Enhancing Student Visualization of Primary Stabilizing Forces Through 3D Protein Models

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Abstract

This Honors Thesis is an action-research project which involves creative design of a lesson plan for a *Principles of Biochemistry* course, aimed at making the challenging topic of protein structure more visual, engaging, and digestible. Action-research projects systematically test new practices, using collection of data as an evaluation of the effectiveness of the new practice. By combining scientifically accurate content with immersive pedagogy strategies, this thesis project explores how 3D protein models can enhance student understanding of primary stabilizing forces within protein structures. In contrast to traditional lecture-style lessons, this project tests if non-traditional pedagogical strategies improve student learning and performance. The lesson plan being tested consists of two parts: (1) guided-instruction construction of a 3D protein model, and (2) a corresponding worksheet. The lesson plan was taught in a flip-style class, in which students were instructed to watch the Echo360 recording of Dr. Sholder's traditional lecture on protein structure. The goal was for students to come to class with some context on the lecture material, before applying the content to an interactive activity during class. During class, students independently constructed their own 3D protein model, while following along with prompts on the corresponding worksheet. The physical protein model adapted Dr. Sholder's 2D representation of a protein (the helical wheel diagram) into a 3D model aimed at enhancing students' visuospatial understanding of molecular interactions. The goal was to help students better understand the learning objective: Compare and contrast the interactions driving the formation of secondary, tertiary, and quaternary structure of proteins. During project implementation– when the lesson plan was taught– students were instructed to construct the model, answer prompts on the worksheet, and answer iClicker "checkpoints" aimed at evaluating student comprehension at each level of protein structure. iClicker data indicated that over half the class benefitted from the lesson plan and interactive 3D protein model. However, more research is necessary to determine the effectiveness of the lesson plan. Some considerations in this project are time management, assessment/evaluation tools, and the flexibility of materials. Overall, this project offers a number of benefits for myself, people in my field, and people outside of my field.

Introduction

As a “child” of both biology and chemistry, biochemistry requires learners to embrace its new material with a solid foundation in both core fields. The complexities of biochemistry become transparent in both learning and teaching biochemistry content. Without the proper prerequisite courses—and a solid comprehension of major concepts—students may struggle to grasp new biochemistry material (Harle et al., 2013). Even a student who performs seamlessly in the context of Biology, but struggles in Chemistry, lacks the core scaffolds necessary to meet their full potential when the two fields intertwine. From the perspective of teaching, educators are challenged with the task of navigating lapses in students’ core foundations in both fields, while still presenting new biochemistry content to meet their own standards and expectations within the course (Harle et al., 2013). Thus, this project explores the use of various pedagogy strategies to determine if pedagogical tools can enhance teacher communication and student visualization of the complex field of Biochemistry.

Background/Theory

Before diving into the specifics of teaching Biochemistry, it is useful to explore the basic roots of how students learn. So, how do students learn? Students typically come into a class with preconceptions or a base level understanding of a topic (Bradford et al., 2000). These preconceptions are essentially the foundations of all new knowledge that they take in. This can be explained through the “Fish is Fish” story in which a little fish wishes to see what life is like outside of the pond (Bradford et al., 2000). In the story, when the fish’s tadpole friend becomes a frog, the fish asks the frog to go on land and tell him what life is like. The frog tells the fish about people and birds, but the fish envisions people as fish with legs and birds as fish with wings. The takeaway is that people construe new knowledge based on their initial beliefs and views of the world. This phenomenon is captured by the philosophy of constructivism, which explains that existing knowledge is utilized to create new knowledge (Bradford et al., 2000). Therefore, an essential role of teachers is to address those potential misunderstandings, so that the new content does not get distorted.

Another key consideration in pedagogy is that the brain plays a large role in students’ learning. There are several neural processes that motivate memory and learning. Based on human evolution, the brain depends on four emotions for survival: cognition, fear, pleasure, and control

(Doyle, 2007). When considering the American education system, most schooling allots a significant amount of control to the teachers, rather than the learners. This is largely a result of early empiricist views that motivation was driven by things like hunger, rewards, and/or punishments (Bradford et al., 2000). While those drives do play a role in motivation, modern research argues that shifting our teaching style to give students more control over their own learning can activate the "control" aspect of the brain. Moreover, giving students more control can also alleviate some of the "fear" (or stress) they may face when they lack control. These ideas can be accomplished through "Learner-Centered Teaching" where the educator provides opportunities for students to take initiative and take on a more active role in their learning (Doyle, 2007).

When presenting new material to students, it is also important to acknowledge that there is a disparity in novice versus expert abilities. In most cases, students come in as "novices" on the topic, whereas teachers are "experts" (Bradford et al., 2000). Experts typically have a stronger ability to notice patterns and organize new information than novices. Providing students with pedagogical tools and independent study skills is a valuable way to give students the capacity to gain abilities experts have. For example, physical models can help students develop important organization and problem-solving skills, as long as they are presented at an appropriate level of complexity catered to the students' knowledge and skills (Bradford et al., 200). It may seem counterintuitive, but simple models may be more beneficial to students than more complex models. On the other hand, it is equally important to not oversimplify content. Research shows that students perform better when provided with only the framework of the lesson, rather than given the information directly. For example, students given partial notes perform better on evaluations than students given the full note set (Lang, 2016). Thus, it is essential to find a balanced level of complexity tailored to students' ability and competency levels.

