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Assessing recall, conceptualization, and transfer capabilities of novice biochemistry students' across learning style preferences as revealed by self-explanations

Jacqueline Hilsenbeck-Farjardo

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The Graduate School

ASSESSING RECALL, CONCEPTUALIZATION, AND TRANSFER CAPABILITIES OF NOVICE BIOCHEMISTRY STUDENTS' ACROSS LEARNING STYLE PREFERENCES AS REVEALED BY SELF-EXPLANATIONS

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

Jacqueline L. Hilsenbeck-Fajardo

College of Natural and Health Sciences
School of Chemistry and Biochemistry
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ABSTRACT

Hilsenbeck-Fajardo, Jacqueline L. *Assessing Recall, Conceptualization, and Transfer Capabilities of Novice Biochemistry Students' Across Learning Style Preferences as Revealed by Self-Explanations.* Published Doctor of Philosophy dissertation, University of Northern Colorado, 2009.

The research described herein is a multi-dimensional attempt to measure student's abilities to recall, conceptualize, and transfer fundamental and dynamic protein structure concepts as revealed by their own diagrammatic (pictorial) representations and written self-explanations. A total of 120 participants enrolled in a 'Fundamentals of Biochemistry' course contributed to this mixed-methodological study. The population of interest consisted primarily of pre-nursing and sport and exercise science majors. This course is typically associated with a high (<30%) combined drop/failure rate, thus the course provided the researcher with an ideal context in which to apply novel transfer assessment strategies. In the past, students within this population have reported very little chemistry background. In the following study, student-generated diagrammatic representations and written explanations were coded thematically using a highly objective rubric that was designed specifically for this study. Responses provided by the students were characterized on the macroscopic, microscopic, molecular-level, and integrated scales. Recall knowledge gain (i.e., knowledge that was gained through multiple-choice questioning techniques) was quantitatively correlated to learning style preferences (i.e., high-object, low-object, and non-object). Quantitative measures revealed that participants tended toward an object (i.e., snapshot) -based visualization preference, a potentially limiting factor in their desire to consider dynamic properties of fundamental biochemical contexts such as heat-induced protein denaturation. When knowledge transfer was carefully assessed within the predefined context, numerous misconceptions pertaining to the fundamental and dynamic nature of protein structure were revealed. Misconceptions tended to increase as the transfer model shifted away from the context presented in the original learning material. Ultimately, a fundamentally new, novel, and unique measure of knowledge transfer was developed as a main result of this study. It is envisioned by the researcher that this new measure of learning is applicable specifically to physical and chemical science education-based research in the form of deep transfer on the atomic–level scale.

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CHAPTER I

INTRODUCTION

The research described herein was part of a multi-faceted study that utilized both qualitative and quantitative research traditions. Data were collected over the course of four semesters with successive refinement on the data collection procedures at the conclusion of each series. Upon completion of this study, insights were gained regarding the nature by which biochemistry novices understand fundamental concepts of biochemistry, specifically heat-induced protein denaturation, in both general and specific terms (i.e. transfer capabilities). Students were asked to *describe* observed (macroscopic) events through text, pictures, and written descriptions and subsequently *explain* these observations on the sub-macroscopic levels. Students tended to explain their observations on either the microscopic or molecular levels, and occasionally through integration of these distinct categorizations. Additionally, insights were gained in terms of how biochemistry novices understood and explained protein structure and dynamic protein structural processes through written self-explanations. The study utilized multiple instruments, most of which were specifically designed for the population of interest. The instruments were designed to assess the participant's ability to recognize, recall, and transfer fundamental concepts, their learning style preferences, the coherency and consistency of diagrammatic and open-ended written responses, and their ability to consistently and accurately integrate macroscopic observations with microscopic phenomenon.

It has been proposed that organization is a key component in the transfer of empirical knowledge to conceptual knowledge (Stracuzzi, 2005). The organization of new knowledge allows one to retain knowledge and transfer it to appropriate situations. Students often have a difficult time conceptualizing biochemistry-related topics (Lee, 2004). There are at least two sources from which this difficulty may potentially arise. First, biochemistry is a "living field" – a field of study that is constantly expanding, evolving, and changing. Secondly, biochemistry encompasses an enormously vast field of study with seemingly infinite detail at each step. The major contributions to biology and chemistry that ultimately led to the term "biochemistry" have been outlined (Frey, 2002), and these - not surprisingly - are the main areas of study in any typical introductory biochemistry course.

To this end, a fundamental question posed by the researcher initially was with regard to how educators could assist beginning biochemistry students in understanding and mentally organizing key concepts such as proteins, enzymes, nucleic acids, proton motive force, membrane structure, allosterism, and chemical interactions without overwhelming the student (i.e., exceeding their cognitive load or capacity). Fundamentally, it seems reasonable that a primary goal of biochemical educators is to aid the novice's organization of knowledge so that conceptualization becomes easier. With regard to the sheer complexity of biochemical phenomena, it may be helpful for students to *visualize* key components of biochemistry to aid in building a basic foundation of knowledge that can lead to accurate conceptualization. In this context, the term "accurate" is emphasized, as the knowledge possessed by many biochemistry students is often fraught with misconceptions or misperceptions. It should be noted here that students in the population of interest in this study are not chemistry majors, thus the goal is not to make experts out of the students, but merely to make them competent at biochemistry on a fundamental level for both theoretical understanding and to have the ability to apply their knowledge to related phenomena.

The Problem

In the course selected for this study, 'Fundamentals of Biochemistry' there is historically a combined dropout and failure rate of 25%-30% (RM Hyslop, personal communication). This number may not be surprising after one considers the breadth of topics covered in this one-semester course as well as the low prior chemistry experience of registered students. Pilot study data collected during Spring 2006 revealed that most students enrolled in this course had minimal chemistry backgrounds (Fajardo, Hyslop, and Suits, unpublished data). In addition, the vast majority of students were enrolled in the course for the sole reason that it was a requirement for their major area of study, and most students did not find the material covered particularly relevant to their majors. In a typical 15-week semester, students rapidly progress from learning about atomic structure, ions, and bonding to predicting products of fundamental organic reactions, protein structure, and fairly complex discussions of metabolic pathways.

When the above features are taken into account, factors leading to the high rate of failure observed regularly in this course become more apparent. It has been suggested that students may fare better in the course if it were extended into two semesters, rather than one, or through strict enforcement of prerequisite information (RM Hyslop, personal communication). However, the impact of these actions is unknown. Thus, it is not readily apparent what could improve the success rate of the course without negating any of the material covered.

Purposes of this Study

The primary purpose of this study was to demonstrate how a novice's conceptual understanding of protein structure/function relationships was influenced by the animation and storyboarding of dynamic biochemical processes involved in heat-induced protein denaturation. Students were given a familiar example of a molecular-level complex, dynamic event – frying an egg. The familiarity of the context was intended to provide students with a cognitive anchor that gave them the proper leverage to describe and explain molecular-level phenomenon based on their macroscopic observations. Essentially, the goal of providing a familiar and concrete context was to generate a comfortable setting for the students, and thus minimize anxiety-induced incomplete responses.

Ultimately, the goal was to understand how novices interpreted and explained dynamic molecular-level events involving complex subject material that was clearly observable on the macroscopic level. Specifically, their written and/or pictorial explanations/diagrams of a given biochemical phenomenon – heat-induced protein denaturation - were collected. This information was initially coded qualitatively and assigned a score based on a pre-established rubric. The scores resulting from the qualitative analysis was then quantitatively correlated to learning style preferences and other variables based on information gained in the demographics survey.

A secondary purpose of this study was to describe the population of interest according to preferred learning styles based on a self-described continuum consisting of two visual (i.e., spatial and object) and one verbal preference (Blajenkova, Kozhevnikov, and Motes, 2006). For the purposes of this study, an *object visualizer* was described as an individual who prefers vivid, concrete, and detailed pictures or snapshots when visualizing a concept. A *spatial visualizer* prefers to visualize concepts schematically and to perform complex spatial transformations mentally. A *verbalizer* prefers to use verbal analytical tools such as mathematics to understand concepts introduced in class. Although verbal learning style preferences were assessed in the data collection, data were not analyzed since the verbal component on the Blajenkova learning style instrument was not validated at the time of this writing. Once the learning styles had been determined (both individually and as a group through grand mean calculation), the preferred learning styles were correlated to three dependent variables that included ability to recall knowledge (memorization), to conceptualize (understand), and to transfer knowledge (on near, intermediate, and high-resolution scales). Within the context of this study, several distinctions were made between cognitive ability, cognitive style, and learning style preference (Mayer, 2003). Within this realm, cognitive ability refers to an inherent high or low spatial ability, and was used to describe what individuals are able to do. This ability can be measured using the Vandenberg or Purdue Mental Rotations Tasks. Cognitive style describes how people think – whether with words or images – in essence, how people process information. Learning style preferences refer to how individuals prefer to have information presented to them (textual or graphical). The latter two self-reported styles will be assessed using the Object-Spatial Imagery Questionnaire (OSIQ), (Blajenkova, *et al.*, 2006).

Theoretical Frameworks

The type of data a chemist collects in an experiment is influenced by his or her choice of instrumentation. For qualitative research studies, a theoretical framework plays an analogous role to that of the analytical instrument. A theoretical framework is a system of ideas, aims, goals, theories, and assumptions about knowledge. The framework dictates how research should be carried out and how data should be reported. In short, the theoretical framework influences what kind of experiments will be carried out and the type of data that will ultimately result from these experiments.

This study is primarily grounded in the constructivist epistemology with an interpretivistic theoretical perspective (Creswell, 1998). The epistemology describes how what is known is known – in other words, it describes the nature of knowledge, and how knowledge is gained. Constructivism-based epistemologies embody many theoretical perspectives, including interpretivism. In this epistemology, there is no objective truth waiting to be discovered. New and unique meanings are built by each individual learner on a foundation of knowledge (groundwork) that is composed of prior experiences and preconceived notions. Consciously or subconsciously, the learner attempts to assimilate and accommodate the new information into their core foundation of knowledge, while (ideally) correcting incorrect or misconceived prior notions. Participants may construct new and unique meanings of what they experience and they may (either consciously or sub-consciously) attempt to assimilate and accommodate new information into their cognitive framework. There is no objective truth to be gained by the learner, but rather a compilation of interrelated observations, explanations, and predictions.

The current study was designed using a mixed-model methodological framework (Johnson and Onwuegbuzie, 2004). In this methodological approach, the quantitative and qualitative research traditions are mixed across the stages of the research process. In theory, data obtained from the qualitative portion (i.e., interviews, written explanations, and diagrammatic representations) are subjected to quantitative analysis either through descriptive statistics, group clustering, or correlations. In the qualitative realm, conclusions were derived from the interpretive analysis of written, diagrammatic, and verbal responses as well as the analysis of self-explanations and descriptions of themes. In the quantitative realm, conclusions were derived for the OSIQ analysis, correlations between OSIQ data and other facets of the data, and relationships between written and diagrammatic explanations (i.e. especially in terms of consistency). Briefly, the rubric was designed such that objectivity was a critical nature. Hence, the rational behind rubric-based assignments was clear. In this case, descriptions, representations, and/or explanations were categorized as being macroscopic, microscopic, molecular-level, or integrated in nature. Upon subsequent analysis, responses were coded according to the chemical detail present as well as the presence of apparent misconceptions. The specific rationales and implementation procedures for this methodological approach are described further in Chapter III.

Preliminary evidence suggests that when students utilize external visualization tools on complicated or technical material, the information may be better internalized, and they may be able to reproduce and transfer that knowledge more effectively (Lim *et al.*, 2003). In this study, students viewed animations and built upon their pre-existing knowledge from the lecture. To this end, structure-behavior-function theory was used as a theoretical foundation for the data-coding component (Hmelo-Silver and Pfeffer, 2004). A widely used framework in computer modeling and programming, the structure-behavior-function theory is a potentially useful data-coding model as applied in the realm of education-research contexts. The specific manner in which this theory will serve as a data-coding theoretical framework will be described in Chapter III.

Limitations/Assumptions

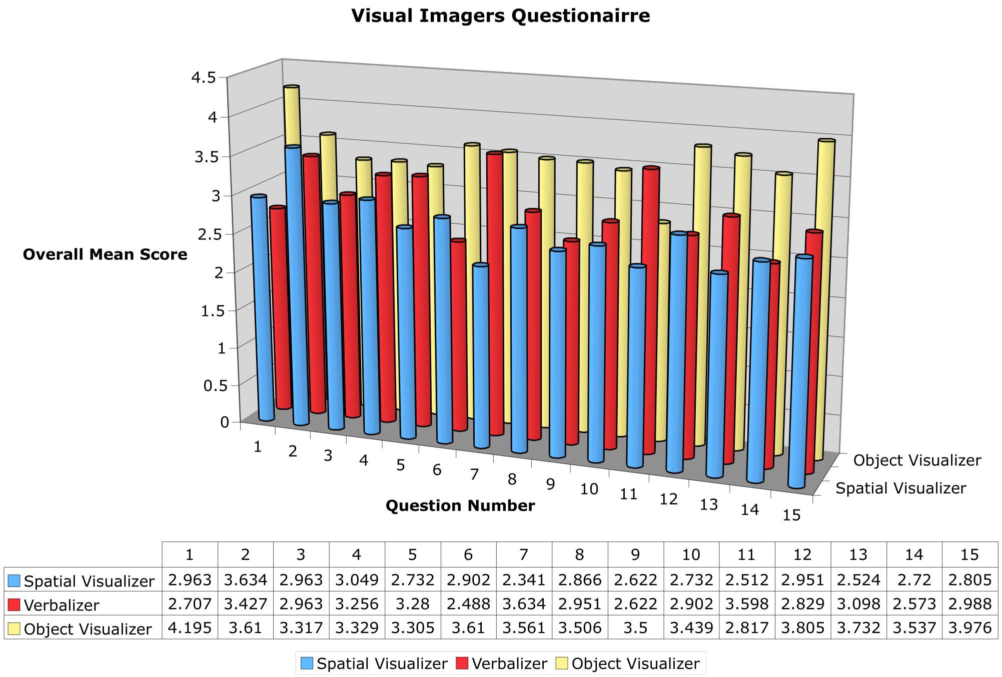
A potential limitation of the study is the question of reliability and validity of the instruments adapted or developed by the researcher for use in this study. Reliability cannot be established until further populations are analyzed. This is because multiple data sets will need to be collected to determine if the results hold from one semester to the next, or one group of general, organic, biochemistry (GOB) students to the next. For the pilot studies, two biochemists and one chemical educator with a background in biochemistry approved the content of the instruments. Both the biochemist and chemical educator approved pedagogical intent such as measures of conceptual understanding, recall, and transfer. The reliability and validity will be established as more data are collected. Due the high combined drop/failure rate associated with the course, some students who participate have previously taken the course, and are thus repeating the course. This limitation may be overcome by using prior-knowledge as a covariate to which all other data may be normalized. The final foreseeable limitation of the study is the use of participants from the same institution, as well as the use of volunteer participants. These limitations have the potential to limit the generalizability of the study. Thus, the use of quantitative measures and methods will help ensure that any potential generalizations are statistically supported.

