling software)," "RINRUS revisions," and "other" for any other categories not previously mentioned.

From each undergraduate student, every answer to *"Explain what an enzyme is?"* was qualitatively analyzed by determining the frequency of certain phrases to determine what students most frequently could recall about enzymes. We searched for key phrases in these answers, such as "catalysts", "lowering activation energy", "lock and key mechanism", and "speed up/

accelerate/induce a reaction" as these are some of the phrases commonly used when describing enzymes in these courses. Evaluating the frequency of these phrases helps determine how much information these students are retain.

Additionally, those students enrolled in the Fall 2020 semester who participated in both pre and post surveys were categorized based on the difference in knowledge from the beginning to the end of the semester. Since so few individuals completed both the pre and post survey interviews, we read through and compared the first and second responses to see if each student had any more specific information to provide about enzymes, including searching for the presence or absence of key words listed above.

Results

Graduate Student Pilot Study

In our graduate student interviews, we focused on determining the accessibility of the RINRUS assignment as well as any changes that needed to be made for undergraduate student success. To begin with, graduate students were worried about undergraduate students' ability to read through the enzyme literature. One of these students suggested including the reading assignment as a pre-lab activity; and another suggested that we only make the students read through the abstract. In addition to this, some of the graduate students experienced some confusion with what information they were supposed to use from the literature which could lead to undergraduate students experiencing confusion as well.

The next issue for graduate students was the ligand viewer. Two students suggested switching to Chem3D rather than the PDB online viewer. In addition to this, some students were concerned with the lack of specificity in the definition of the seed of the complex, and issues with enzymes that have multiple ligands or crystallization cofactors. During insertion of the ligand chains into RINRUS, graduate students suggested providing more specificity in what chains are supposed to be inserted, especially multiples. Finally, in visualizing the complexes through MOE, graduate students were concerned about accessibility for undergraduate students. As many do not use MOE until much later in their degree path, 1 student suggested inserting pictures into the procedure to show what to click on for each question, and 3 students suggested providing a step-by-step video to either work alongside or watch before the assignment began. These interviews showed that some changes were essential before presenting the RINRUS assignment to undergraduate students.

General Chemistry I and General Biology I (Summer 2020)

Of the 18 students who participated in the survey in General Chemistry I, many understood the basic function of enzymes. In response to the question asking students to explain their understanding of enzymes, 10 mentioned that an enzyme is, or acts as, a catalyst, and 8 explained that enzymes accelerate the rate of a reaction. For example, 1 student wrote:

> "An enzyme is a substance that could partially act as a catalyst to induce a specific reaction because it is produced by a living organism."

Many students noted that enzymes are proteins. 1 student stated:

> "Enzymes are molecules that act like catalysts. I have only taken CHEM 1110 so that is about all I know right now."

Although many students were aware of what enzymes are, 2 students mentioned that they were unsure of what an enzyme was and what its functions were.

While most of the students understood the very basic functions of an enzyme, there was no evidence of a higher level of understanding of their mechanisms of action. Of the 4 General Chemistry I students who participated in the interview, most did not provide answers that showed any understanding of enzymes. All 4 students mentioned that their professor did not go over enzymes during the semester, and 1 student mentioned that they were unsure of what an enzyme was during the interview. Overall, their understanding of enzymes was essentially that they were biological catalysts, with only one student mentioning that they accelerate the rate of reaction. It is important to note that students do not learn about kinetics or reaction rates until General Chemistry II, so this prior knowledge likely came from high school instruction. From the interviews, we also confirmed that students at this level have had minimal experience in reading scientific literature.

Twelve students in General Biology I participated in the survey, and 7 of these students specifically stated that enzymes act as catalysts. Five students mentioned that enzymes speed up a reaction, and 3 students specified that enzymes work to lower the required activation energy of a reaction. Several of these students noted that enzymes are a type of protein. These students did show a more advanced understanding than students from General Chemistry I; 1 student specified:

> "An enzyme is a biological catalyst that speeds up chemical reactions by lowering the activation energy of a reaction. The enzyme has an area where a specific substrate can attach, and the enzyme can break that substrate down. The enzyme itself does not break down and can be used again."

Four students in the class noted that enzymes are very specific about what they break down, and 3 students said that enzymes are not used up in a reaction. Only 3 students in General Biology I participated in interviews. Each of the three students noted that they went over enzymes in class. One student said:

> "What they do is lower the activation energy of chemical processes, making it occur faster than they would if they were not there. They are not changed or lost during the process."