While models can be used *in class* to help students build skills of noticing patterns and organizing information, it is also important to encourage students to practice these skills on their own, *outside* of the classroom. For instance, metacognition—one's ability to self-monitor current levels of understanding and predict performance on future tasks—is a great way for students to become experts (Bradford et al., 2000). The main goal of metacognition is for students to identify what they do and do not know. Metacognition can even help students identify their own misconceptions! Although metacognition must occur on an individual level, teachers can increase students' metacognition skills by providing opportunities for self-assessment, reflection, and sense-making (Bradford et al., 2000). Teachers can promote student self-assessment by providing opportunities for students to (1) work individually to write down their steps and thought processes, (2) define vocabulary terms or major concepts (both before and after the lesson), (3) provide questions with possible answers for students to vote on, (4) to have problems/questions for students to complete at the end and then check their answers, and (5) foster group discussions (Doyle, 2007).

Mixing up allocation of "control" is another effective way to promote students to practice question-asking and problem-solving skills (Lang, 2016), while also solving the issue of fear/stress-driven learning due to lack of control. For example, self-explanations allow students to develop problem-solving skills while understanding the core themes of the topic. Meanwhile, think-pair-share activities, which involve students working on a problem and discussing their answer with a neighbor, can utilize peer power and allow students to teach each other through asking questions and clarifying misconception (Lang, 2016). While these discussion forums offer skill-building opportunities, they also have the potential to create misconceptions. Thus, instructor feedback is critical. In large classes, bringing the class back as a whole after independent/partner work is a quick way to address misconceptions given the class size. Another approach is to circulate the classroom while students are working on their own/with partners/in groups and answering as much individual feedback as possible (Lang, 2016). All in all, it is important to provide a variety of different types of discussion prompts and feedback opportunities.

As mentioned above, students' fragmented preconceptions may influence the development of misconceptions when learning new information. So, it is important to assess and address those misconceptions. One method of identifying student preconceptions is through frequent formative assessments that test students' comprehension beyond simple recall (Bradford et al., 2000). For instance, an exam with questions that prompt students to apply major concepts to specific scenarios. For this project specifically, *Principles of Biochemistry* students' base knowledge has been assessed in previous research conducted by Sholders et al. (manuscript in preparation). This research indicates that students exhibit lower than expected learning gains in protein structure and folding throughout the course of the semester (Laybourn et al., 2024). This research is confirmed by other studies reported within the literature.

One study on protein structure, folding, and stability explains ten common challenges students face when learning about protein folding. The study explains that students can often grasp the difference between protein structure levels but get confused on how protein structure relates to stability and activity (Robic, 2010). Additional studies expanded on this, indicating that many students struggle with the visuospatial aspects of protein structure. For instance, one study explained that students struggled specifically with the "mental rotation" of images (Herman et al., 2006). Since protein folding occurs on the molecular level and cannot be experienced or observed directly, therein lies a source of confusion. It is crucial to provide some sort of visualization when teaching the topic of proteins since they cannot be directly observed. Otherwise, it is virtually impossible for students to envision protein structure; thus, hindering their ability to make inferences on how structure impacts function (Harle et al., 2012).

Many teachers try to accommodate for inability to directly observe molecular level processes by providing students with external representations of proteins. However, this sometimes imposes yet another learning barrier in terms of students' ability to make "translations" between different representations of proteins. For example, a student may not understand the connections between a ball and stick representation and a ribbon representation of the same protein (Wu et al., 2004). In particular, another study tested undergraduate level students' understandings of primary and secondary protein structures through having them draw out the structures and the associated stabilizing forces. Their drawings indicated that many students did not struggle to identify/recognize primary structure, but when asked to draw out secondary structure, their interpretations were "fragmented" and "lacked coherence." This shows that conceptualizing secondary protein structure is challenging for undergraduate students across the board (Harle et al., 2013). So, how do we fix this? Providing students with multiple representations of the same information may be a solution (Wu et al., 2004).

In this project, students' visuospatial misconceptions of protein structure are addressed by presenting an alpha helix of a protein through two representations. The first representation is a 2D image and the second representation is a 3D physical protein model. Prior studies have utilized a variety of materials to model protein structure, including mobile apps, computer sites, pipe cleaners, foam cut-outs, pony beads, and more (Marshall, 2014). Another study even suggested the use of Mini-Toobers, which are foam tubing with a wire core (Herman et al., 2006). Both studies explained that any visualization-based activity can help students develop conceptualization skills rather than simple memorization. However, if represented poorly, students may develop or strengthen their alternative conceptions, so it is important to maintain scientific accuracy of models (Wu et al, 2004).

To put it simply, effective teaching involves first understanding how students learn. It is important to consider how preconceptions and allocation of control impact student learning. In addition, providing opportunities for students to practice metacognition, independent work, group discussions, and receive instructor feedback are all important processes in guiding students to shift from novices to experts. An initial step of designing lesson plans is to assess and address student misconceptions. Once misconceptions are identified, appropriate strategies can be determined and implemented.