Significance of Study

The proposed research provided a deeper understanding on how animations of molecular-level phenomena can be used as a tool to identify novice ability to recall, understand, and transfer knowledge. The animation of frying an egg provided the novice participants with a cognitive anchor by presenting a context that was familiar to them. Ultimately, the results of this study provided insights into the role that learning style preferences have on students' understanding in the context of fundamental undergraduate biochemical topics. Additionally, student-derived diagrammatic representations and written descriptions and explanations revealed deeply ingrained misconceptions held by the participants, thus providing a picture of common misunderstandings of fundamental dynamic biochemical structure/function relationships that could affect the success rate of the course.

Preliminary Analyses

Participants solicited for the pilot study of Fall 2005 were enrolled in a 200-level introductory biochemistry course. The students were primarily nursing or other allied health majors. Most of the students had some high school chemistry background. The students typically had little accurate understanding of basic chemical principles, and even less understanding of basic biochemical principles. They tended to have little appreciation for either, a motivational factor. Using the Object-Spatial Imagery Questionnaire, it was noted that students overall were object visualizers, indicating a strong preference for static, two-dimensional drawings over schematic, dynamic representations (Figure 1).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
🟦 Spatial Visualizer	2.963	3.634	2.963	3.049	2.732	2.902	2.341	2.866	2.622	2.732	2.512	2.951	2.524	2.72	2.805
🟥 Verbalizer	2.707	3.427	2.963	3.256	3.28	2.488	3.634	2.951	2.622	2.902	3.598	2.829	3.098	2.573	2.988
🟨 Object Visualizer	4.195	3.61	3.317	3.329	3.305	3.61	3.561	3.506	3.5	3.439	2.817	3.805	3.732	3.537	3.976

Figure 1. Object, spatial, and verbalizer preferences resulting from the preliminary study. Here Preferential learning styles (spatial, object visualization or verbalizer) were assessed using the Object-Spatial Imagery Questionnaire (Blajenkova, *et.al*). A pseudo, repeated measures one-way ANOVA showed significant differences among the students responses ($f\,(2) = 17.67$, $p = 1.09\text{e-}05$) with the highest mean indicating overall preference for spatial visualization (artistic).

Prior-knowledge assessment surveys were collected from 100 students prior to lecture instruction on the relevant topics. Since the students had no formal lecture on the material covered on the assessment, these were defined as prior-knowledge assessments. The prior-knowledge assessments were scored using a rubric based on two components: a conceptual component consisting of written and a pictorial sub-components and a recall component. The conceptual component was designed such that students were required to draw a picture or representation of a biochemical phenomenon and provide a written description or explanation of their diagrammatic response. This component consisted of six open-ended questions. The responses were scored using a rubric of 0 to 4. Note that a score of 0 was an indication no conception, 1 was an indication of a misconception, 2 was an indication of some understanding (i.e. surface-level knowledge) with some misconception, 3 was an indication of understanding with minimal misconception, and 4 was an indicator of deep, expert-like understanding.

Overall percentages of scores 2 or greater for the pre- and post- are shown (Table 1). A preliminary analysis of the data revealed in Table 1 indicated that participant scores on the pictorial component of the post-test generally improved more than the written component post scores. Thus, recognition and recall ability improved, yet most participants were unable to explain their drawing. It was apparent that most students had very little understanding of amino acid, peptide, protein structures, or enzyme structure-function relationships, with the large majority scoring 0 or 1 on the non-multiple choice questions. Only seven out of the 100 had any idea of what a generic protein might look like (score of 2 or greater), and of these seven, only four could adequately explain their drawings (Table 1). The qualitative portion of the study revealed that students still had little to no conceptual understanding or mental model of protein structure, even after the protein-structure unit had been covered in lecture. When asked to draw what came to mind when they heard the word “protein,” the majority still thought of non-chemistry related pictures (i.e., peanut, egg, or steak). Only one out of the six students interviewed had a biochemistry-based mental model of a protein, but this student had the same mental-model on the prior-knowledge assessment.

Table 1.

Tabulation of the preliminary conceptual component data. The conceptual component consisted of six open-ended questions. There was a pictorial and written component to most questions. The responses were scored using a rubric of 0 (blank or nonsense) to 4 (deep, accurate understanding). A score of two indicates surface-level knowledge with some misconceptions. Overall percentages of scores two or greater for the pre- and post- are shown. Student scores on the pictorial component of the post generally improved more than the written component post scores, indicating recognition and recall, but inability to explain their drawing.

	Amino Acid Structure		Peptide Bond Formation		Peptide vs. Protein		Generic Enzyme Reaction		Enzyme Definition		Protein Model	
Rubric Score	Pictorial	Written	Pictorial	Written	Pictorial	Written	Pictorial	Written	Pictorial	Written	Pictorial	Written
No Change 0-1	38	59	64	65	-	38	49	54	-	37	57	60
Change 2+	26	7	2	3	-	4	1	2	-	5	4	3
Change 0-2	5	3	4	2	-	26	19	14	-	26	8	7
Change 2 to 3+	1	1	0	0	-	2	1	0	-	2	1	0
Total (score 2+)	32	11	6	5	-	32	21	16	-	33	13	10
%-age with 2+ (Pre)	37%	10%	3%	4%	-	6%	1%	3%	-	7%	6%	4%
%-age with 2+ (Post)	46%	16%	9%	7%	-	46%	30%	23%	-	47%	19%	14%

The recall component consisted of four multiple-choice questions. The responses were either correct or incorrect, and scored accordingly. Every recall question improved during the post-test assessment, though some more dramatically than others. The results of total responses for the recall component are shown in Table 2. The overall percentages of correct for each question (pre- and delayed post-) are shown in Figure 1. The results revealed that students gained enough surface-level knowledge to recognize and recall specific concepts.

Table 2.

Tabulation of recall data from the preliminary study.

	R-Group	1˚ Structure	2˚ Structure	4˚ Structure
% Correct (pre)	62%	58%	43%	16%
Post (wrong to correct)	9	5	8	17
Post (correct to wrong)	0	3	2	2
Post (wrong to wrong)	13	17	26	31
Post (no comment to wrong)	0	0	3	1
Post (no comment to correct)	1	3	4	2
Post (no comment to no comment)	0	0	0	1
Post (correct to correct)	47	42	27	16
Not correct (out of 70)	57/70	50/70	39/70	35/70
% correct (post)	81%	71%	56%	50%

The preliminary results of the Fall 2005 study indicated that students' overall lacked a conceptual model of fundamental biochemistry topics. During the course of the protein-structure and enzyme catalysis units, the students became familiar with key terms and concepts, but did not develop an accurate "picture" or conceptual framework to which they could apply their new-found knowledge. The knowledge assessment consisted of two components – recall and conceptual. The recall component consisted of four multiple-choice questions that were based primarily on protein structure hierarchy. The researcher, J. Fajardo, considered these questions to be recall-based simply because they did not present any level of understanding beyond what was asked in the question. A limitation of recall-based questioning is that it is possible that correct responses may be obtained by chance alone.

Overall, incoming students had little prior knowledge in terms of biochemical background. During the first semester of data collection in which participants did not view an animation (hence, differences were based solely on the effect of lecture), post-knowledge assessment scores in general improved over prior-knowledge assessment scores. Upon closer inspection of the data, it became apparent that improved performance on the post-test was attributable to gain in surface-level knowledge (recall) (Figure 2).

Recall questions were designed as multiple-choice in nature. It was also observed by the researcher that the majority of students in both the prior- and post-knowledge assessment pictured a food item when hearing the word “protein”. Scores for the conceptual diagrammatic component improved from prior- to post-knowledge assessment. There was little improvement on explanations of diagrams from prior- to post-knowledge assessment (the conceptual written portion). The implication of this observation was that students had difficulty explaining diagrams using words. Student post-unit interviews indicated they had difficulty “picturing” concepts such as protein structure. Post-interviews revealed that students perceived they were unable to transfer or use their newfound knowledge to applications relevant to their vocation.

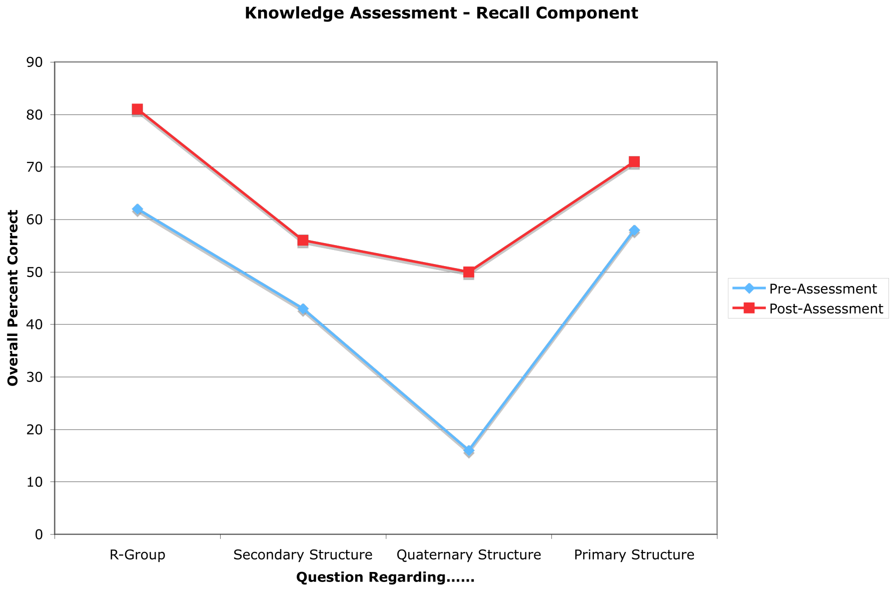


Figure 2. The overall percentages of correct recall question (pre- and delayed post-) are shown. The results show that students gained enough surface-level knowledge to recognize and recall specific concepts associated with protein structure.

Definitions

Cognitive Style: A description of how people process information in terms of how they think, perceive, and remember information or use given information to solve a problem.

Conceptual Understanding: An individual's notions of scientific concepts, principles, laws, and theories that scientists use to explain and predict observations of the natural world .

Conditionalized Knowledge: Deep, integrated knowledge about a specific topic (i.e. protein structure) and ability to apply that knowledge to varying contexts (i.e. high transfer ability).

Cognitive Anchor: A concept or situation that is (or is assumed) to be familiar to the majority of the participants. In this study, the concept of a frying egg was introduced as a cognitive anchor. The primary purpose of a cognitive anchor is to provide a common foundation that is equally familiar to all participants. A secondary purpose of providing a familiar context is to set the participants at ease.

Constructivism: An epistemology set forth by Jean Piaget that describes knowledge acquisition as a process in construction (via assimilation and accommodation) rather than discovery of an objective "truth".

Deep Transfer: Formerly called high-resolution transfer; to represent, describe, diagram, or explain a phenomenon that is introduced in the original learning task but is associated with a high-resolution scale. This concept involves the same context of the learning material but at a high-resolution scale. As opposed to near and intermediate transfers of knowledge, the idea of deep transfer is relevant only in science-based contexts, specifically contexts that require molecular, atomic, or sub-atomic depths of understanding. The idea of deep transfer is a concept not yet coined in the literature, and was developed as a means to understand details associated with structure and change at the molecular level.

Diagrammatic Representations: Pictures drawn by participants to describe observed behavior or phenomenon at the macroscopic or molecular-level.

Epistemology: A philosophical assumption that concerns the relationship between the researcher and that is being researched; how what is known is known.

High-Resolution Transfer: Please see Deep Transfer

Inert Knowledge: In contrast to conditionalized knowledge, this knowledge is not activated in relevant context, thus may be more superficial (see Recall Knowledge).

Intermediate Transfer: Often referred to as parallel transfer (REF); to represent, describe, diagram, or explain a phenomenon that is introduced in the original learning task but is associated with a different context. In this case, the original phenomenon was heat-induced protein denaturation through frying an egg. The intermediate transfer context was radiation-induced protein denaturation from excessive cell phone use as well as heat-induced protein denaturation resulting from high body temperatures

Interpretivism: The understanding of social reality through observation and interpretation; in contradistinction to explaining natural reality.

Learning Style Preference: A description of how an individual prefers a method of instruction (i.e. how an individual prefers to learn). Within this study, object- and spatial- visualization learning styles will be assessed.

Near Transfer: To represent, describe, diagram, or explain a phenomenon that is introduced in the original learning task and is associated with the same context. In this case, the original phenomenon and transfer context involved heat-induced protein denaturation through frying an egg.

Object Visualizer: A specific learning style associated with a preference to mentally picture information as highly detailed, non-rotatable snapshots (i.e. artistic images).

Ontology: The study of the nature of reality; multiple subjective realities exist and are based primarily on the participants of the study.

Phenomonology: The study of a specific phenomenon through description or interpretation of that phenomenon; the objective here is to give meaning to an observed phenomenon through descriptions and interpretations.

Recall Knowledge: Knowledge that is surface-level, i.e. inert knowledge. For this study, recall knowledge was assessed using multiple-choice questions.

Self Explanation: Any content-derived verbalization or written statement generated in a learning environment primarily to give reasons for an observed behavior or phenomenon.

Self Explanation Inference: A specific self-explanation that includes a postulation by the participant not directly stated in the original learning context.

Spatial Ability: The ability to perform mental rotations, translations, and transformations of objects in space.

Spatial Visualization: A specific learning style associated with a preference to mentally manipulate objects in space (i.e. through rotations, inversion, and translations). Note that this term is often – perhaps incorrectly - defined as the ability to perform spatial manipulations.

Thematic Analysis: Categorizing qualitative data through a set of codes established by means of a rubric.

Theoretical Framework: A system of ideas, aims, goals, theories and assumptions about knowledge, how research should be carried out and how research should be reported; a theoretical framework is the analytical instrument of education research.

Verbalizer: A learning style preference where one relies primarily on verbal/analytical strategies for learning.

Written Descriptions: In this study, written descriptions were primarily associated with diagrammatic representations. In this realm, the participants clarified their drawings in a written format.

CHAPTER II

REVIEW OF THE LITERATURE

Learning Styles

Learning styles and their effect on academic performance is difficult to measure (Arroyo, 2006). The recent literature, however, is teeming with reports of the influence of learning styles on learning and academic performance as well as measures and diagnostics of learning style preferences. A review by Cassidy (2004) revealed that research into learning styles and their influence on learning has been active for at least four decades, although the amount of activity at any given time has varied.