This student followed by listing the 4 levels of structure for proteins. One of the other students explained that enzymes interact with inhibitors that affect how the enzyme works. These students shared a greater understanding of enzyme concepts. Similarly to General Chemistry I students, however, these students also had little experience with reading scientific papers.

General Chemistry II and General Biology I (Fall 2020)

Students in General Chemistry II were asked to participate in pre- and post-surveys as well as interviews. Twelve students participated in the pre-survey, and several of these students had a basic understanding that enzymes act as catalysts to accelerate the rate of a reaction. Of these 12 students, 4 were simultaneously taking General Biology I. Over half the students also mentioned that enzymes are proteins. However, most students could not provide more specific answers. One student who was also enrolled in General Biology I noted:

> "Enzymes are proteins within a living organism. They help speed up processes and chemical reactions. They do so by lowering the activation energy."

Of the 12 responses to the survey, this was the only response that specifically mentioned that enzymes lower the activation energy required for a reaction. Three students mentioned that enzymes have an active site and are very specific in what molecules are able to bind. The post-survey showed similar results on a smaller scale. Four students participated in the post-survey, only 2 of whom had also participated in the pre-survey. Of the two students who completed both surveys, both seemed to have a greater amount of knowledge about enzymes at the end of the semester, but specifics were not used. For example, 1 student wrote in the pre-survey:"*I believe enzymes break down other molecules*." This is not a completely correct statement as some enzymes repair and construct proteins, DNA, etc. In the post-survey, however, this student specified:

> "An enzyme can be used to speed up a reaction by cutting down the activation energy."

Of the 4 responses received, 3 students mentioned that enzymes accelerate the rate of a reaction, and 3 mentioned that enzymes are proteins. Two of the students who were taking this section of General Chemistry II participated in interviews. Both students mentioned that they were unsure if their professor taught them about enzymes throughout the semester, and neither student was simultaneously taking General Biology I. One student said,

> "The last time I remember talking about enzymes was in high school anatomy."

This student also said that enzymes are used to break substances down, and that we have enzymes in our saliva and digestive system. The other student mentioned that enzymes act to speed up bodily processes and mentioned they would know more once they took a biology course. Through analysis of interviews, it was clear that these students did not have a good understanding of what an enzyme is, how it works, or how it interacts with substrates. When asked about their comfortability and experience in reading scientific literature, both students mentioned sometimes reading psychology journals. One of the 2 mentioned:

> "I'll just Google random stuff that I'm interested in and then I know to skim the abstract…I don't really go too much into the statistics because that stuff is over my head right now."

These students reinforced that, while they did not always understand every piece of a work of scientific literature, they could determine the important aspects when necessary. In a comparison of class content to knowledge, we determined that students in General Chemistry II did not obtain much of the information given to them regarding enzymes in that class alone. Students were taught about solid state materials, including proteins, and the properties of these materials. In addition to this, they were also given a laboratory exercise to navigate through the PDB website.

This exercise focused on viewing the main protease of the SARS-CoV2 virus. In this assignment, students were informed of the different levels of structure of a protein and the difference between superfamily, family, and species. These students were also asked questions such as "*Does this drug have a dipole moment? Hydrogen bonding?*" and "*What keeps these ligands associated with the protein?*". While this course focused on the structure of proteins and, in turn, enzymes, students generally did not seem to correlate one with the other when asked for all information on enzymes.

Twenty-five students in General Biology I participated in the pre-survey. Eighteen of these students mentioned that enzymes are catalysts for a reaction, and 17 students showed that enzymes are proteins or biological molecules. Fourteen students mentioned that enzymes speed up the rate of a reaction, and 8 specified that enzymes are very specific in the ligands they will accept, noting the lock and key and induced fit models. One student said that enzymes can be affected by an influence in their environment, such as temperature and pH levels, and 1 other student mentioned the 4 levels of structure of proteins. Few students mentioned that enzymes are not used up in a reaction. One student, for example, wrote

> "An enzyme, usually proteins, are used to speed up a reaction that takes place in cells. They are a part of an enzyme-substrate complex that allows the reaction to catalyze, and enzymes can be used multiple times."