Lesson Plan

In this action-research project, I tested the potential benefits of a non-traditional pedagogy approach on student learning. With the help of Dr. Sholders and Dr. Balgopal, I created the lesson plan (a 3D protein model and corresponding worksheet) and taught it in one of Dr. Sholder's BC 351 *Principles of Biochemistry* lectures. Through creative design, I strove to address the three major pedagogical considerations above: (1) identifying student misconceptions, (2) giving students more control, and (3) acknowledging disparities in novice versus expert abilities. In addition to addressing said considerations, I hoped my lesson plan would instill skills beyond the single lecture, by having students practice metacognitive and self-assessment skills in the activity.

First, to identify student misconceptions, I used Dr. Sholder's manuscript in preparation (Laybourn et al., 2024) to assess BC 351 students' base level knowledge of biochemistry. The pre- and post-course evaluations (see Methods) helped me identify core biochemistry topics students showed historically low student achievement in. Based on these evaluations, and my personal confidence and interests, I chose to design my lesson plan on the topic of protein structure and folding. Next, I read a plethora of literature explaining previously studied student misconceptions within said topic. A major student misconception is visuospatial thinking and reasoning of molecular interactions.

After identifying and addressing student misconceptions, I focused on investigating the best pedagogical methods of presenting the visuospatial aspects of protein structure and folding to students using a physical model. The overarching goal of the 3D protein model is to foster student development of visuospatial thinking and reasoning of molecular interactions. In attempt to give students more control, I designed my lesson plan to be hands-on and give students the opportunity to individually construct their own model. I tried to find materials that students would be able to manipulate themselves. Considering Marshall and Herman's material suggestions, I decided to use pipe cleaners and pony beads. I emphasized the importance of presenting multiple representations of the same information by adapting Dr. Sholder's helical wheel model into a 3D protein model. In other words, I took a 2D representation and presented it to students in a different, more hands-on form. To ensure scientific accuracy, I made sure to keep the colors of the pony beads consistent with the universal symbols in the field of chemistry. To further avoid development of misconceptions, I kept the 3D representations of protein model consistent with the 2D representations of Dr. Sholder's alpha helical model (Sholders et al., 2012). Overall, I thought having students construct and manipulate their own 3D protein model would give them more control over the protein folding topic. My goal was that having more control will relieve some stress/fear, so students can instead focus on the activity itself and on building a stronger foundation of core concepts.

To account for novice versus student abilities, I decided to simplify some of my original ideas for the 3D protein model. Initially, I wanted my model to help students understand the impact of mutated amino acids on protein structure and how proteins can exist in various semi-folded states rather than only folded or unfolded states. However, I realized that this may overcomplicate the model, so I instead decided to narrow down the model to focus more on the simple differences in noncovalent interactions between primary, secondary, and tertiary structure. I felt that this was more relevant to students' base knowledge and abilities on the topic of protein folding and hoped that a simpler model would help them break past some of their prior misconceptions and develop a stronger, more accurate foundation from which they could build more complex topics off of. On the other hand, I also made sure to recognize the dangers of oversimplifications. Emulating the pedagogy style of fill-in notes, I aimed to give students the frameworks to help them build their protein, without giving them too much of the answer right away. For instance, I gave them two amino acid positions to start with, and they were instructed to determine the rest of the sequence themselves. The goal was that they would have to build their own connections, which encourages them to ask questions and relate the activity to their prior and new knowledge.

Reiterating some of the literature above, models can be useful to help students build "expert" level skills (i.e. pattern recognition and organizational skills), but it is important to encourage students to practice those skills outside of the classroom as well. Through creative design of my worksheet, I incorporated some pedagogical tools to give students opportunity to practice building those skills during the lesson. The ideas of metacognition and self-assessment strategies helped me design a follow-along style worksheet which corresponded with the in-class construction of the 3D protein model. To reiterate, teachers can promote student self-assessment by providing opportunities for students to (1) work individually to write down their steps and thought processes, (2) define vocabulary terms or major concepts (both before and after the lesson), (3) provide questions with possible answers for students to vote on, (4) to have problems/questions for students to complete at the end and then check their answers, and (5) foster group discussions (Doyle, 2007). I incorporated strategies 1, 2, and 4 by creating a "Preconceptions" and "New Understandings" section in the worksheet. These sections had tables for students to define each level of protein structure and their respective primarily stabilizing interactions. The tables were the exact same so that students could compare their answers from before the lesson and after the lesson. I incorporated strategy 3 by designing iClicker questions for students to answer after each activity in the lesson plan. For example, students were instructed to construct a primary protein structure and then answer an iClicker about the bonds that were present. Four answer options were provided, and answers were discussed as a class after students submitted their answer. This also touched on strategy 5, because students were able to discuss answers with neighbors. In addition, I provided key questions on the worksheet that said "Discuss with a neighbor: …" to emphasize the pedagogy method of discussion-based learning. Overall, the worksheet encompasses a variety of pedagogy strategies focused on facilitating metacognition.

To further encourage bridging the gap between novice and expert abilities, I practiced pedagogy methods for encouraging discussions and inquiry-based teaching when implementing my lesson plan. For example, I made a point to mix up allocation of control by having students practice individual, partner, and whole-class work. Independent work was accomplished through individual construction of their 3D protein model; partner work was achieved through iClicker questions and "discuss with a neighbor" prompts in the worksheet; and whole-class work was conducted by introducing the topic to the class and explaining each iClicker answer to the class in its entirety.