Originally, psychologists were the primary researchers in learning style research; however this type of research has increasingly been reported in vastly different domains such as medicine, business, management, vocational training, and education (Cassidy, 2004). Recent validated research indicates that cognitive measures can be loaded into four factors: cognitive style, spatial ability, general achievement, and learning preference (Mayer and Massa, 2003). For the purposes of this study, cognitive style may be defined as a description of how people process information. Do they think of information in words or pictures, for instance? Spatial ability is a measure of what people are able to do. Preference is not associated with spatial ability, and individuals may be characterized as having high or low spatial ability based on the outcome of one of a number of validated spatial ability assessments (see for instance, the Vandenburg Mental Rotations Task).

General achievement is based on standardized verbal or mathematical test scores. Learning preferences represent how individuals prefer information presented (for example, textual or graphical). The four factors to which cognitive measures may be loaded presents an important implication in that significant differences are present in individual cognitive styles, abilities, and preferences. Furthermore, these differences may have profound effects on discipline-specific aptitude. Cassidy (2004) provides a complete overview of current cognitive and learning style theories, models, and measures of learning styles.

The Object Spatial Imagery Questionnaire (OSIQ) has been formally validated and tested for reliability in assessing participants self-preferential learning styles as either verbalizer, or spatial or object visualizer (Blajenkova, *et al.*, 2006). This will be the instrument used to assess learning style preferences in the current study. Object-spatial preferences may play a significant role in achievement in certain courses because they assess individual differences in cognitive and perceptual function (i.e., cognitive-centered traits) (Cassidy, 2004). It has been demonstrated that spatial and object abilities are negatively correlated (Chabris, in press), which lends even more credence to the idea that object-spatial differences have the potential to effect an individual's learning and understanding of a particular topic. That is, in general, if a person prefers representations that are highly spatial in nature, they will likely not prefer representations that are highly object-based, and vice versa. The profound effect of learning style preferences has led some educators to adapt their curriculum to accommodate the different types of learners in their classroom (Davis and Karunathilake, 2004). Similarly, marked improvement in ACT-writing scores was observed when a remedial writing-style course was tailored to the predominant learning styles of students in the classroom (Rochford, 2003). This evidence is supportive of the idea that learning-style preferences may affect performance under certain conditions. Thoughtful analysis of learning theory has yielded “prescriptions” for better teaching practices that take individual preferences in learning styles into consideration (Schwartz, Martin, and Nasir, in press).

It has also been reported that learning styles may be discipline-specific, and students in some cases appear to be able to style-flex (adapt) their baseline learning style to meet the requirements of the learning task (Jones, Reichard, and Mokhtari, 2003). The use of learning style data has generated a controversy about how to utilize such information in the real-world classroom setting (Keefe, 2001). Should learning environments be tailored to match the predominant learning styles present in any given course or should cognitive skills be augmented to fit the course? What do seemingly extraneous factors such as age of the population have on the decision? Cognitive style (how one prefers processing information) has been studied as a function of age (Neils-Strunjas, Krikorian, Shidler, and Likoy, 2001). In this study, it was observed that older adults who preferred visual-object representations were able to recognize faces and names more easily than their highly verbal-preferential counterparts. It has been found that cognitive and learning style preferences impact the way people interpret common metaphors (Boers and Littlemore, 2000). A "self-regulated learning model" has been proposed that promotes the influence of teaching and learning variables that are not only individually unique but also context-dependent (Valle, et al., 2003).

Instruments used to assess learning style preferences include but are not limited to the Human Information Processing Survey (HIPS) that distinguishes individuals on the bases of right- left- or integrated thinking styles, where the regions refer to different physical locations of the brain (Alkhateeb, 2004). Another study, using a Gregorc Style Delineator instrument, found that “sequential thinkers” were better suited to science and math fields, whereas “random thinkers” excelled in fine arts programs. All thinkers performed equally well in liberal arts and social science disciplines (Drysdale, Ross, and Schulz, 2001). This conclusion provides a strong rationale for having learning styles as a central theme to the current study’s data collection and analysis strategy.

One must be cautious when assessing learning styles. Non-validated interviews and questionnaires may lead to little correlation between learning styles and performance (Davis and Franklin, 2004). Even in carefully controlled studies, often influences of learning style preferences can have no measurable effect on performance (Price, 2004). A reliable quantitative analytical scheme has been developed for repeated measure samples to assess the role of learning style on various classroom effects (Sonnenwald and Li, 2003). In addition, one must be cautious regarding assumptions and generalizations inferred about the modern student populations of interest. Many assumptions have been made that this new “computer-generation” will prefer informational technology-modes of learning based on their background, but that even for younger students, the primary desire in the classroom is a well-trained instructor (Oblinger and Hawkins, 2005).

Self-Explanations

The fundamental importance and value of student-generated self-explanations has not been under-emphasized. These explanations – whether they are textual, verbal, or diagrammatic – act as a mirror that reflects the mental model or understanding of the participant. Self-explanations can provide a measure of the extent of understanding or misunderstanding of a concept as well as provide insights into how knowledge evolves over time. Self-explanations may reveal abstract, cognitive struggles such as relationships between macroscopic observations and microscopic events such as relationships between protein structure and function to primary sequence. Technological learning implementations may have the potential to be either beneficial, detrimental, or indifferent to the students learning and conceptual understanding of microscopic events. The development of design principles has the potential to optimize the beneficial aspect of the animations, but the design principles should be grounded in established learning theory related to the population of interest.

The potential richness of self-explanation data has been explored in various domains. In particular, the generation of self-explanations has yielded useful insights regarding the understanding of mental models and “mental model repair” (Chi, 2000 and references therein; Uttal, Fisher, and Taylor, 2006), transfer effects (Atkinson, Renkl, and Merrill, 2003), improvement of communication skills (Brna, Cox, and Good, 2001), and overall improvement on learning (Mayer, Dow, and Mayer, 2003; Renkl and Atkinson, 2002). The questions that arise regarding self-explanation research are (1) what are the best ways to collect self-explanation data and (2) what are the best ways to analyze self-explanation data?

The theoretical basis for the richness of self-explanation data is that knowledge acquisition is mechanistically based on integration of new knowledge with pre-existing knowledge. Thus, explicitly promoted self-explanations facilitate the integration of new knowledge (procedural or declarative) into the cognitive framework (Chi, DeLeeuw, Chiu, and Lavancher, 1994; and Chi, 2000). Chi and colleagues have reasoned that the effect of self-explanations is a dual process consisting of the generation of inferences and repairing the mental model. It has been proposed that the primary reason tutoring is such a highly effective form of teaching is that, in a one-on-one environment, the tutee is encouraged to co-construct knowledge (Chi, 1996). As a result, the tutee generates self-explanations that often lead to deep learning and the removal of misconceptions. Self-explaining is a spontaneous, regular occurrence in daily life. The process of self-explaining allows new information to be accommodated within the context of prior beliefs and in doing so promotes the formation of generalizations (Lombrazo, 2006). Therefore, self-explanation research fosters the roles of prior knowledge and explanation-based reasoning in the context of learning theory.

Chi's theory of self-explanations has been applied to knowledge transfer research (Atkinson, Renkl, and Merrill, 2003). In this study, near transfer was defined as the ability to solve a problem as steps in the worked out example were gradually faded away. Far-transfer required the students to identify the underlying principle illustrated in each worked-out solution step then solve a far-transfer problem. The overall goal was to elicit self-explanations from students so they could identify the principle of interest. Prompting students to generate self-explanations resulted in greater far-transfer success.

Students prompted to generate self-explanations appeared to have overall higher gains in learning than those who do not generate self-explanations. In one case, students given a pre-question to guide their self-explanations during learning were significantly more likely to answer at a higher-level on the problem-solving transfer test (Mayer, Dow, and Mayer, 2003). The storyboard and transfer components of the current proposed research were built on the theoretical foundation laid by Mayer and colleagues. In another case, students were able to solve mathematical problems more effectively after self-explanations were elicited in a computer-based learning environment (Renkl and Atkinson, 2002).

In another study that demonstrated significant learning gains through the eliciting of student-generated self-explanations, participants were instructed to explain, summarize, listen to another person's explanation, or listen to another person's summary of Darwin's theory of evolution through natural selection prior to beginning an expository text on evolutionary biology (Coleman, Brown, and Rivkin, 1997). Students either (1) read and explained or summarized the text, (2) read and explained or summarized the text and then explained or summarized to their partner, or (3) did not read the text, but waited for their partner's explanation or summary and were asked to be prepared to answer relevant questions afterward. Interestingly, there was no significant difference in the summarizers or explainers ability to complete near-transfer problems, but explainers were significantly better able to complete far-transfer problems than summarizers. Overall, explainers and summarizers outperformed students who did not read the text, but waited for their partner's explanation or summary. This study will be useful not only in coding explanations, but also for providing a theoretical foundation for the learning benefits of student-generated self-explanations.

Analytical schemes for coding self-explanation data appear to be context dependent, though some methods have been designed as general coding strategies (Chi and VanLehn, 1991; Resnick, Salmon, Zeitz, Wathen, and Holowchak, 1993). According to Chi, explanations may initially be coded according to constituent knowledge present, followed by further sub-categorization based on the source of information that generated the piece of knowledge. Two major sources of information often found in self-explanation analysis are (1) deduction of knowledge gained while reading the learning material and (2) generalization to global systems.

Another coding scheme of self-explanations is based upon eight categories: reread, paraphrase, operation, sub-goal, goal, metacognitive, inference, and incorrect inference (Mangwari and Sweller, 1998). This is a categorical coding strategy that may be useful during data analysis for this study. A useful coding scheme for assessing the degree to which student explanations were consistent and how this related to conceptual change has also been reported (Watson, Prieto, and Dillon, 1998). The authors coded the explanations into "systemic networks" from which categories could be identified. The identified categories were then combined thematically to produce patterns of explanation. The authors provide a useful background on research done in the realm of consistency of student explanations across varying sub-disciplines of science, as well as a useful coding scheme for evaluating self-explanations for content and consistency.

Transfer of Knowledge

Transfer of knowledge is a domain of research that has been gaining ground in the recent literature. In general, transfer of knowledge is the application of what is taught in the classroom or other academic setting to contexts beyond the scope of the learning task (Fuchs, *et al*., 2003). Several scales for the transfer of knowledge have been reported in the literature and most often include near-transfer, intermediate (or parallel) transfer and far-transfer (Fuchs, *et al*., 2003; Johnson, 1995; Mayer, 2005; and Woltz, Gardner, and Gyll, 2000). Mayer has developed a theoretical framework on how to apply the phenomenon of near and far-transfer in the context of multimedia learning situations

(Mayer, 2005). This framework was applied towards the development of the present study, primarily to the transfer component. The researcher has added two additional transfer components to the current study – intermediate transfer (similar context, same phenomenon) and deep transfer (same context, same phenomenon, higher resolution).

It has been suggested that teaching methods aimed at facilitating the transfer of learning promote the formation of conditionalized knowledge rather than inert knowledge (Fuchs, et al. 2003). Conditionalized knowledge is organized to reflect a deep understanding, and includes a set of specifications in which it is useful (Bransford, Brown, and Cocking, 1999). Inert knowledge is non-conditionalized because it is not activated in relevant contexts. It has been noted that what is taught in one classroom is rarely applied by students in other classes, in their daily lives, or in the workplace, although teachers tend to assume that the knowledge is transferring (Johnson, 1995). Factors that appear to influence the degree of transfer that is attained are the speed at which a concept is understood (perceptual speed), knowledge, and attention disengagement processes (i.e., the degree to which the participants become unfocused) (Woltz, Gardner, and Gyll, 2000). Woltz and colleagues found that all three factors played a role in the transfer capacity of the skill people are acquiring. Interestingly, their study also found that working memory did not have an effect on the transfer capability.

Schema (pl. schemata) is an abstract term used by cognitive psychologists to describe an elaborate network of mental structures that represent some aspect of the world within the mind of an individual. For example, when education researchers describe the importance of prior knowledge as a factor in the study of learning, they are generally referring to the series of schemata that have been adopted by an individual to organize current knowledge and to provide a framework for future learning and understanding. A schema that may be applied to this research, for example, would be the individuals understanding of the dynamic nature of heat-induced protein unfolding and subsequent aggregation. A schema of this fundamentally complex concept would likely be dependent upon the individuals' knowledge of heat-induced protein denaturation including prior macroscopic observation of a frying egg and knowledge of hierarchical protein structure, intra- and intermolecular interactions, and even the nature of heat.

As an x-ray crystallographer will reveal, a structure consists of two components, elements (i.e. fundamental entities or building blocks) and relations between or within the fundamental building blocks. Thus, a complete structural representation must include not only the fundamental make-up of the structure, but also relations between or within the fundamental components. For example, a sequence analysis of a protein may reveal a tyrosine at position 29. This information is not entirely useful alone, but the true value of this knowledge lies within a structural representation of the protein and a depiction of the relationship between tyrosine at position 29 and, for example, an adjacent water molecule. Alternatively, the significance of tyrosine at position 29 may only be understood with respect to neighboring amino acids (i.e. relations), where sequence similarities may reveal potential structural features and/or functional properties.

Similarly, structural representations of mental models are used within the field of cognitive psychology to understand the relations between and within fundamental components. Within this realm, the fundamental component(s) or building blocks of a mental model are identified. These components include prior knowledge, presence of apparent misconceptions, and relations between the components, which are elucidated.

For the remainder of this discussion, reasoning will be characterized as being either analogical or relational.

Historically, the idea of transfer in an educational context has been considered a case of analogical reasoning. This implies that if two or more “items” or “components” agree with one another in some respect, they – by inference – will likely agree in other ways as well. This step-wise comparison process is referred to as “mapping”. Analogical reasoning requires that comparisons are made based on resemblance between specific particulars in more than one system that are otherwise unlike. In other words, analogical reasoning entails mapping relations between one source, (i.e. the original learning task) with a target (i.e. a situation that is superficially disparate yet fundamentally similar). Analogical transfer occurs when knowledge is generalized from one context to another through the iterative process of mapping a variety of features (i.e. abstract, structural, or functional) from a known situation or original learning task to a novel, seemingly disparate context (Gentner, 1983; Gentner and Toupin, 1986; Gick and Holyoak, 1983). Gick and Holyoak (1983) found that transfer performance was poor when students were prompted to summarize, describe verbally, or represent the problem diagrammatically prior to partaking in a transfer task. By contrast, transfer performance increased substantially when two analogs were provided to students prior to being given the disparate problem set. In both cases, participants were read at least one story illustrating a specific problem and the appropriate solution. The transfer task involved the solving of problems that were disparate, yet analogous to the original learning task. Bernardo (2001) similarly showed that, when compared to a control group, students who used the analogical reasoning readily transferred information between analogous sources and target problems. This particular study revealed that students employing analogical reasoning were much more adept at retrieving the underlying problem construct and successfully applying the underlying analogous information to the target problem. Analogical reasoning has even been successfully applied to preschool-age children (Brown and Kane, 1988). In this case, children were given problem sets with disparate contextual settings but similar solutions. Children were provided an example and then asked to complete a transfer task. In general, children benefited from prompts that encouraged them to reflect upon similarities between the examples with the problem sets. Contrary to the Bernardo study described above, children who provided explanations or elaborations (either on their own or when prompted by a researcher) were much more effective at transfer than when explanations or elaborations were provided by the researcher.