Five students participated in the post-survey, 2 of whom also completed the pre-survey. The 2 students that completed both, had a similar level of understanding of enzymes. One of these students specified that enzymes are useful "in processes such as the DNA-to-protein path and immunological defenses", showing that over the course of the semester, they learned more about functions of enzymes as they relate to health. Of the other 3 responses to the post-survey, 1 mentioned circumstances in which enzymes are necessary within the body, and all 5 students mentioned that enzymes catalyze reactions within the body.

Five students in General Biology I participated in an interview. These interviews allowed students to explain much more of their understanding of enzymes. Four of the 5 students mentioned that enzymes work by lowering the activation energy necessary for a reaction to occur. One student referred to enzymes as a "*Support system for reactions to take place.*" One of the students related enzymes to processes that happen within the body, such as the electron transport chain. Two students mentioned the way in which enzymes bond to ligands, and most of the 5 students mentioned the specificity of the binding of enzymes to ligands. One student even noted that there are specific receptors that the enzymes look for, and they must be in the proper orientation for binding of enzymes to ligands to occur. This student also mentioned that enzyme changes are dependent on their environment, including pH, temperature, and concentration levels.

Overall, all 5 students that participated in an interview showed that they understood the functions of enzymes quite well, but only 2 mentioned the specific interactions with ligands. These students, however, seemed to absorb and understand most information provided to them through lecture. When asked about their experience and comfortability in reading scientific literature, most students interviewed said they had a very base-line comprehension level, with 1 student mentioning:

> "It's written very dense, and it's a lot of material to work through. But as long as I set that time aside, you can certainly understand the purpose of the experiment."

Most of the students interviewed showed that they had little experience, but that they were capable of evaluating a paper to determine the main ideas. In General Biology I, students learn many specifics about enzyme interactions and functions. Throughout the first unit of General Biology I, students learn about cells and the molecules of life. One section of this unit is devoted to teaching students about enzymes. In this section, students learn how enzymes lower activation energy, how they bind to their substrates, which molecules can act as enzymes, and how pH and temperature affect enzyme-catalyzed reactions.

The 2nd unit of this class is entirely focused on enzymes, energy, and communication, and focuses on the specific functions of enzymes, including how enzymes are used in transport methods, glycolysis, photosynthesis, and metabolism. Comparing this information to the students' answers in the surveys and interviews indicated that students were much more aware of some of the basic concepts of enzymes than some of the more intricate details about enzymes. Overall, retention about enzymes seemed to be decent when concerned with basic enzyme function, few students retained more intricate enzyme binding details.

Summary of Results

Overall, General Biology I students had better understanding of enzymes and enzyme function. Most of these students were able to explain what enzymes are and what function they provide within the body. Several of these students were also able to elaborate on some key features, such as the structure of proteins (therefore enzymes), and a basic description of how enzymes bind to ligands. Most students enrolled in General Chemistry I could give no more information than that an enzyme can be a protein, and enzymes speed up chemical reactions. Students in General Chemistry II did not seem to have much more of an understanding of enzymes than those enrolled in General Chemistry I.

A majority of students who completed the pre and post surveys for General Chemistry II were not concurrently taking General Biology I, which likely accounts for a lack of increase in knowledge for the two classes, as General Chemistry II does not elaborate on enzyme specifics heavily. However, General Chemistry II does define and introduce them in the context of catalysis, transition states, and kinetics.

Discussion and Conclusion

Currently limited work has shown different methods for teaching students about enzymes, such as using the visual-spatial aspect of the Multiple Intelligence Theory by incorporating PowerPoints into lecture (Yalmanci and Gözüm, 2013). By providing students with the opportunity to not only visualize, but also manipulate, a 3-D enzyme-ligand complex within the RINRUS assignment, we expect students will retain more of the key concepts regarding enzyme-ligand binding and will have an experience that they will remember and take on to further classes.

In the 1st research question, we asked, "How do graduate chemistry students perceive the RINRUS assignment as it pertains to understanding enzymes?". Interviews with graduate students reaffirmed that the RINRUS assignment will be useful in teaching undergraduate students about enzymes to prepare them for courses in both the biology and chemistry majors. Importantly, this pilot and the interviews gave us critical feedback on the issues that undergraduate students might have. We have been able to substantially improve the assignment based on this feedback.

In the second research question, we asked, "What information about enzymes are beginner undergraduate biology and chemistry students obtaining and retaining from their courses?". We found that students in introductory courses at the University of Memphis are retain very little about enzymes. The primary piece of information they are obtain is about proteins. Although most enzymes are proteins, not all proteins are enzymes, and many students do not accurately relate the two concepts.