Methods

Assessment

Dr. Sholder's has been conducting his own research on effective teaching strategies within the field of Biochemistry across previous semesters of his BC 351 *Principles of Biochemistry* course at Colorado State University. Dr. Sholders provided data on pre- and post-course evaluations from said semesters. His pre- and post-course evaluations are a useful way to determine students' base level assessment. On the first day of class—before receiving any instruction or course content—students take a pre-course assessment, indicating their base-level knowledge. This includes knowledge that students obtained from pre-requisite courses or additional external sources. At the end of the semester—after students have received instruction and course content—students take the exact same assessment (the post-course evaluation). The post-course evaluation offers insight into areas where students' knowledge improved, stayed the same, or declined.

These assessments were useful in determining the topics in which students have historically exhibited the least academic achievement in BC 351. "Table 4– Questions with Statistically Insignificant Changes Between Pre and Posttest scores" from Dr. Sholder's existing research was used to determine which topics showed the lowest changes in student achievement between the beginning of the semester and the end of the semester in his BC 351 courses historically (see Figure 1). The format of the pre- and post-course evaluation exam has about five to six questions per major concept covered in BC 351 lecture. For instance, questions 1-5 correspond with the topic of amino acid side chain properties/interactions; questions 6-11 correspond with the topic of protein folding and mutations; etc. Using data from Figure 1, certain topics showed trends of low student achievement. Particularly, the topic of protein folding and mutations (aka questions 6-11 on the pre-course evaluation) was one of the topics students showed low academic achievement in. While there were several other topics students struggled with, protein folding was a topic that I felt most confident in my own understanding and ability to teach to others. Thus, analysis of Figure 1 data combined with my own understandings/abilities were the basis of my topic choice for my Thesis project.

Table 4 – Questions with Statistically Insignificant Changes Between Pre and Posttest scores

	S-01 (n=121)			S-02 (n=202)			S-04 (n=183)			S-05 (n=96)			S-06 (n=170)			Combined (n=858)		
?#	Pre	Post	p	Pre	Post	p	Pre	Post	p	Pre	Post	p	Pre	Post	p	Pre	Post	p
12													39%	49%	0.09			
18	20%	16%	0.44															
20										32%	44%	0.17						
26							48%	57%	0.10									
28										51%	59%	0.27						
41										32%	42%	0.12						
4	47%	46%	0.88							38%	42%	0.75						
7	78%	86%	0.07							72%	80%	0.22						
11	51%	40%	0.12							46%	39%	0.39						
39	79%	79%	1.00				73%	81	0.07									
40	54%	65%	0.20							52%	58%	0.55						
1	67%	77%	0.08				68%	76%	0.06	68%	78%	0.20						
6	59%	62%	0.67				52%	60%	0.09	52%	58%	0.08						
22				47%	50%	0.43	51%	50%	0.90				48%	50%	0.68			
27							63%	64%	0.91	65%	74%	0.14						
31	51%	54%	0.47				43%	48%	0.30				42%	46%	0.53			
13	55%	66%	0.08	48%	52%	0.42	45%	55%	0.04	42%	53%	0.17						
32	20%	25%	0.23				20%	29%	0.07	28%	21%	0.41	15%	21%	0.17			
21	36%	36%	1.00				31%	27%	0.49	34%	39%	0.53	21%	24%	0.58	27%	31%	0.12
23	81%	81%	1.00	81%	87%	0.13	85%	81%	0.33	79%	72%	0.23				80%	82%	0.43
14	40%	52%	0.07	43%	49%	0.29	46%	41%	0.40	49%	59%	0.21	45%	52%	0.20	44%	49%	0.09

Figure 1. Table 4 from Dr. Sholder's pre-existing research on effective teaching strategies for BC 351. Table 4 organizes data collected from several semesters. This table shows which questions from our Learning Objective assessment instrument illustrated no significant changes between pre- and post-course evaluation. The questions toward the top showed this in only one section, the next grouping showed this in 2 sections, the next 3 sections and so on. The bottom three questions were questions in which students she little to no improvement upon in all sections evaluated.

Creative Design

My thesis project was designed in two parts: (1) a 3D protein model, and (2) a corresponding worksheet. Using Dr. Sholder's helical wheel diagram as a starting point (see Figure 2), I explored different materials that could be used to transform his 2D protein representation into a 3D protein model. I considered using toothpicks and mini marshmallows but decided they would be too flimsy and messy for students to work with. I tested the sturdiness and malleability of pipe cleaners and found that they worked well for my intended purpose. In fact, the pipe cleaners were the perfect length to evenly space out 9 pony beads—which corresponded to the number of amino acids in Dr. Sholder's helical wheel diagram (see Figure 3). The pipe cleaners represented the protein backbone and the pony beads represented amino acids. Specifically, the pony beads represent the alpha carbon of the amino acid while the colors represent the R-group property of the amino acid. Keeping colors consistent with the universal "color-code" within the field of Chemistry, yellow pony beads represented hydrophobic amino acids, blue pony beads represented positively charged amino acids, and red pony beads represented negatively charged amino acids. To prepare for lecture, materials were assembled for the respective class size of 250 students. Materials included a Ziplock bag (1 per student) containing one pipe cleaner, five yellow pony beads, two blue pony beads, and two red pony beads. Materials were put into a total of three boxes, which were spread out in the front and back of the classroom for students to grab before starting the activity.