In this paper, the culmination of transfer studies is a concept referred to as "high resolution" transfer. Whereas analogical reasoning strategies were employed within the context of intermediate transfer, relational schemas were induced within the context of deep transfer. Relational schemas represent the structure of a situation or dynamic activity within an environment. Relational schemas are used primarily in artificial intelligence contexts to describe the organization of, for example, a database. The description would ideally include all connecting fields and interrelationships within that database. A common biochemical context for relational schema would be an image of a metabolic pathway chart. Within the context of learning, the properties of a relational schema must includde an explicit relation, a binding that preserves the truth of a relation, a potential for higher-order relations, omnidierectional access, potential for transfer between isomorphs, and ability to predict unseen items in isomorphic problems (please see Halford, Bain, Maybery, and Andrews, 1998, and references therein).

Within the context of deep transfer, the previously characterized properties of relational schema include an explicit relation (i.e. protein structure), a binding that preserves the truth of a relation (i.e. intra/intermolecular interactions), and potential for higher-order relations (i.e. addition of heat to the system). The context also includes omnidirectional access (i.e. when presented with all but one component within a structure, the remaining component may be retrieved), potential for transfer between isomorphs (i.e. conversion of three dimensional structure to two-dimensional line drawing), and ability to predict unseen items in isomorphic problems (initial structure after addition of heat; after continued addition of heat. The importance of transfer in a learning environment is clear, however – despite the research described previously – it is well known to all those who educate that students often struggle greatly in achieving it (Gick and Holyoak, 1980).

Nursing Education

College students who are pre-nursing, sport and exercise science, or nutrition and dietetics majors are the primary focus of this study. Relevant education literature is sparse for this particular population (Gonzalez, 2006); however, the growing importance of bioscience in modern nursing education has been increasingly emphasized. Knowledge of biological principles is critical to nursing competence in this modern age, yet a variety of factors have led, in some instances, to a shift away from bioscience topic areas in nursing education (Clancy, McVicar, and Bird, 2000). The factors included (1) nursing students lack of confidence in the understanding and application of biological concepts and (2) nursing educators lack of confidence in teaching such concepts. This shift away from these topic areas resulted in nursing students feeling less confident about their skills in the workplace.

An apparent disconnect between requirements of modern nursing practice and nursing education has been reported (Cuthbert, et al. 1999; Friedel and Treagust, 2005). The vast majority of nursing educators and students surveyed indicated that a solid working knowledge of bioscience – including biochemistry - is essential for modern nursing practice (97%). Roughly 75% of the educators and students alike felt that biosicence is the basis of modern nursing practice. Nearly half of the educators felt their own bioscience background was insufficient to function effectively in a modern nursing workplace. The incorporation of biosciences (including biochemistry) into the allied health curriculum is a relatively modern phenomenon, thus nursing and other allied health educators are often not qualified to teach such subjects to their students (Larcombe and Dick, 2003). Larcombe and Dick addressed this issue in terms of not what should be taught (i.e., biochemical education should be a focus) but by whom it should be taught. Should specialized lecturers be brought in from bioscience-related university departments to fill the information gap?

A recent nursing-based phenomenological study found an interesting modern dilemma in the health sciences and health science education (Jordan and Hughes, 1998). Recent nursing school graduates were quickly able to adapt to the workplace environment, to understand the “why” behind doctor’s orders, and to participate in inter-professional discussions. This positive outcome of a bioscience-emphasis education unexpectedly resulted in workplace friction, primarily with the senior nurses. The senior nurses overall lacked a modern bioscience-based education and this hindered the less senior nurses from developing new highly knowledgeable bioscience-based roles in the workplace. This finding implies that the issue of bioscience education in nursing education is not solely a classroom issue, but has broader implications in the workplace environment.

Biochemistry Education

The potential applications of teaching with visualization in undergraduate biochemistry classrooms are vast. As a former protein crystallographer, I realize that current advances in the medical and biochemical sciences are virtually one hundred percent dependent on visualization of the structure of interest. However, visualizing these complex nanoscopic images is a challenging feat as the structures and processes of interest are essentially invisible to humans. One can make inferences and hypotheses to explain various phenomena, but there is no way to know what is really happening. Scientists use innovative visualization technologies to make the invisible become visible (structure determination). The results of such structural determinations yield beautiful, artistic “pictures” (Figure 3).

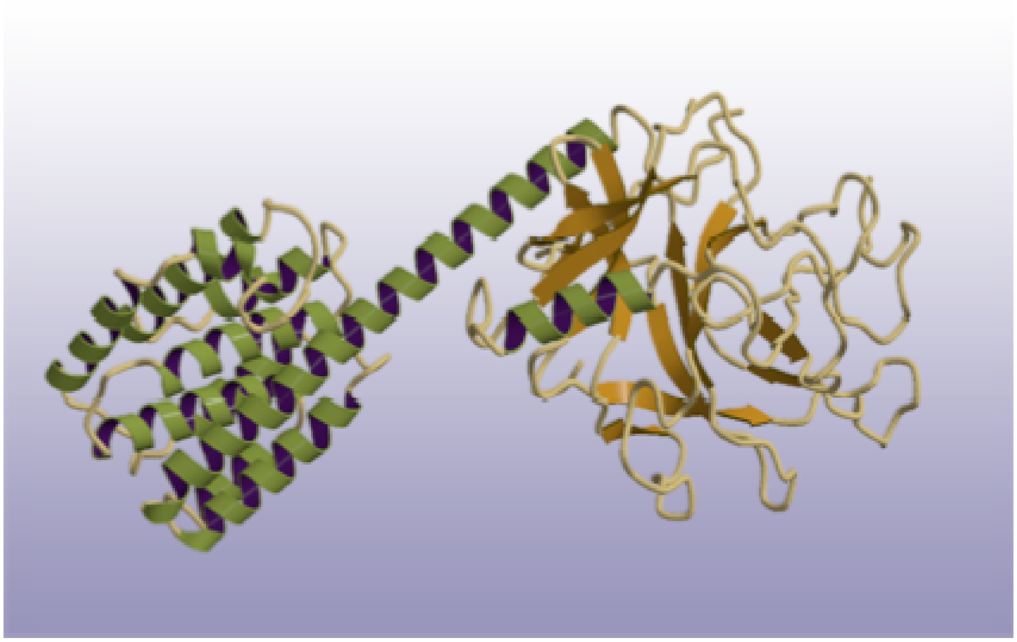


Figure 3. A representation of a toxic protein from *Escherichia coli* bacterium solved by the researcher, JF, using x-ray crystallography is shown. With a basic foundation of biochemical principles, the picture can be used to elucidate possible functional mechanisms, thus reinforcing the idea of protein structure-function relationships (Hilsenbeck, Park, Chen, Youn, Postle, and Kang, 2004).

What is the current drive for modern molecular visualization? We as a species have a history of visual thinking. One critical component of human intelligence is the ability to visualize objects and their transformations in space (spatial ability). Humans have varying degrees of spatial ability, however, from one individual to another. An important factor in understanding the complex three-dimensional relationships found in the physical sciences relies upon this ability. Our inherent spatial ability (no matter how strong or weak) can allow us not only to make plans of action, but also to predict the resulting outcome. This is the basis of the scientific method. Modern developmental psychology idealizes that it is the way we see that shapes our brains, rather than what we see. The way our brain "sees" ultimately shapes our knowledge (Nye, 2004). Neurophysiologic research indicates that billions of nerve cells are required to flash “messages” along cross-linked pathways that allow us to see, hear, feel, smell, or taste. The data acquired by the brain through our senses is transformed into a form that we can understand, such as through perception of features including depth, color, and texture. It is through this data processing that abstract concepts and processes are better understood. Understanding is assessed by the ability to translate observed visual patterns into new thoughts and ideas. Using visualization techniques, scientists utilize an inherent sense of visual thinking. In a similar manner, scientific advancement and technology provide an opportunity to collect data with greater and greater detail. Art then steps in to represent the data to make conceptualization easier. The process results in a beautiful mix of science, art, understanding, learning, and ultimately advancement.

There are five key inter-related concepts students need to understand to have a deep appreciation for protein biochemistry (Whitehead and Pence, 2002). Students should understand that proteins comprise a major part of all cells and perform the majority of functions required for life. They should also understand that the primary function of most genes is to produce protein products that perform specific functions and have specific activities. Third, it should be clear that mutations in the genetic blueprint (DNA) or in the transcription process (RNA) ultimately affect the amino acid sequence of the protein, thus altering its ultimate functional capability. Fourth, students should understand that the function of a protein is determined primarily by its shape and amino acid sequence. These factors ultimately lead to the protein’s ability to interact with other proteins, drugs, lipids, or nucleic acids. Finally, students should realize that although some proteins may have similar shapes with little sequence similarity, similar sequences often yield similar shapes. Similar shapes often yield similar function.

To successfully understand these somewhat abstract concepts, one needs to understand not only the fundamental basics of protein structure but also the forces that promote and govern such structure, and their relationships to each other. To effectively communicate this information, molecular visualization programs have been designed to allow the user to interactively manipulate a representation of a protein structure. The user may highlight various regions of interest or structural features, enlarge (zoom in), translate, or rotate the displayed protein structure (Rhodes, Molecular Graphics Manifesto).

Although protein chemists are the primary users of the molecular visualization tools described above, these tools have been increasingly incorporated into higher education curriculum (Richardson and Richardson, 2002). How successful, then, is the recent effort to incorporate molecular visualization tools into the biochemistry education framework? Although the field of biochemical molecular visualization is in its infancy, a handful of articles have been published recently regarding molecular visualization classroom implementation. For example, the Richardson Laboratory at Duke University did a study with undergraduate students who were exposed to the kinetic image software program Kinemage (Richardson and Richardson, 2002). These students were nearly twice as likely to get an exam question regarding biological handedness correct as students who did not view the kinemages (94% correct vs. 56%) (Richardson and Richardson, 2002). Similarly, a study at the University of Massachusetts-Amherst reported positive learning outcomes from the use of molecular visualization in lecture and lab when compared to instruction without the use of this technology (White, Kim, Sherman, and Weber, 2002).

Inquiry-based learning is a tool that has been implemented into the biochemistry classroom with increasing frequency. Students at Tuskegee University were given inquiry-based assignments that relate their understanding of the protein structure–function relationship (Willian, 2002). At the University of Illinois, Chicago, an undergraduate biochemistry laboratory was developed to provide students with relevant skills in bioinformatics-based research (Stahelin, Forslund, Wink, and Cho, 2003). After becoming familiar with the new skills, students participated in a research-like project where they dictated the project goals and outcomes. A similar bioinformatics-based study was conducted at Indiana University (Feig and Jabri, 2002). Long-term benefits provided by the course were difficult to analyze, but students who took part in this study were much more active in future physical biochemistry courses than students who were not involved. Although the results are anecdotal, it seemed student perceptions of computer-assisted learning for biochemistry were greatly improved during the study.

A senior-level course offered at Mississippi State University implemented a workbook that provided web-based tutorials (Boyle, 2004). Using these tutorials, students would find conserved domains in proteins or chromosomal locations of a gene involved in a well-characterized genetic disease. The main drawback was that the workbooks were often outdated by the time implementation occurred. In another approach, which was more unstructured, students were given a specific task and were allowed to find their own path to the results. A similar practical implementation was introduced to third year undergraduate students in England (Gibbins, Sosabowski, and Cunningham, 2003). The goal was to teach students how to identify the genetically altered sequence in the *RoundUp Ready* soybeans– a non-plant sequence incorporation. Overall, there was a significant increase in confidence level and accuracy in students taught using computer-assisted techniques as compared to traditional (non-electronic) techniques.

Research detailing the overall effectiveness of molecular visualization programs in molecular literacy is still in its infancy (Honey and Cox, 2003). While some researchers argue that computer-based graphics do not contribute (or at best minimally contribute) to students' conceptualization of biochemical phenomena (Parslow, 2002), many educators agree that– if used appropriately– computer-based learning methods can improve students understanding of biochemical topics (White, Kim, Sherman, and Weber, 2002). Hundreds of biochemistry tutorials have been compiled in an online database, the World Index of BioMolecular Visualization Resources (Martz, 2004). The mere length of this database gives rise to the notion that many educators and chemists believe it is worthwhile to incorporate molecular visualization software programs into their curriculum.

It seems to be a reasonable assertion that if visualization tools are appropriately implemented in the classroom there may be a profound positive effect on novice understanding of complex and often abstract biochemical concepts. Instructional animations may have the potential be more effective than their static counterparts under conditions that are considerate of fundamental principles of cognitive psychology such as cognitive load theory and working memory overload (Ayers, Kalyuga, Marcus, and Sweller, 2005; Mayer and Moreno, 2003).

Currently, very little research has been done in the realm of learning style preferences among biochemistry students, particularly for the pre-health science population. The goal is to understand the role of learning style preferences on recall, conceptualization, and transfer skills involving biochemical phenomena for this population in particular, which may ultimately lead to contributions to learning theory in general.

CHAPTER III

METHODOLOGY

Overview

The importance of cognitive and preferential learning styles on academic performance has not been underemphasized (Alkhateeb, 2004; Cassidy, 2004, Dalgety and Coll, 2005; Davis and Karunathilake, 2004; Davis and Franklin, 2004; Drysdale Ross, and Schulz, 2001; Price, 2004; Rochford, 2003; Schwartz, Martin, and Nasir, in press; Sonnenwald and Li, 2003; and Valle, Cabanach, Nunez, *et al.*, 2003). Of particular interest in this study was the role that learning style preferences had on the academic performance of students in highly theoretical and abstract courses. The central objective of this research study was to understand the role that learning style preferences had on novice chemistry students enrolled in a one-semester undergraduate "Fundamentals of Biochemistry" course that covers basic topics in general chemistry, organic chemistry, and biochemistry. Learning was also assessed using a variety of instruments that were specifically designed to measure the depth of student understanding of dynamic biochemical processes. The specific levels of understanding that were of interest in this study were recall knowledge, conceptual understanding (and similarly apparent misconceptions associated with their understandings), and transfer ability on the near, intermediate, and high-resolution scales. The presence of misconceptions throughout each component were noted and interpreted as a separate measure of understanding. The magnitude of each measure of understanding was then correlated to each individual participants learning style preference.