From student responses in interviews, it is clear that General Biology I students learn much about enzyme function, however, they frequently have trouble understanding enzyme structure and function in regard to enzyme-ligand binding. Many students in General Biology I have the potential to understand and excel when it comes to enzyme specifics; however, they need to be specifically taught these concepts. The RINRUS assignment can be useful in helping these students understand the enzyme specifics that they will need for more advanced courses in both biology and chemistry majors. The assignment is also a way to introduce students to reading scientific literature in their first few years of college to provide a basis for the increased reliance on primary literature in upper division courses. Students will revisit proteins again in Organic Chemistry and Bioorganic Chemistry (both required for biology and chemistry majors) and in the Biochemistry course.

Within this research study, few students completed interviews and surveys. This can, in part, be a result of the COVID-19 pandemic. However, a common theme found is that students in introductory undergraduate chemistry courses are retain very little about enzymes although they retain understanding of proteins more generally. While students are taught about proteins, they often have trouble relating to enzymes. While General Biology I students learn about enzyme function, they still do not retain knowledge about enzyme structure and function and how that relates to enzyme-ligand binding. The PowerPoint lectures we reviewed did not tend to teach students specific information about enzyme-ligand interactions. Including an intervention in this course could increase long-term enzyme understanding.

In this study, we have shown that the current methods for teaching undergraduate biology and chemistry students about enzymes can be improved to enhance student understanding and retention. We have shown that existing PowerPoint lectures do not adequately teach students specific information about enzyme-ligand interactions, and providing a hands-on, small group activity is more likely to help students better understand this information. For example, as Oludipe and Awokoy (2010) showed, having peers to deliberate with is very useful in not only relieving anxiety but also allows for the sharing of ideas and information that may be pertinent to the exercise. Separately, the characterization of what students currently retain from their courses may be useful to professors, as it could help professors understand what topics need to be prioritized when teaching students about enzymes.

Our future directions are to continue development of the RINRUS assignment and test it with General Biology I students to determine its effect on their understanding of enzyme structure and function.

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Appendix A - Graduate Student Interview Questions

Biographical information – focus of study, career goals, background education.

Think aloud activity: students instructed to go through the assignment and talk through their process for completing the activity and answering the questions. Students asked to note specific areas they were confused or did not understand the assignment or what was expected of them.

1. What was your overall experience with this assignment?

2. Were there any parts you found difficult?

5. How did this assignment influence your thinking about enzyme modeling?

3. How did this assignment influence your thinking about biochemical research?

4. Did you have any issues with the Protein Data Base when transferring enzyme models into the software?

5. Do you have any feedback on how to make the Protein Data Base website easier to navigate?

6. Did you have any trouble downloading or using files from the Protein Data Base?

7. Did you have trouble with the instructions in the RINRUS software?

8. Did peer discussion threads on eCourseware/Desire2Learn enrich the exercise?

9. Do you think this task would be appropriate for beginning undergraduate students? Why or why not?

10. What revisions would you suggest to make this assignment more accessible in general?

11. What revisions would you suggest to make this assignment more accessible to beginning undergraduate students?

12. Did this assignment improve your understanding of enzymes and ligand-binding?

13. Do you have any additional comments or suggestions on how to improve this assignment?

Appendix B - CHEM 1110, CHEM 1120, and BIOL 1110 Survey Questions

1. What is your major?

2. What year are you in school?

3. How did you study for this class?

4. How would you determine if you understood a topic or if you needed to study it further?

5. (BIOL 1110 only) In what ways were the practice tests prior to exams helpful for you?

6. Explain what an enzyme is and how it works. Include any information you know about the structure of enzymes and their interactions with other molecules.

7. Are you planning on taking classes in the Biological Sciences department? If so, which do you plan to take?

8. (For BIOL 1110 and CHEM 1120, respectively) Are you currently enrolled in General Chemistry II/General Biology I?

Appendix C – Undergraduate CHEM 1110, CHEM 1120, and BIOL 1110 Interview Quesitions

Enzyme Questions

1. Throughout CHEM 1110/CHEM 1120/BIOL 1110, what did you learn about enzymes?

    a. Explain your current understanding of enzymes.

    b. From what you have learned so far about enzymes, are there any concepts you had a hard time understanding? If so, what are those concepts?

    c. What new information did you learn about enzymes in BIOL 1110 compared to CHEM 1110? (BIOL 1110 students only)

2. If any, what is your experience and comfortability with reading scientific papers thus far?