The activity parallels prompts in the worksheet, so that students can visualize how amino acids and different types of bonds interact in the process of protein folding, while being asked to apply the 3D model to the learning objective. The goal of the activity is to facilitate comprehension of the visuospatial aspects of proteins by providing the opportunity for students to be hands-on and interactive. Another goal of the activity is to help students "unlearn" some of the common misconceptions of protein folding referenced in relevant literature.

The second aspect of creative design includes an instructional worksheet that aligns with the construction of the 3D protein model. The worksheet is divided into several parts. First, the worksheet identifies the necessary materials and instructs students to raise their hand if they are missing anything. This aspect was designed to compensate for potential errors in material preparation. Next, the learning objective is stated clearly on the worksheet to give students context to the skills they should be able to walk away with at the end of the lesson. The "Preconceptions" and "New Understandings" sections both prompt students to fill out a table by defining and identifying the different levels of protein structure and their respective stabilizing forces. These sections encompass pedagogy strategies of self-assessment and metacognition by having students fill out the same table before and after completing the lesson plan. There are also three "Activity" sections. Each of the "Activity" sections is formatted through a real-time demonstration of how to construct the model, prompts for discussion, and an iClicker "checkpoint" to assess students' comprehension. For example, in "Activity 1" the instructor displays the materials on a projector and demonstrates how to put the pony beads onto the pipe cleaner to construct a primary protein structure. Then, the instructor allows students time to individually construct their own primary protein structure and answer some questions on the worksheet with a neighbor. Before moving on to “Activity 2,” the instructor brings the class back as a group and has students answer an iClicker question. The instructor explains the answer to the iClicker and then moves on to “Activity 2” and repeats said process.

The goal of the worksheet is to provide students with a structured guide that helps them apply the 3D protein model to ideas within the learning objective. Many pedagogy strategies are incorporated into various aspects/sections of the worksheet. For instance, as stated above, the “Preconceptions” and “New Understandings” sections facilitate metacognition. In addition, individual construction of the 3D protein models allows for individual work, the discussion prompts encourage group collaboration, and the iClickers encourage instruction on a whole-class scale.

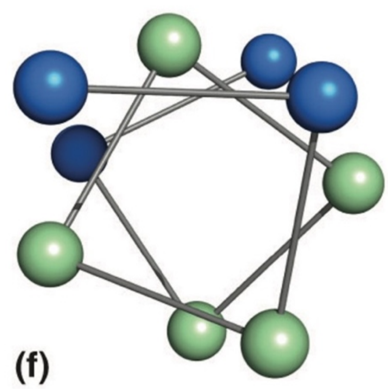

Figure 2. Dr. Sholder’s helical wheel diagram. The helical wheel diagram depicts a 2D representation of an alpha helix of a protein. The lines represent the peptide bonds holding amino acids together. The spheres represent the alpha carbon of the amino acids.

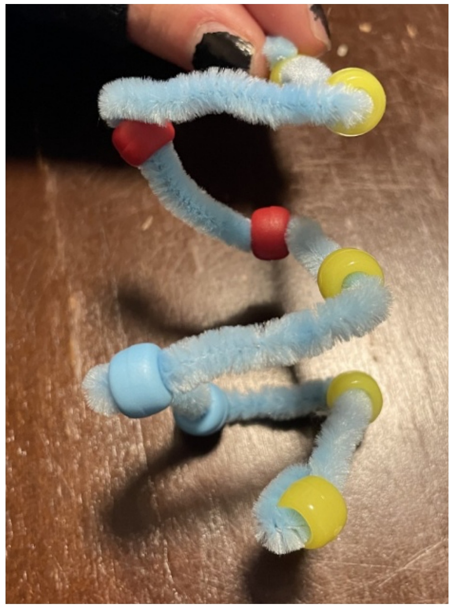

Figure 3. An example of the interactive 3D protein model students constructed in class. This image shows an alpha helix, or secondary level of protein structure, which is a direct translation of Dr. Sholder's alpha helical diagram in 3D form.

Implementation

The lesson plan is formatted as a flip-style class. Flip-style classes typically require students to complete "preparation" outside of class and then practice/apply those concepts during class-time while the instructor is present. In other words, students learn on their own and then do their "homework" in class. Thus, before coming to class, students were instructed to watch and take notes on an Echo360 recording of Dr. Sholder's traditional lecture on protein structure from a prior semester. Providing students with said lecture acted as a control to ensure students were given access to the same instructional content previous iterations of Dr. Sholder's BC 351 students were taught. Furthermore, it allowed students to come to class with context about the topic of protein structure/folding before engaging in the activities within my lesson plan.

During lecture, Dr. Sholders introduced me to the class and explained that I would be teaching my lesson plan as part of my Honors Thesis project. He was present for the remainer of the lecture to support me and help answer students' questions as needed. However, I took most of the control in actual implementation (teaching) of my lesson plan. Therefore, my role involved introducing the topic and learning objective, demonstrating each phase of 3D protein model construction, circulating the class and answering students' questions during independent 3D protein model construction, and facilitating and explaining iClicker questions.