All students enrolled in two sections of a ‘Fundamentals of Biochemistry’ course at the University of Northern Colorado were solicited for participation in this study. The vast majority of students enrolled in this course were female and were primarily pre-nursing majors. Sport and exercise science as well as nutrition and dietetics majors were also enrolled in the course and therefore solicited for participation. The vast majority of students enrolled in the course were required to complete the course for fulfillment of their major requirements.

A primary source of data that were used in this study came from the collection and thematic analysis of student-generated self-explanations. Self-explanations are in essence any content-derived verbalization or written statement generated by the student in an academic setting. The primary function of self-explanations is to give reasons for something or details of something (Chi, 2000). The process of self-explaining is the act of generating self-explanations to oneself after being presented with the learning text. A self-explanation inference occurs when the self-explanation consists of a piece of knowledge or postulate that was not directly stated in the learning context. The potential richness of self-explanation data has been explored extensively (Chi, 2000, including the citations therein). Self-explanations proved to be a useful tool for the researcher, i.e., J. Fajardo, to understand the evolving mental models of the participants (Uttal, Fisher, and Taylor, 2006). The self-explanation inference was also a useful tool to measure knowledge transfer (Atkinson, Renkl, and Merrill, 2003). In addition to providing information for this research, student-generated self-explanations have been shown to improve the communication skills of novices in the particular domain in which the self-explanations were generated (Brna, Cox, and Good, 2001) as well as to result in an overall improvement of learning (Mayer, Dow, and Mayer, 2003; Renkl and Atkinson, 2002). Note that the process of self-explaining is *not* a method of conveying information, but a method of understanding something personally. For the purposes of this research, students generated self-explanations of molecular-level phenomena as they attempted to understand their own macroscopic observations of an egg turning white as heat is applied.

Research Questions

Q1. Using the Object-Spatial Imagery Questionnaire (OSIQ), what are the predominant, preferential learning styles of novice students in a fundamental biochemistry course (object or spatial)?

Q2. What is the relationship between learning style preference and ability to recall specific features of protein structure?

Q3. What features (statements, meanings, themes, or general descriptions) are found in a selection of biochemistry novice descriptions and self-explanations of relationships between molecular phenomena and macroscopic observations (i.e., frying an egg)?

Theoretical Framework

The type of data a chemist collects in an experiment is influenced by his or her choice of instrumentation. For qualitative research studies, a theoretical framework plays a role analogous to the role of the instrument. A theoretical framework is a system of ideas, aims, goals, theories and assumptions about knowledge, how research should be carried out and how research should be reported that influences what kind of experiments can be carried out and the type of data that result from these experiments.

Thus, the researcher must carefully follow an epistemology that has been pre-defined prior to data collection. It is through this pre-defined epistemology that it is known how what is known is known; in other words a description of the nature of knowledge and how that knowledge is gained. Epistemologies are characterized by a specific relationship between the researcher and the subject being researched. Within this realm, the researcher may attempt to lessen the distance between themselves and the participants of the study (i.e., in qualitative research). Specific epistemologies include empiricism, rationalism, and constructivism. In constructivist epistemology, a term first coined by Piaget (1967), knowledge is acquired through assimilation and accommodation of new information. There is no objective truth to be told or gained; rather knowledge is constructed rather than discovered. Constructivism-based epistemology, the specific epistemology used here, may embody many theories and perspectives including interpretivism. In this perspective, the researcher acts as both an observer and interpreter. It is through the interpretivistic perspective that one attempts to *understand* social reality rather than *explain* natural reality. A subcategory of the interpretivistic theoretical perspective is phenomenology, a description or interpretation of a phenomenon (a concept experienced by subjects), and reduction of observations and themes to a central meaning.

Phenomenology is a subcategory of the interpretivistic theoretical perspective. Whereas interpretivism attempts to *understand* social reality through observation and interpretation, a contradistinction to *explaining* natural reality, as is often found in the natural and physical sciences (Creswell, 1998), the sub-categorical phenomenological perspective is used to describe or interpret meaning out of a specific phenomenon (a concept or “thing” experienced by the participants). Data are subsequently reduced to a central meaning, as understood by the researcher. In this case, the researcher described and interpreted data obtained from student-derived representations, explanations, and descriptions. Both diagrammatic depictions and written explanations were used to infer a level of understanding based on the complexity of such representations. Ultimately, themes arising from the categorized data were reduced to a central meaning. Diagrammatic representations have previously been used to infer a level of understanding through diagrammatic assessments (Brna, Cox, and Good, 2001). In the Brna *et al.* study, diagrams were used to understand relationships between task, prior knowledge, and self-explanation.

Setting

Data for this study were collected at a mid-sized state university in the western region of the United States. The university is ranked 11th overall in the state where it is located and incoming students generally rank within the 75th percentile on ACT and SAT test scores overall. Nearly one in four students at the institution represents an ethnic minority, and 62% of the total number of students are female. Slightly more than four out of five students at this mid-sized institution are undergraduates. The university prides itself on a strong education emphasis, with a majority of physical science degrees in physical science education. The university also offers a state board of nursing-accredited Registered Nurse (RN) to Bachelor or Science in Nursing (BSN), Master of Science in Nursing (MSN) with emphasis in education, clinical, trans-cultural, or family nurse practitioner (NP) degrees, as well as a doctoral degree in nursing education established three years prior to the collection of data for this study. Nearly three out of four nursing majors are at the undergraduate level, with over 5% of all university graduates obtaining a degree in nursing on a yearly average.

Participants

A total of 120 students enrolled in two sections of a “Fundamentals of Biochemistry” course at a mid-sized western university were solicited for participation. Slightly less than 75% of the combined enrollment from all course sections completed every aspect of the research. This participation rate was expected based on pilot study participation rates. The course sections were selected on the basis of instructor– the instructor was the same as that in the exploratory and pilot studies, thus minimizing a potential instructor effect.

The vast majority of participants for this study were female (84**%**) and three out of four were pre-clinical nursing majors. The average self-reported grade point average of all participants was 3.16. Slightly less than two out of three (61%) reported having had a chemistry course prior to the course they were currently enrolled.

Instrumentation

The instruments that were used for this research study are outlined in Table 3. The Object Spatial Imagery Questionnaire (OSIQ; formerly called the VIQ - Visual Image Questionnaire), Instrument #1, was developed and validated by the Kozhevnikov Laboratory at Rutgers University (Blajenkova, *et al.*, 2006). The questionnaire was designed to assess whether students prefer to be presented with information verbally or visually. The visual preferential learning style is further sub-classified into self-reported spatial and object preferred learning styles. The total questionnaire length was 45 questions, using pre-defined clusters consisting of 15 questions each for the three groups, verbal, visual object, and visual spatial. Students successfully completed the questionnaire in the allotted time of 10 minutes or less. Scores for the OSIQ were based on the Likert-scale, where a response of “1” indicated a level of agreement pertaining to “strongly disagree” and a response of “5” indicated a level of agreement pertaining to “strongly agree” (Appendix A). The demographics form, Instrument #2, provided the researcher with descriptive pieces of information about the participants. The participants were asked to provide their gender, year in college, major, self-reported GPA, previous chemistry courses, and course intentions or goals.

Table 3.

Instruments used during the course of this study.

Appendix		Title of Instrument
A	1.	Object Spatial Imagery Questionnaire (OSIQ)
B	2.	Demographics / Information form
C	3.	Prior-Knowledge assessment used as a delayed post-test of content knowledge
D	4.	Template for frying egg storyboard
E	5.	Self-paced frying egg animation tutorial questionnaire based on the following online source: *http://www.sumanasinc.com/webcontent/anisamples/nonmajorsbiology/proteinstructure.html*
F	6.	Near, intermediate, and deep transfer assessments

The researcher developed the knowledge assessment, Instrument #3, during the Spring of 2004 at the University of Northern Colorado (Appendix C). Two course instructors and one chemical educator with a biochemistry background validated the questionnaire content. The instrument was designed to include measures of recall knowledge and conceptual understanding. For the purposes of this study, a total of ten questions were considered measures of conceptual knowledge and five questions considered measures of recall knowledge. The questions considered measures of conceptual knowledge consist of both diagrammatic and open-ended written components, and were designed to be measures of a participant's understanding of a specific biochemical content area as interpreted by the researcher. Four diagrammatic components of the prior knowledge assessments were also associated with a written component. The written component that was associated with each diagrammatic component was strategically designed by the researcher to encourage the participant to describe or explain the associated diagram or depiction. In addition to the open-ended written responses associated with a diagrammatic representation, two open-ended written questions considered conceptual in nature that were not associated with any particular diagrammatic component were also included in the prior-knowledge assessment. All questions on the knowledge questionnaire pertained to protein structure or enzyme action. Recall questions were all multiple-choice questions (with only one correct response) and were all based on protein structural hierarchy or structural changes upon heat-induced denaturation. The recall component was designed to test ability of the participant to remember information rather than being a complex measure of understanding.

One can continuously measure students understanding of protein structure through recall or conceptually-based questioning methods. It is even possible to imagine that results of such questioning techniques would provide a valid basis for interpretation as far as the level of understanding for any particular participant. The researcher, however, believes that students can know and understand the "right" or correct answer that has been sought of them, yet it is entirely possible that the student may have little to no understanding of the meaning or implications of that "right" answer. In order to establish a means to assess student's understanding of their recall- or conceptually-based responses, the researcher developed a sub-component to the study, henceforth referred to as the Animation Component. The animation component was completed by all of the participants during a span of two weeks in eight individual laboratory sections, beginning with the laboratory sessions occurring during the ninth week of the semester. This laboratory session was chosen for two reasons. First, the students had already had instruction during lecture on fundamental protein structure concepts and could thus be expected to be familiar with the content of the animation. Second, the laboratory scheduled on this date has historically been completed within one and one half hours; thus, there is ample time to incorporate the animation tutorial. During week one, participants were introduced to an animation that visually merged macroscopic observations with molecular-level phenomena of a heat-induced denaturation process. A cognitive anchor was provided to the students in the form of a frying egg as the basis of the phenomenon.

Prior to viewing the animation, the participants completed a storyboard template. The storyboard template, Instrument #4, is shown (Appendix D). Within this component,, participants were asked to storyboard, using both pictorial representations and written explanations, their understanding of processes that occur when frying an egg. Both pictorial representations and written explanations were coded simultaneously, as the rubric allowed for integration. Data were coded as representations of either macroscopic, microscopic, molecular level, or some form of integration. This rubric is henceforth referred to as a modified five-point rubric. Items coded as macroscopic are depictions that would be observable by the naked eye (i.e., the egg turning white); microscopic depictions would include representations that would be observable under a microscope, i.e., cellular-level. Depictions representing the molecular-level would be characterized by specific representations of atoms or molecules; examples of these characterizations include inter- or intramolecular bond representations, specifications of regions of polarity, or even the depiction of water. Recall that in preliminary analyses, the researcher established a five-point rubric for evaluating written responses and student-drawn pictorial representations to numerically evaluate each student response. The rubric ranged from 0 to 4, with 0 indicating blank or nonsense; 1 indicating significant misconception present; 2 indicating apparent surface-knowledge present but little deep understanding; 3 indicating apparent understanding on a deeper level; 4 indicating expert-like deep conceptual understanding. Preliminary analyses revealed that the five-point rubric was too subjective; thus the modified five-point rubric based on molecular-level descriptions and/or explanations was developed and are described further in Table 4.

Table 4.

Modified five-point rubric for qualitative responses.

Score	Characterization of Response	Description
0	No response	Response left blank or "I don't know"
1	Macroscopic	Description or response is an attribute that is visible to the naked eye
2	Microscopic	Shape is emphasized; no atomic or molecular-level detail is apparent
3	Molecular Level	Response contains reference(s) to atoms, bonds, inter- or intra-atomic forces
4	Integrated	Combination of at least two different response characterizations

The animation questionnaire, Instrument #5, was distributed to all students during the ninth week of laboratory (Appendix E). The tutorial questionnaire was designed to foster the generation of self-explanations or self-explanation inferences from the students. It has been noted that many students attempt to establish a causal relationship between continuous, dynamic events, a process called naïve reasoning (Goodwin and Johnson-Laird, 2006). Questions from the questionnaire were classified as recall, conceptual, evaluation (regarding features of the animation), or transfer for the purposes of analysis.

Over time, the heart of this dissertation study became known as the transfer component. The transfer component consisted of three assessment scales designed by the researcher to measure transfer of knowledge as near, intermediate, and deep. Students' ability to transfer knowledge was measured and categorized using these scales. For the near-transfer scale, students answered a series of questions based on knowledge gained by viewing the animation. Ultimately, the students were required to generate a self-explanation(s) to justify an answer.

Near-transfer, for the purposes of this study, was defined as a situation representing the same phenomenon and context as the original learning task but is designed specifically on the molecular-level. In this realm, the phenomenon is heat-induced protein denaturation and subsequent aggregation. The context is the "frying of an egg." For Part One of the near transfer component, students were asked to draw a picture of their representation of a group of unfolded proteins, as well as a group of aggregated proteins. They were also asked to explain their pictorial representations in written text-form next to the pictures. For Part Two of the near transfer component, students were provided with a pictorial representation of both an aggregated structure of proteins and an unfolded, disordered protein taken directly from the frying egg animation.

Students were then asked to provide written descriptions for each picture. The students were asked to specifically describe what the pictures are attempting to represent.

For the purposes of this study, *intermediate-transfer* is defined as a situation that is the same phenomenon as that in the original learning task, but has a different context associated with it. This type of transfer is sometimes referred to as parallel transfer. During this intermediate transfer component, students were given a situation involving the same phenomenon (induced protein structural changes) in a different context (exposure to radiation). The protein structure is altered by radiation induction, rather than by heat. Only a preliminary analysis of intermediate transfer data will be presented.

Deep transfer, formerly called high-resolution-transfer, is a concept not as yet used in the psychological or educational literature. For the purposes of this research, high resolution-transfer was defined as a situation that is similar in phenomenon to the original learning task, but is focused on a discrete, fundamental level not addressed in the original learning task. In the current study, the students viewed and interpreted an atomic-scale resolution picture of a region in ovalbumin taken directly from x-ray crystallographic data. They were encouraged to confront their knowledge of molecular level events not from the global picture of the whole protein (or proteins in solution) but from a true molecular-level perspective (Appendix F). High resolution-transfer can be more accurately defined as a transfer context that incorporates the same phenomenon as the learning context, though on a different, more highly resolved scale. Measurement of high resolution-transfer required the use of a high-resolution image of a several-Angstrom wide region within egg-white protein. Students were provided with a high-resolution image and were subsequently asked to describe, both pictorially and textually, how the picture would change if heat (up to 100 ˚C) were applied.