Due to time constraints, I was unable to teach my lesson plan in its entirety. Unfortunately, students were only able to get to "Activity 2" of the worksheet, meaning they did not complete construction of tertiary protein structure, or its associated worksheet prompts and iClicker questions. However, Dr. Sholders was able to facilitate iClickers 6-8 in the lecture immediately following implementation of my lesson plan. Said iClickers were helpful in predicting effectiveness of my lesson plan.

Evaluation

Two types of iClickers were utilized for my thesis project. The first category of iClicker questions are "checkpoints" aimed at identifying student comprehension of each level of the visuospatial aspects of protein structure. These questions are framed to prompt students to provide a "factual" answer about a specific level of protein structure. These iClickers are more objective and fact-based. The goal was to allow instructors to evaluate if students were following along with the course material in real-time as they are constructing a specific conformation of the 3D protein model. This provided instructors opportunity to provide feedback and explain content more in depth by identifying the percentage of students who answered the iClicker question correctly (or incorrectly). iClickers 1-5 fall into this category (see "Results" section).

The second category of iClickers are "feedback" questions in which students could indicate whether they found the lesson plan beneficial to their learning regarding the topic of protein structure. These questions are more subjective and formatted on a scale of "Strongly Agree" to "Strongly Disagree." The goal was to allow students to give feedback on whether they found the use of the 3D protein model effective/beneficial. The scale system was useful in data analysis, as surveys would've been too time consuming to analyze given the timeframe of my thesis project. iClickers 6-8 fall into this category (see "Results" section).

Results

Data

iClicker data has been formatted into respective tables below. The first column of each iClicker question shows the answer options that were presented to the class. The correct answer has been bolded. The second column of each table shows the percentage of students who voted for each answer.

I. iClicker 1: Based on your model, what do you think the spaces in between each amino acid represent?

Answer Options	Percentage of Student Answers
A) Hydrogen bonds	6%
B) Ionic bonds	4%
C) Pi bonds	1%
D) Peptide bonds	**89%**

II. iClicker 2: How many side chains will be in a single turn of an alpha heliz and where do these point?

Answer Options	Percentage of Student Answers
A) 3 to 4 and inward to the helical axis	3%
B) 3 to 4 and outward away from the helical axis	**90%**
C) 2 to 3 and inward toward the helical axis	2%
D) 2 to 3 and outward away from the helical axis	5%

III. iClicker 3: What is the correct sequence of amino acids (beads) that will allow for the formation of an amphipathic alpha helix?

Answer Options	Percentage of Student Answers
A) Yellow red red blue blue yellow yellow yellow yellow	1%

B) Yellow red red yellow yellow blue blue yellow yellow	12%
C) Yellow blue red yellow yellow blue red yellow yellow	49%
D) Yellow yellow red red yellow blue blue yellow yellow	18%
E) B & D	**20%**

IV. iClicker 4: If you made positions 6 and 7 (while keeping all other positions the same) a negative charge the helix would not form. What noncovalent interactions would be disrupted in this scenario?

Answer Options	Percentage of Student Answers
A) Peptide bonds; the primary stabilizing force of primary structure	Did not cover in class.
B) Side chain hydrogen bonds; the primary stabilizing force of primary structure	Did not cover in class.
C) Side chain hydrogen bonds; the primary stabilizing force of secondary structure	Did not cover in class.
D) Backbone hydrogen bonds; the primary stabilizing force of secondary structure	Did not cover in class.

V. iClicker 5: When forming your tertiary structure, what was the primary consideration that had to be taken into account?
   a. This question was a short response question. Did not cover in class; no data available.

VI. iClicker 6: Have you ever used physical objects to model molecular interactions?

Answer Options	Percentage of Student Answers
A) Yes	78%

B) No	22%

VII. iClicker 7: Having now used the physical object to model molecular interaction do you feel more confident of the spatial arrangements within protein structures?

Answer Options	Percentage of Student Answers
A) Strongly agree	7%
B) Agree	37%
C) Neutral	36%
D) Disagree	18%
E) Strongly Disagree	3%

VIII. iClicker 8: Would you use physical models to visualize molecular processes/interactions again?

Answer Options	Percentage of Student Answers
A) Strongly agree	14%
B) Agree	40%
C) Neutral	33%
D) Disagree	10%
E) Strongly Disagree	4%

Data Analysis

Unfortunately, due to time constraints I did not teach the entirety of my lesson plan, so I did not get to ask all the iClickers in class. Thus, data may be skewed.

My lesson plan was taught to Dr. Sholder's BC 351 class on September 16, 2024. Due to time constraints, only a few of "checkpoint" iClickers were covered in class. iClickers 1-3 were covered in class, while iClickers 4-5 were not covered and are thus omitted from data analysis and discussion. iClickers 6-8, which comprise the “feedback” iClicker questions, were covered in the lecture after the lesson plan by Dr. Sholders on September 17, 2024.

For category 1, the “checkpoint” iClickers were used as indicators of students' visuospatial comprehension of protein structure and the primary stabilizing interactions involved. 89% of students answered iClicker 1 correctly, indicating that the majority of the class understood the primary stabilizing forces of primary protein structure. 90% of students answered iClicker 2 correctly, indicating that the majority of the class understood the primary stabilizing forces of secondary protein structure. Overall, only 11% of students thought the side chains were facing inward, an answer which illustrates they do not understand the alpha helix structure at all. Thus, those were the students who we hoped to help benefit the most from the use of the 3D protein model. 20% of students answered iClicker 3 correctly, but an additional 30% chose one of the correct answers. In total, 50% of the class did answer correctly, indicating that half of the class understood the amino acid interactions necessary to allow for the protein to fold into an alpha helix. These results were expected, as prior studies have determined that students face the most difficulty in visuo-spatial understanding between secondary and tertiary structure (rather than between primary and secondary structure).