A clear distinction has been made between a person's ability to mentally rotate objects in space and their ability to view an object from different perspectives (Hegarty and Waller, 2004). The high resolution-transfer component required students to view an atomic-level representation of hydrogen bonding and to describe what would happen to that representation if heat were added (on the molecular level). Visualizing protein structure three-dimensionally requires that one can rotate the protein to see both local and global structural changes as a function of heat, as well as – and more importantly - viewing a particular localized site within the protein to see all hydrogen bonds potentially affected by the heat at that location. If students have low spatial aptitude, their ability to complete the deep transfer component may be hindered.

Experimental Design

During the first week of Spring 2007, students enrolled in two sections of Chemistry 281, Fundamentals of Biochemistry, were asked to complete three research-related materials:

a. Object Spatial Imagery Questionnaire (OSIQ)
b. IRB consent form
c. Demographics / Information form

Though two different instructors taught different sections of the course, only students from one instructor were solicited for participation, thus the effect of instructor was controlled. Students were solicited for participation during the first week of the semester during the lecture component. The OSIQ, the IRB consent form, and the demographics forms each required approximately 10 minutes to complete.

Approximately one-half way through the semester, prior to starting the unit on biochemistry, students in the selected sections were asked to complete an “advanced organizer” on protein-structure related material (the prior-knowledge assessment). All participants were required to complete the prior-knowledge assessment for further participation in the research. Near the end of the semester (several weeks after the conclusion of the protein structure unit), participants had the opportunity to make modifications on their own copy of the prior-knowledge assessment. The participants made these modifications on a photocopy of their original prior-knowledge assessment using a green pen provided to them by the researcher.

The prior-knowledge assessments were completed by all participating students during the lecture component, and due to unforeseeable time constraints dictate, the post-knowledge assessments was distributed to participants in each of their individual laboratory sections. The post-knowledge assessment was used to assess knowledge gained after completing all components of the research. The goal of this test was to assess the students’ knowledge and understanding of fundamental concepts of biochemistry before and after they had received lectures on the material from the professor and only after viewing an animation aimed at connecting macroscopic observations with microscopic phenomenon. This information was used as a covariate in subsequent analyses to normalize the data.

Approximately midway through the biochemistry unit, students completed a questionnaire pertaining to a frying egg animation (see Appendices D and E) that they viewed individually during individual laboratory sections. This laboratory session will henceforth be referred to as the “Lab Animation Tutorial”. All students completed the lab animation tutorial, regardless of participation in the research. Students were informed that their data would not be graded and would be used solely for the purposes of the research. Data collected from students who were not participants in the research study was not analyzed.

During the lab animation tutorial, all students initially completed a “storyboard” that was designed to provide a depiction of their individual beliefs on what they believe occurs when an egg is fried. Subsequently, the researcher assessed the responses on the modified five-point rubric. The students were provided space to use both pictorial representations and written explanations in their depictions. This storyboard served as a prior-knowledge assessment of their understanding of heat-induced protein denaturation and aggregation. Students then ordered a jigsaw puzzle that was composed of four snapshots taken from the animation they were about to see. The students were then instructed to explain their choices for ordering in a textbox provided below each snapshot. After completing the jigsaw puzzle, students then viewed a pre-assigned version of an animation of frying an egg. The selected animation was chosen because it incorporated macroscopic and surface-level observations with global dynamic molecular-level events. Due to the global familiarity of the context (frying an egg), the researcher believed that the animation could provide a cognitive anchor for the students, as well as a comfortable setting.

Two versions of the animation were used; continuous play with narration and pause capability as well as a step-through version consisting of text and built-in pauses.

All computers were equipped with headphones. Students were randomly assigned to each version, such that approximately half of all participants viewed one version initially, and the other half of all participants viewed the alternate version. After viewing the animation, students were asked to answer the post-animation questions (recall, conceptual, transfer, and evaluation-type questions) and turn in the entire questionnaire to their laboratory instructor. The transfer component was completed during the laboratory component one week after the participants completed the laboratory animation tutorial and required approximately 40 minutes for completion.

Data Analysis

Data analysis was primarily quantitative, though qualitative analyses were also required. Over 100 prior-knowledge assessments, lab animation tutorials, and transfer components were collected from participating Chemistry 281 students.

Qualitative Analysis

Qualitative data analyses were categorical in nature. Thus, responses were coded according to the revised five-point rubric (macroscopic, microscopic, molecular-level, or integration) as well as the presence of an apparent misconception or chemical detail. Qualitative data were also be categorized according to keyword (descriptive, action, matter), misconceptions (absence of concept, poor understanding of concept, or appropriate use of concept), as well as knowledge integration. The coding of datawas focused on macroscopic (non-salient) versus microscopic (salient) features of student-generated drawings, representations, written explanations, and written descriptions. These features will then be categorized according to whether they describe matter, an event, or an abstraction. How these components are integrated can then be assessed.

A recently published article provides a reasonable foundation for using written self-explanations and drawings to understand mental model organization (Uttal, Fisher, Taylor, 2006). Also, strategies for comparing student-derived pictorial representations have been described (Panagiotaki, Nobes, and Banerjee, 2006).

Quantitative Analysis

The OSIQ data was initially quantitatively analyzed through principal component analysis (PCA) to verify that the three factors are actually present within the sample. ANOVA was also used to determine significant mean differences among the three learning style groups (verbal, visual spatial, and visual object). Specific grouping of individual participants will be described shortly.

Research Hypotheses and Methods

The quantitative components were designed to be either descriptive or inferential in nature. Thus the following hypotheses were established:

Research question 1:

> Using the Object-Spatial Imagery Questionnaire (OSIQ), what are the predominant, preferential learning styles of novice students in a fundamental biochemistry course (object or spatial)?

The null hypothesis stated that there were no significant differences between the means of spatial and object learning preferences in the population of interest. The alternative hypothesis was that at least one learning style preference produced a mean significantly different from the other means.

All of the participants (N=120) completed the OSIQ during one of two lecture components shortly after the beginning of the academic semester. The OSIQ consisted of object, spatial, and verbal learning style components as described in depth by Blajenkova, *et.al.* (2006). This assessment was administered once during the data collection phase of this research study. Student responses were recorded on paper initially, then transcribed electronically by the researcher. In this case, students were categorized according to high-object, low-object, and non-object categorical variables based on the summative value of scores for each of the learning style preference categories. Summative scores for each component - object, spatial, and verbal - were determined and students were grouped according to the method of Chabris (2006).

Briefly, students were placed in one learning style category if their summative score for that category was greater than five points relative to the other categories. There were a total of 15 questions per category using a Likert-based five-point scale, thus summative scores could range from 15 to 75. It was determined that there were an inordinate amount of students who preferred the object-based learning style. Thus, students were regrouped into high-object, low-object, or non-object categories. Students whose summative object score was greater than or equal to the mean were categorized as high-object visualizers; all others were categorized as low-object visualizers. Students whose summative scores were a minimum of five points greater for either the spatial or object categories were classified as non-object visualizers. Students who scored within five points of each other were initially classified as a preferred combination learning style, however for ease of categorizing, these students were classified as either object (if their combination included object) or non-object for all other combinations. Simple analysis of variance (ANOVA) was subsequently used to compare the means for these three groups to ensure that they were significantly different and Bonferroni’s post-hoc test was used to determine which group means were significantly different. Additionally, Pearson's correlation was used to ensure that the learning style preferences were uncorrelated.

Research question 2:

> What is the relationship between learning style preference and ability to recall specific features of protein structure?

The null hypothesis stated that there was no relationship between learning style preference and ability to recall specific features of protein structure. The alternative hypothesis stated that at least one significant relationship would be found between learning style preference and a student's ability to recall specific features of protein structure.

To assess recall knowledge, students were given five multiple-choice questions that focused on a variety of aspects involving protein structure. These multiple-choice questions were provided with the prior-knowledge assessment that was distributed to the students during their lecture component one-week prior to starting a unit on biochemistry (Appendix C). The multiple-choice questions were also distributed to the students immediately after the completion of the biochemistry unit during the laboratory sessions. During this post-assessment, participants were provided with a photocopy of their original prior-knowledge assessment and they were asked to make any changes or modifications to their original responses. All participants were provided with green-colored pens for completion of the post-test prior-knowledge assessment so that the researcher could easily distinguish pre- and post-test responses.

Pre- and post-test scores were compared and overall gain in recall knowledge was tabulated. Recall gain was subsequently compared to the participants preferred learning style (high-object, low-object, and non-object). The primary interest here was to understand the relationship, if any, of multiple factors (in this case, high-object, low-object, and non-object preferred learning styles) with one dependent variable (in this case, recall gain). Thus, multiple linear regression (MLR) provided the researcher with a specific mathematical form of the relationship and subsequently provide a measure of the proportion of variance in the dependent variable, recall gain, by each of the learning style preference categories. While ANOVA would allow the researcher to make multiple group mean comparisons while maintaining the alpha at 0.05 and automatically test for interactions, the purpose here was to determine if learning style preference can be used as a predictor for gain in recall knowledge. Thus, MLR was chosen as the most beneficial statistical tool for this purpose.

Research question 3:

> What features (statements, meanings, themes, or general descriptions) are found in a selection of biochemistry novice self-explanations of relationships between molecular phenomena and macroscopic observations (i.e., frying an egg)?

A compilation of student data taken from the laboratory animation and transfer components were initially coded qualitatively according to the revised five-point rubric. Briefly, descriptions, representations, and/or explanations were categorized as being macroscopic, microscopic, or molecular-level in nature. Upon subsequent analyses, responses were coded according to the chemical detail present as well as the presence of apparent misconceptions. These data were subsequently analyzed by Chi Square non-parametric analysis. Within this realm, categorical variables included chemical detail (present or not) and presence of at least one misconception.

An additional rubric was developed by the researcher to understand responses on both the principles of chemical detail and misconceptions, simultaneously. This five point “sub-coding” scale was characterized by the following distinctions: a score of 0 indicated that there was no response (blank) or the response was "I don't know"; a score of 1 indicated that misconceptions were apparent and that there was concurrently very little elaboration or chemical detail provided with the response; a score of 2 indicated that the response held no apparent misconceptions but there was very little elaboration or chemical detail; a score of 3 revealed the presence of apparent misconceptions but that there was also an attempt by the student to either describe or explain the observed property with some elaboration or chemical detail (for example, through discussion of interatomic bonds or forces); finally a score of 4 indicated that there were no apparent misconceptions in the response and that this was combined with moderate elaboration and/or chemical detail.

Reliability and Validity

The evaluation of the diagrammatic and written components underwent inter-rater reliability tests with two additional raters in addition to the researcher. At least five randomly selected examples were used for inter-rater reliability (approximately five percent of all responses). All three raters are considered content-area experts, and one rater is also considered a pedagogical expert. The internal validity of the study will be maintained in the following ways. First, the method of triangulation will be used (Merriam, 1998). The prior- and post-knowledge assessments were scored by the researcher and by at least one other expert in fundamental biochemical principles. In the instance that the researcher and the secondary grader had an instance of low inter-rater reliability, one of the advisors of the project (J. Suits and R. Hyslop) critiqued the survey of interest and made a final decision. Low inter-grader reliability was defined as more than 1 point of the five-point rubric. The assessment is scored based on a scale of 0-4. Two scores that were more than two points off indicated low inter-rater reliability. Due to the objective nature of the rubric, it was anticipated by the researcher that inter-rater reliability would be fairly high overall.

Researcher Personal Stance

As a researcher, I am supportive of the effects of visualization-based technologies in the undergraduate and graduate level biochemistry classrooms. I am a trained protein crystallographer, and through the experience of crystallography, realize the profound effects of visualization on accurate conceptualization of the fundamental theoretical concepts. Chemists and chemical educators agree that strong spatial ability is a necessary ability to understand chemistry. Students who struggle with spatial visualization often are not successful with higher-order chemical sub-disciplines such as organic and biochemistry, and these students may especially benefit from visualization technologies. The field of biochemical molecular visualization is in its infancy. Careful and systematic studies of both the qualitative and quantitative tradition must be carried out to assess the impact and effectiveness of this visualization technology in teaching.

CHAPTER IV

RESULTS

The purpose of this study was to investigate students' abilities to transfer information taught to them during a one-semester Fundamental of Biochemistry course. Overall, students were taught key concepts of general, organic, and biochemistry in a sequential order. Thus, key concepts of prior units were taught continuously and further applied as the semester progressed. For example, the concepts of acid/base chemistry were initially introduced during the first month of the semester. These concepts were further applied during the latter part of the semester in terms of amino acid and protein structure, as well as enzyme action and inhibition. Key molecular structure concepts were also introduced during the general chemistry unit, such as chemical bonding. This portion of the unit included such topics as valence electrons and the Octet Rule; ionizations, oxidations, and reductions; ionic compounds and polyatomic ions; covalent bonding; molecular geometry; bond polarity and electronegativity. Understanding of these concepts was further enforced during the organic and biochemistry units. The basic premise of this study was to initially characterize the population according to either spatial or object-based learning style preferences and subsequently to understand how these learning style preferences affected various factors of learning.

Overview of Results

A primary source of data from thematic analysis of student-derived self-explanations, i.e., from their own self-reported understanding of either observed phenomena or inferred molecular-level phenomena. Throughout the course of this study, self-explanations provided the researcher, J. Fajardo, a means to not just appreciate students' understanding of various concepts, but to assess the depth of that understanding. Student-derived self-explanations of both the textual (i.e., written) and diagrammatic realms were thus used to understand evolving mental models of participants through objective coding of the responses. Ultimately, deeply-held misconceptions pertaining to the complex and dynamic processes of heat-induced protein denaturation became clear to the researcher.

Initially, three measures of learning were used to assess the depth of understanding. Recall knowledge was characterized as primarily surface-level, i.e., inert knowledge and was assessed using only multiple-choice questions (Appendix C). With this format, only one correct answer out of four distinct options was possible; thus, correct answers included a sufficient level of possible "guessed" responses. As a result, recall knowledge was, for the purposes of this study, generally considered to be the least representative of "true" understanding (Roediger and Marsh, 2005).

Student understanding was more appropriately measured on the basis of conceptual knowledge. Students were asked to describe what they knew of various features of protein structure and enzymatic action. This was not considered a transfer exercise because there was no original learning task within the realm of the research. Rather, the conceptual component was distributed to the participants prior to and immediately after the unit on biochemistry (see Chapter III for more information). Questions used to assess conceptual understanding usually required the participants to provide both diagrammatic representations and open-ended textual explanations. Responses were categorized as being primarily macroscopic, microscopic, molecular-level, or integrated in nature, as described in Chapter III.

Finally, transfer of knowledge was assessed similarly in that participants were asked to provide both diagrammatic representations and open-ended textual explanations of their drawings. In addition, the transfer component also contained pictures taken directly from a learning context that had previously been taught to the students. Within this component, the participants were asked to explain the provided pictorial representations with open-ended textual responses. An animation of the heat-induced protein denaturation process was used as a tool to identify the novices abilities to transfer knowledge on three scales of transfer – near, intermediate, and deep. Due to the sheer magnitude of data collected and concurrent time restrictions, results were focused primarily on the near and deep scales of transfer.

Classification of Participants' Drawings

Qualitative data were collected from the participants in the form of diagrammatic representations and open-ended textual explanations. Due to the sheer number of participants in this study, the researcher found it beneficial to quantify the overall responses. Thus, an objective rubric was established to code the qualitative data, thereby making it possible to quantify these data and identify fundamental characteristics, themes, and trends from within the data.

Overall Themes

Initially, a qualitative clustering method (Guest and McLellan, 2003) was employed to elucidate general themes and patterns within the data set. Preliminary qualitative analysis of the data reveals six distinct groups of learning style preferences. Samples for this qualitative summary were selected at random from within each group of students through random sampling of each group. Each group was identified through OSIQ scores by the researcher. This is described in the following paragraph.

Preliminary qualitative cluster analysis was composed of four independent variables (red font in Table 5) and five dependent variables (blue font in Table 5) The independent variables were two learning style preference scores (i.e., initially spatial, object, and verbal) and the animation randomly assigned to each student. Spatial, object, verbal scores indicate the degree of preference for that learning style where a higher score means a greater preference for that learning style. On the learning style preferences questionnaire, "similar score" was defined as having a score +/- 0.2 points of each other between spatial, object, and/or verbal scores for one individual. High scores were defined as ≥ 4, intermediate scores were defined as $3 < x < 4$, and low scores were defined as < 3. Each number represents the average response out of 15 questions related to the specific learning style.

The dependent variables (blue, Table 5) were animation preference, characterization of their storyboard and jigsaw puzzle, apparent misconception in the jigsaw explanation, and overall course grade. Students who preferred the narrated version of the animation were assigned a score of 2; those who preferred the non-narrated, step-through with text version were assigned a score of 1. Prior to viewing the animation, students were requested to draw and describe what they believed happened to an egg when it is fried on a hot frying pan. Descriptions were characterized on the following rubric: 0-no response; 1-macroscopic explanation; 2-microscopic explanation; 3-molecular-level explanation; 4-integration of two or more levels in the explanations. Jigsaw puzzles were characterized on the same rubric. For the jigsaw puzzle, students were provided with four snapshots of an egg frying that were out of sequence. Each snapshot was accompanied with a zoom box with an image portraying the protein in different states of conformation. Students ordered the snapshots into what they thought was the correct sequence and then provided explanations as to what they believed to be occurring in that particular snapshot. The “misconception” category represents the presence of misconception(s) in the explanations (0-no apparent misconception; 1-apparent misconception). Macroscopic explanations were not assigned a misconception score. Course grades are categorical and defined as 0=F, 1=D, 2=C, 3=B, and 4=A, where a grade of A or B was considered doing “well” in the course, and a grade of D or F was considered by the researcher as doing poorly in the course.

Preliminary qualitative analysis of the data reveals six distinct groups of learning style preferences. As shown in Table 5, only one student (Student Number 1125) out of 120 had a high spatial learning style preference along with a low object and low verbal preference. This student was randomly assigned to the text with built-in pauses animation but indicated a preference for the continuous narrated version of the animation. Student 1125 consistently wrote explanations that integrated both the macroscopic and molecular-levels that did not have any apparent misconceptions. This student performed poorly in both the lecture and the lab, and ultimately dropped the course.

Table 5. Preliminary qualitative cluster analysis of learning style preference data for 11 students who were randomly selected from their respective learning style groups.

GROUP	Student ID	Spatial Score[a]	Object Score[a]	Verbal Score[a]	Animation Assigned[b]	Animation Preference[c]	Story-board[d]	Jigsaw Puzzle[d]	Miscon-ception[e]	Course Grade[f]
High Spatial (Low Object, Low Verbal)	1125	5.0	2.9	2.1	1	2	4	4	0	0
High Object (Low Spatial, Low Verbal)	803	2.3	4.9	3.2	2	2	1	1	0	1
" "	1126	2.5	4	3.1	2	2	4	4	1	3
High Verbal (Low Spatial, Low Object)	833	2.2	2.4	4.1	1	2	1	1	0	2
High Verbal (Low Spatial, Intermediate Object)	1138	2.1	3.1	4.1	1	0	3	3	1	4
Similar Spatial/Verbal (Effect on Object)	801	3.1	1.9	3.3	2	2	1	3	1	0
" "	847	4.1	2.6	4.3	1	1	3	4	0	3
Similar Spatial/Object (Effect on Verbal)	815	3.0	3.2	3.9	1	1	3	3	1	4
" "	1171	3.8	4.0	2.8	2	2	1	4	1	0
Similar Object/Verbal (Effect on Spatial)	1153	2.6	4.2	4.1	1	0	1	3	1	1
" "	802	2.2	3.7	3.5	2	2	1	3	0	3

[a] Average scores for each of the 15-item OSIQ components, object, spatial, and verbal.
[b] Version of randomly assigned animation; 1=text/built-in pause points; 2=narrated/continuous play.
[c] Animation preference; 1=text/built-in pause points; 2=narrated/continuous play.
[d] Characteristic of response; 1=macroscopic; 2=microscopic; 3=molecular level; 4=integrated.
[e] Presence of at least one apparent misconception; 0=no misconception; 1=misconception.
[f] Final course grade obtained by the participant, where 0=F; 1=D; 2=C; 3=B; and 4=A.

Students 803 and 1126 (see Table 5) indicated a high preference for object visualization with concurrent low preferences for spatial and verbal styles. Both of these students were randomly assigned to the narrated version of the animation, and ultimately both preferred that version to the text version. Student 803 consistently explained observations on the macroscopic level. This student performed poorly in the class overall (final course grade was a D). Student 1126 consistently explained observations on the molecular level with apparent misconceptions. Both students performed above average in the course overall (final course grade was a B).

Students 833 and 1138 indicated a high preference for verbal learning styles with concurrent low preferences for spatial and low to intermediate object-based learning styles. Both of these students were randomly assigned to the text version of the animation. One (833) preferred the narration version, while the other (1138) did not indicate a preference. Student 833 consistently explained observations on the macroscopic level and ultimately performed average in the course (final course grade was a C, Table 5). Student 1138 consistently explained observations on the molecular level with some apparent misconceptions. This student ultimately performed above average in the course (final course grade was an A, Table 5).

Three other groups identified were those who individually had similar spatial/verbal scores, similar spatial/object, and similar object/verbal scores. The preliminary data analysis with this small sub-sample suggests that students within this sample who individually had similar spatial and verbal scores tended to have low object scores (see students 801 and 847). Both of these students preferred the animation to which they were assigned. One (847) consistently explained observations on the molecular level or integrated macroscopic and molecular levels with no apparent misconceptions. This student performed above average in the course (final course grade was a B, Table 5). Student 801 provided a macroscopic description of events that occur when an egg is fried for the storyboard. When this student was provided snapshots of both macroscopic and molecular levels on the jigsaw puzzle, they provided a molecular level explanation with apparent misconceptions. This student performed poorly in the course overall (final course grade was a D, Table 5).

Students with similar spatial and object scores varied on their verbal scores (see students 815 and 1171) in this small, sub-scale preliminary analysis. Both of these students preferred the animation to which they were assigned. One student (815) consistently provided descriptions and explanations that were based on the molecular-level. This student's molecular-level explanations had apparent misconceptions; ultimately the student performed exceptionally well in the course. Another student in this category (1171) provided a storyboard that was based exclusively on a macroscopic description of events that occur during the process of frying an egg. This student was able to integrate their macroscopic observations with a molecular-level explanation when provided with the snapshots from the jigsaw puzzle, although the explanation in this case had apparent misconceptions. Ultimately, this student performed very poorly in the course.

Within this small sub-sample, students with similar object and verbal scores individually tended to vary on their spatial scores. Students 1153 and 802 both had lower scores on the spatial component with respect to the object and verbal. Both of these students initially provided macroscopic descriptions on the storyboard, but ultimately provided molecular-level explanations with no apparent misconceptions. These two students had varying performances in the course overall, with one performing below average and the other above average. Student 1143 had similar object and verbal scores, but had a spatial score higher with respect to the object and verbal. This student provided an integrated description of events that occur while frying an egg on the storyboard. This student provided a molecular level explanation of events depicted on the jigsaw with no apparent misconception. This student performed above average in the course.

Overall, preliminary qualitative analysis of sub-sampled data revealed that students who consistently provide molecular-level or integrated macroscopic and molecular-level explanations tended to perform at an above average level in the course. There appeared to be no relationship between learning style preference and performance in the course. Subsequent data analyses will incorporate prior knowledge, knowledge gain, and source of motivation into these data. These factors will also be analyzed quantitatively with data from the whole.

Research Question 1

> Using the Object-Spatial Imagery Questionnaire (OSIQ), what are the predominant, preferential learning styles of novice students in a fundamental biochemistry course (object or spatial)?

Descriptive Analysis

The learning style preference data were quantitatively analyzed. Initially, students were grouped into spatial and object learning style preference categories according to the method of Chabris (2006). Likert-based numerical responses from intermixed questions were summed for each of the 15-question components. The Likert-based scale ranged from scores of 1 (strongly disagree) to 5 (strongly agree), thus summation scores for each component could range from 15 to 75 points. Summation scores for the whole population were run to assess internal relationships between the learning style preferences. It was determined that the summed spatial and object scores were essentially uncorrelated (Figure 4). Thus, the scores on one scale (i.e., object) account for less than 1/10 of 1% of the variance in scores on the other scale (i.e., spatial). The scales of spatial and object learning style preferences therefore measure distinct attributes of cognitive preference.

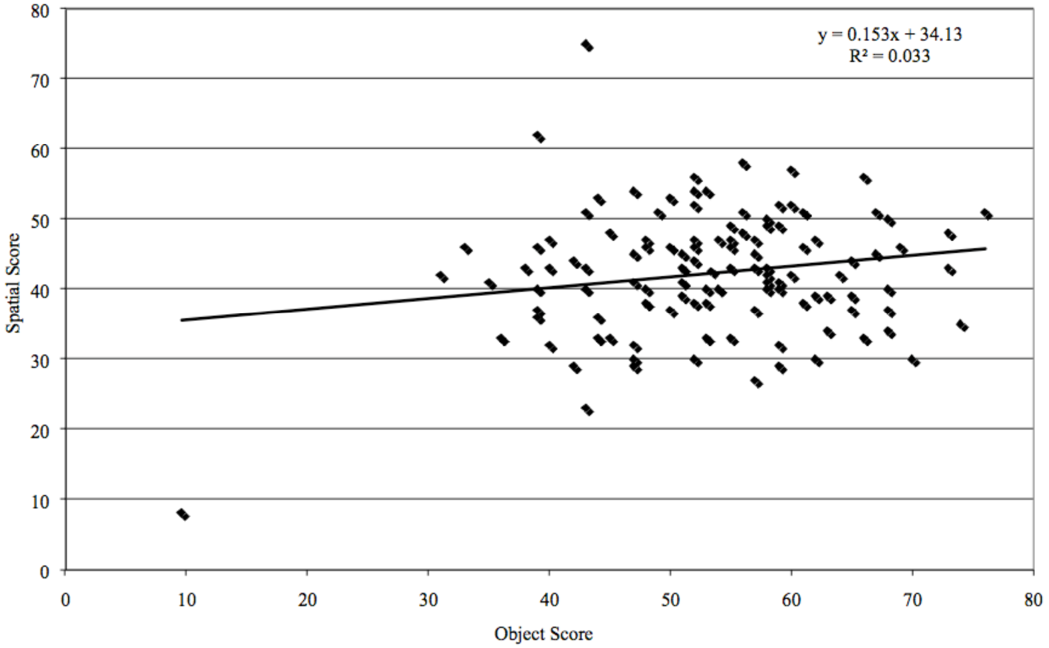


Figure 4. Correlation-based analysis between the object and spatial components from the OSIQ is shown. The lack of correlation between the two categories implies that each component measures distinct preferences of learning.

The residual plot obtained from OSIQ regression analysis reveals that the regression model was appropriate (Figure 5). The residuals are randomly distributed around the x-axis, there are few odd fan or curved trends in the plot, and the average of the residuals appears to be zero, and indication that the linear regression model was suitable. This residual represents the difference between the observed response variable Y and the value predicted by the regression line. Moving average analysis is shown in Figure 6 to reveal the overall trend in total score distributions for each component, object and spatial.

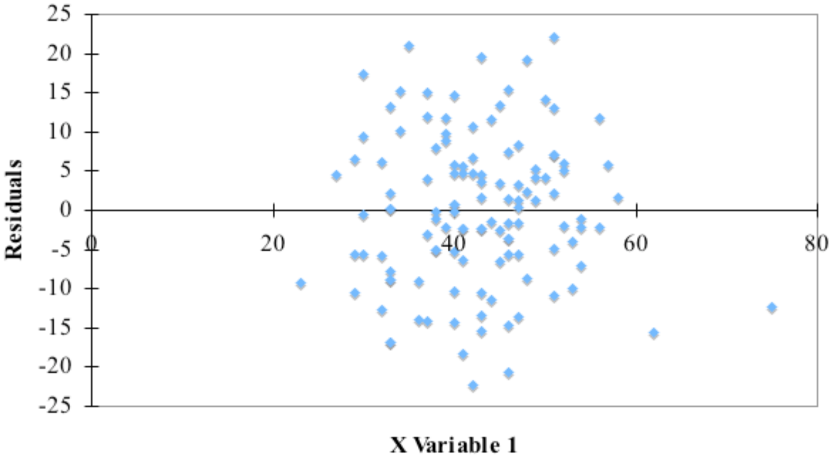


Figure 5. Residual plot for for OSIQ data. The scatter of residuals from the object component about the x-axis, variable 1. The random scatter of residuals about the x-axis is an indication that the linear regression model was appropriate model for regressing the data.

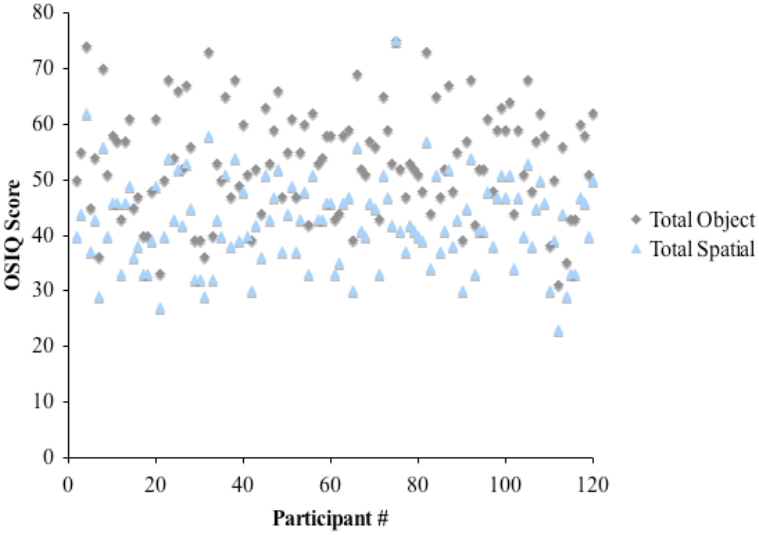


Figure 6. Moving average analysis of object (gray) and spatial (blue) scores. These data were plotted in such a way so as to reveal the general tendency of the population of interest to prefer object-based learning styles.