For category 2, the “feedback” iClickers were used designed as measures of students' receptiveness to the use of the 3D protein model and indicators of if they found the lesson plan beneficial to their understanding of the topic of protein folding. Based on iClicker 6, 78% of students have used physical objects to model molecular interactions prior to my Thesis project. This indicates that the use of models is common and has proven effective in prior studies, so the general basis of my Thesis project was beneficial.

Based on iClicker 7, 44% of students answered “Strongly Agree” or “Agree,” indicating the 3D model used in my lesson plan was helpful to their visuo-spatial understanding of protein folding. 36% were neutral, indicating it did not benefit or harm their understanding. 22% indicated that it was harmful to their understanding. Overall, over half the class was either benefitted or not impacted from the use of my model, indicating that it was generally beneficial for students. However, a little less than a quarter of the class indicated that it was harmful to their understanding of protein understanding, which is not ideal and suggests that there is a large room for improvement in the design of my model/lesson plan.

Based on iClicker 8, 54% of the class answered “Strongly Agree” or “Agree,” indicating that they would use physical objects again to model molecular interactions. 33% of the class answered “Neutral,” and 14% answered “Disagree” or “Strongly Disagree.” This data suggests that the use of models in general was beneficial to their understanding because they were likely to use similar models again in the future. However, this question was a bit vague and does not necessarily indicate that they liked my specific model. Thus, there is a need for a more quantifiable way to measure students’ receptiveness to the particular model I designed, though this data *can* be used to predict that it was generally helpful for students.

Discussion

Effectiveness of Non-Traditional Pedagogy Approaches

This Honors Thesis investigates the effect of a non-traditional lecture on student visualization of protein structure within a foundational biochemistry course, and its potential benefits on student performance and visuospatial comprehension. BC 351 students participated in a flip-style class involving construction of a 3D protein model. The goal of the lesson was for students to walk away with the skills to compare and contrast the interactions driving the formation of secondary, tertiary, and quaternary structure of proteins. Results suggest that the non-traditional pedagogy strategies were generally beneficial for students, though no solid conclusions can be made at this time.

Based on iClickers 1 and 2, students were able to correctly identify the noncovalent stabilizing interactions in both primary and secondary protein structure. However, these questions could have been recall-based, since the answers do not necessarily require students to consider the visuospatial reasoning behind the interactions. As such, iClickers 1 and 2 are not a significant measurement of student visuospatial comprehension. On the other hand, iClicker 3 did require to students to consider the visuospatial reasoning behind stabilizing interactions. Since only 50% of students answered this question correctly it is hard to determine if students’ visuospatial misconceptions were enhanced or diminished by use of the 3D protein model. iClickers 6-8 aimed to solve this mystery by directly asking students to indicate if they found the specific 3D protein model effective. Overall, 44% of the class did indicate that the model was beneficial, suggesting that the non-traditional pedagogy strategies did in fact enhance their visuospatial reasoning behind primary stabilizing forces in proteins. In conclusion, while the literature and data support my thesis, more research needs to be done before it can be concluded that this project improved student learning outcomes in protein structure and spatial reasoning for students within BC351.

Implications of Thesis Project/Future Research

While my lesson plan offers several benefits, there are also several caveats in my thesis project. One major caveat within my thesis project was time management. The activities in the lesson plan were a bit too detailed to be completed in the given lecture duration of 50 minutes. As stated above, time constraints limited the implementation of the lesson plan as students were only able to get through Activity 2 which aimed to help students visualize the primary stabilizing forces of secondary protein structure. Thus, Activity 3 (which focused on understanding primary stabilizing forces in tertiary structure) and the New Understandings (comparing table to preconceptions) sections of the worksheet were not covered in class. In addition, the iClickers associated with tertiary protein structure were not covered in class. Unfortunately, missing those activities hindered student's ability to grasp the part of the learning objective focused on the stabilizing forces of tertiary structure through use of the 3D protein model. However, I did create a video walking through the parts that we did not get to cover in class. The video explained how the activity would have gone and reviewed the iClickers that were missed. Students were given access to said video, and thus have access to a useful resource pertaining to the learning objective as well as an opportunity to practice metacognition.

Another caveat within my thesis project was evaluation design. Originally, I had planned to use two types of evaluation of the effectiveness of my 3D protein model and lesson plan on student achievement within the topic of protein structure. One being pre- and mid-course evaluations and the second being iClicker evaluations. First, I planned to expand on Dr. Sholder's pre- and post-course assessments and add a "mid-course evaluation" catered specifically to the topic of protein folding. Specifically, questions 6-11 aligned with the original two learning objectives for protein structure/folding: (1) Compare and contrast the interactions driving the formation of secondary, tertiary, and quaternary structure of proteins and apply these concepts to the process of protein folding and stability, and (2) Predict the effects of mutations on the stability of a protein and state an argument for why they think their prediction is correct.

However, after collecting and analyzing data across the pre- and mid-course evaluations, the questions were determined to not be targeted enough toward my thesis project. This was largely a result of my decision to simplify the 3D protein model; thus, simplifying the learning objective. The learning objective I stated to my students was not addressed by the specific questions on the mid-term evaluations. With Dr. Sholder's assistance, we concluded that the data should not be included as part of my evaluation on the effectiveness of my lesson plan (though it was still necessary in my process of choosing a relevant topic).

Therefore, evaluation of effectiveness of my lesson plan on aiding students' visuospatial comprehension of protein structure was based purely on the iClicker questions. Due to time management issues (explained above), only iClickers 1-3 were covered during the lecture in which I taught my lesson plan. Rather, iClickers 4 and 5 were covered in the post-lecture video I created, and iClickers 6-8 were covered by Dr. Sholders in lecture the day after my lesson plan was taught in class. This poses several issues when analyzing data. First, iClicker data may have been collected from several different populations of students. For example, BC 351 lectures are live streamed on the "Echo360" platform. So, even iClickers 1-3 could have included answers from students who were watching the lecture at home and did not have access to the materials necessary to construct and manipulate the 3D protein models used during my lesson plan. Second, iClickers 4 and 5 were never taught in class. Although the answers were debriefed in the post-lecture video, iClicker data was not collected. Last, data from iClickers 6-8 was collected the day after I taught my lesson plan. Thus, there were probably a few outliers of students who were or were not there on either day. Therefore, the iClicker data was collected inconsistently. While the obtained iClicker data does offer some *indications* of the effectiveness of my lesson plan, it is not reliable enough to make any solid conclusions. However, since my lesson plan was only taught during one 50-minute lecture period, more data would need to be collected regardless.

Last, a major weakness of my 3D protein model was the flexibility of the material. Specifically, the pipe cleaners were too flexible. Their shape did not hold, so it was hard for students to follow along when I demonstrated how to bend the pipe cleaner into the proper secondary protein structure orientation. Thus, students may have been too focused on the materials than the actual lesson content. While circulating the room, Dr. Sholders and I also noticed that many students had bent the pipe cleaners in a way that was misleading to their understanding of where the amino acids would be positioned in a real protein. This may have imposed some misconceptions about the secondary protein structure and thus the interactions stabilizing it.

Overall, there were several caveats in my thesis project. Since I wasn't able to finish the lesson plan in its entirety, it is difficult to determine if the teaching strategies I implemented were effective. Moreover, time constraints imposed data collection issues since we did not get to all of the iClickers as intended. Without the pre- and mid-course evaluations, my data is insufficient in making solid conclusions on the impacts on students' understanding of protein structure and on the effectiveness of the teaching strategies I used. Also, the flexibility of the pipe cleaners seemed to be more harmful than helpful. Due to these issues, more research is needed to determine if the teaching strategies are beneficial for students' foundational grasp on protein structure and interactions. I would suggest future researchers utilize Mini-Toobers, which seem to be a bit less flexible than pipe cleaners. I would also suggest future researchers be particularly mindful of their time management. Last, I would suggest them to design their own pre- and post-assessments catered specifically to the learning objective used, as a more quantifiable means of analysis.

Reflections

My thesis project has several benefits for myself, people within my field, and people outside of my field. In terms of personal benefits, I believe my Honors Thesis is highly valuable for my career as a Pediatric Occupational Therapist. First, occupational therapy encompasses many visual and hands-on approaches, which parallel the visuospatial aspects of my 3D protein model. Moreover, as an occupational therapist I would be teaching others– in an informal setting– how to improve day to day tasks, sensory skills, and fine motor skills. When communicating with my clients' parents, I may need to explain the medical and/or physiological reasonings behind some of the occupational therapy methods and at home practices I would want my patients to practice. Therefore, being able to explain jargon-heavy/complex topics in a more digestible way is an essential skill for my career. Additionally, while I am hoping to get my Occupational Therapy Doctorate degree, a couple of the universities I am applying to also have PhD programs that I have been interested in applying to! If I do end up getting my PhD, my

Thesis directly applies to teaching, especially if I wanted to become a professor within the field of Sciences.

For people within my field, my thesis project is directly beneficial to professors teaching an undergraduate level introductory biochemistry course or other science courses that cover the topic of protein structure/folding. My project offers a replicable lesson plan with a useful 3D protein model that can be used verbatim or modified. I believe this lesson plan is a valuable and replicable way for educators to help Science majors build a solid foundation on the basics of protein structure from which they can build stronger understandings of more complex topics.

Last, this project is important to people outside of my area of interest because it is testing the effectiveness of various pedagogy strategies that may be useful for a variety of topics/fields, learner age groups, and classroom environments. In a broad sense, I believe that the creative aspect of my thesis (the 3D protein model) may encourage other teachers to adopt more visual or hands-on activities for certain topics within their own classrooms. At the very least, it could encourage teachers/communicators to try expanding their method of teaching to encompass a wider range of communication strategies, and/or to communicate a topic in different contexts. On the other hand, it is also useful for learners (in any context), because it also encourages them to practice a variety of studying and learning skills, such as expanding and clearing up misconceptions based on their prior knowledge, participating in group work/discussions, and applying a simple concept to more complex scenarios.

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