Initially, students were categorized as having a spatial learning style preference if their summed spatial score was at least five points greater than their object score. Students were considered "unclassified" if the difference between their spatial and object scores were less than five points. Categorizations based on the Chabris method are summarized in Table 6 and described below. It was observed that there was at least one significant mean difference between the groups ($p < 0.0001$). The grand means and standard deviations were as follows: for the spatial, object, and unclassified components were 2.9 +/-0.5, 3.6 +/- 0.6, and 3.0 +/-0.5 respectively (N=120). The linear normal probability and random scatter residual plots indicated that the assumptions of normality, homogeneity of variance, independence and linearity were met (Figures 7 and 8).

Table 6.

Descriptive analysis of OSIQ data – preliminary grouping.

Learning Style Preferences	% Distribution	N for Each 15-Item Components	Mean (StdDev)
Object	60	120	3.6 (0.6)
Spatial	3	120	2.9 (0.5)
Unclassified	37	120	3.0 (0.5)

Gaussian Mixture Modeling (GMM) was used to model data densities within each learning style preference component, i.e., object and spatial. Summative scores for each of the two 15-item components underwent GMM in order to establish data distributions within each component. It was observed that summative object scores were relatively normal and well distributed about a Gaussian curve (Figure 7). A hyperbolic distribution of the object score data is shown in Figure 8 for ease of visualization. Similarly, Figures

9 and 10 reveal the data distribution observed for the 15-item spatial visualization component.

Recategorization of Students Into Groups

Initially, students were categorized as having object visualization preferences (N=60) or spatial visualization preferences (N=3) as previously shown (Table 6). Due to the unequal weight distribution between the learning style categories, the researcher sub-divided the object visualization group into two discrete categories, high object and low object visualization preferences. In this case, the mean was used to re-categorize students as either high or low object preferences. Object scores were henceforth considered “high” if the summed score for the object component was greater than or equal to the mean value of 57.3. Object scores were considered “low” if the summed score for the component was less than the mean. Using this re-categorization method, the following groups were created, as shown in Table 7. Due to the greater weight distribution for each classification, all subsequent statistical analyses in this study used OSIQ groupings based on this strategy.

Table 7.

Descriptive analysis of OSIQ data – refined grouping.

Learning Style Preferences	% Distribution (N=57)	Characterization
High Object	39% (n=22)	Σ Object score ≥ 57.3 (object component mean)
Low Object	37% (n=21)	Σ Object score < 57.3 (object component mean)
Non-object	17% (n=10)	Includes spatial and unclassified groups
No-response	7% (n=4)	_

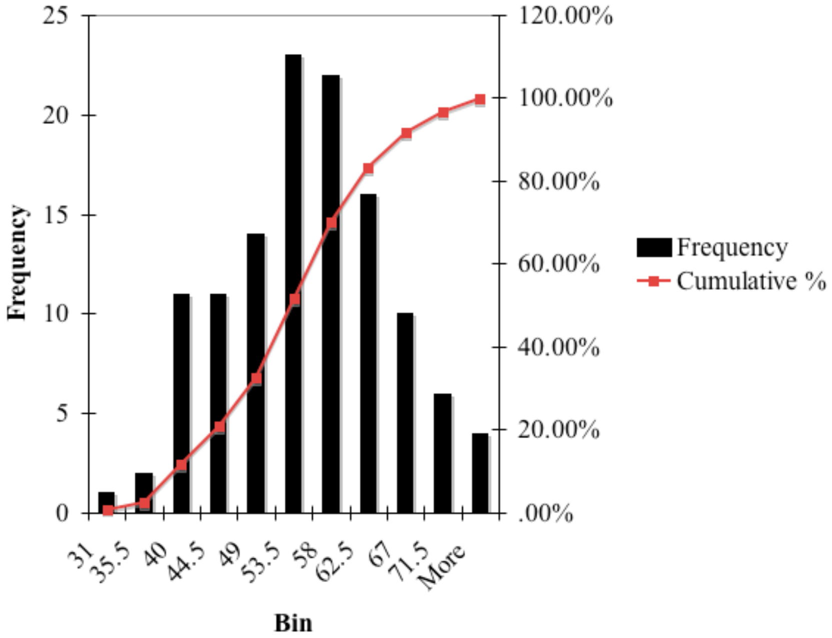


Figure 7. Object component histogram revealing the relative frequency distribution of data per class interval (i.e., bin; x-axis). The mean object component score was 57.3. The plot shows the largest frequency of object summation scores occurring between 53.5 and 58.

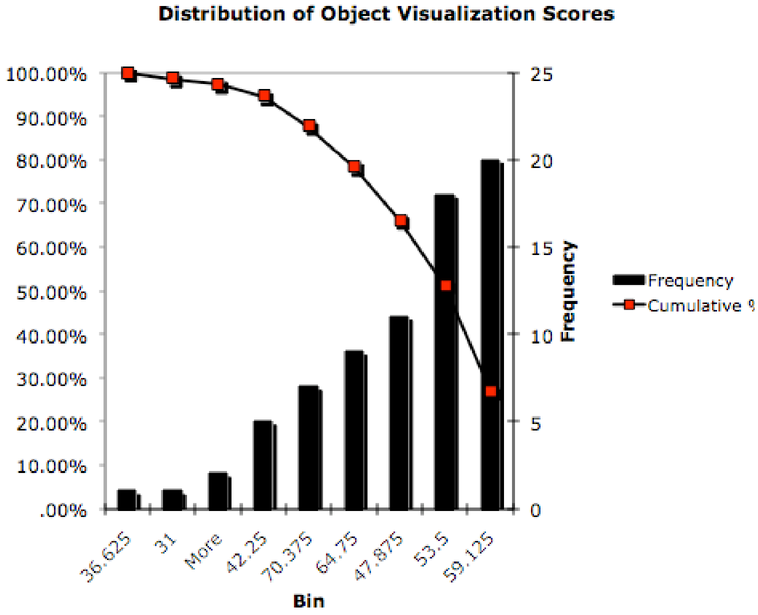


Figure 8. Distribution of object visualization scores. Summation object-component scores from the OSIQ were plotted against frequency of occurrence to show the hyperbolic-like cumulative %.

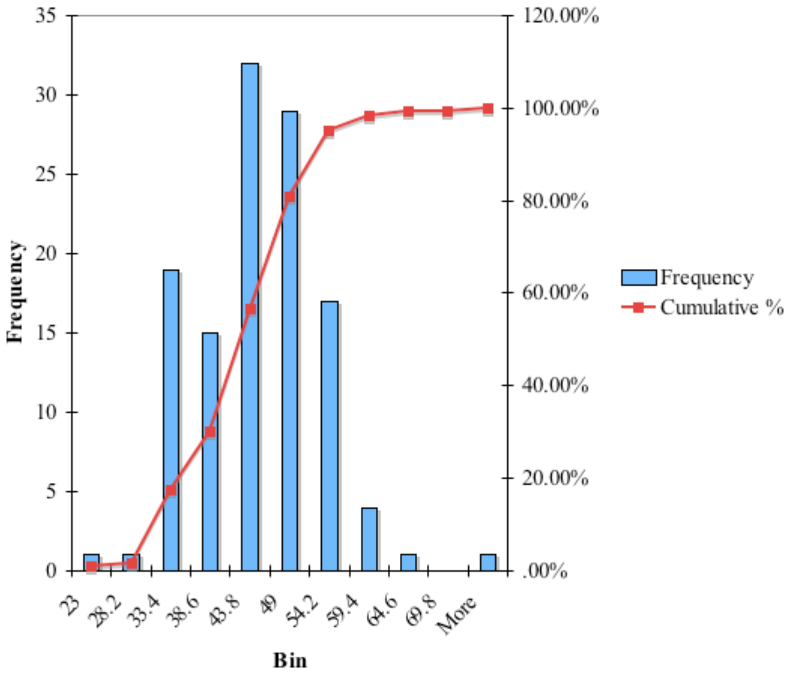


Figure 9. Spatial component histogram revealing the relative frequency distribution of data per class interval (i.e., bin; x-axis). The mean spatial component score was 43.0. The plot shows the largest frequency of object summation scores occurring between 43.8 and 49.

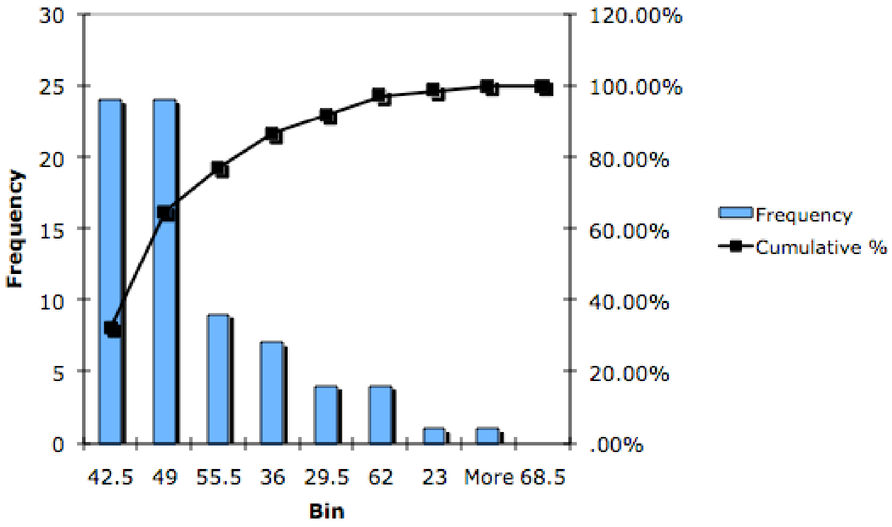


Figure10. Distribution of spatial visualization scores. Summation spatial-component scores from the OSIQ were plotted against frequency of occurrence to show the hyperbolic-like cumulative %.

Research Question 2

> What is the relationship between learning style preference and ability to recall specific features of protein structure?

The Multiple-Choice Component

Educational psychologists often view recognition and recollection of information in a classroom setting as a fundamental means of learning and achievement of high academic performance (Pintrich and DeGroot, 1990, and references therein). Often, educators employ the use of multiple-choice questionnaires (MCQs) as a means of quick and efficient formative and summative assessment. The advantages of such assessment techniques are numerous and well established, and include quick feedback for the student and the instructor, ease and efficiency in grading, and readily available statistical analysis capabilities. Using MCQ examination techniques, instructors can quickly and easily gauge which concepts were received well by the learners as well as concepts that were apparently poorly understood by the classroom population as a whole. In this study, the researcher sought to understand the relationship, if any, between object and spatial-based learning style preferences and ability to recall information through MCQ assessment techniques. Participants in the study completed six multiple-choice questions that pertained exclusively to various facets of protein structure (Table 8).

Table 8.

Recall questions used in this study.

Recall Question	Possible MCQ Responses
What functional feature makes one amino acid unique from all other amino acids? Please circle the ONE answer you feel is the most accurate.	a. The N-terminal b. The C-terminal c. The R-group d. The peptide backbone
Due to hydrogen bonds that form between the backbone amino hydrogen of one amino acid with the carbonyl oxygen of another, the protein or polypeptide obtains the three-dimensional form of an alpha-helix or a beta-pleated sheet. This best describes a protein's:	a. Primary structure b. Secondary structure c. Tertiary structure d. Quaternary structure
In some cases, such as with hemoglobin, multiple subunits (or polypeptide chains) interact together to form:	a. The primary structure b. The secondary structure c. The tertiary structure d. The quaternary structure
The sequence of the amino acids in the protein is determined by the original DNA sequence of the gene for the protein. This protein sequence describes the protein's:	a. Primary structure b. Secondary structure c. Tertiary structure d. Quaternary structure
What initially happens to the structure of a protein when you heat it?	a. The protein breaks into fragments b. Nothing – the structure is not affected by heat c. The protein unfolds d. The protein becomes part of the vapor phase

The recall questions were distributed to all participants in pre-/post fashion as described in Chapter III, Methodology. This particular kind of assessment strategy is very common in pedagogical research as it allows one to quickly and easily detect learning outcomes as a result of a particular teaching strategy or intervention with minimal statistical effort or intrusion upon the classroom environment. It was determined through paired sample for means t-test analysis that pre-/post-test scores were significantly different (Table 9).

Table 9.

T-test: Paired Two Sample for Means.

	Recall (pre-test)	*Recall (post-test)*
Mean	2.07	3.19
Variance	1.82	1.71
Observations	41	41
Pearson Correlation	0.37	
Hypothesized Mean Difference	0	
df	40	
t Stat	-4.83	
P(T<=t) one-tail	1.00E-05	
t Critical one-tail	1.68	
P(T<=t) two-tail	2.01E-05	
t Critical two-tail	2.02	

The paired t-test statistic results represent the difference between the pre- and post-test values as pertaining to the multiple-choice-based recall component. The values of interest here are not individual means of pre- and post-test scores but the difference between the two values as a whole. It is therefore useful to statistically describe the differences between pre-/post-test scores, in other words, gain in recall knowledge for this set of questions over the course of one academic semester. Thus, summary statistics with 95% confidence interval options were calculated and shown in Table 10.

Table 10.

Descriptive analysis of recall gain.

Gain in Recall Knowledge Scores[a]	
Mean	1.12
Standard Error	0.23
Standard Deviation	1.49
Sample Variance	2.21
Kurtosis	0.58
Skewness	1.03
Range	6
Minimum	-1
Maximum	5
Count	41
Confidence Level (95.0%)	0.47

[a] Recall knowledge was assessed from pre-/post- multiple choice questions from the prior knowledge assessment (Table 8).

There was an average gain of +1.12 points on the recall component between pre- and post-test components. Thus, in order to claim that this gain is significant, it must first be established that a gain of 1.12 points overall is sufficiently different from zero. Note here that the mean divided by the standard error is equal to the absolute value of the "t-stat" value in Table 10. Thus, it can be stated with confidence that the mean gain in recall knowledge (M=1.12, SD=0.47, N=41) was significantly greater than zero, t(-4.83, two-tail p=2.0E-05, providing evidence that participating students gained overall on recall knowledge throughout the course of one semester. A 95% confidence interval about the mean recall gain score was calculated (0.65), indicating that the probability of observing a gain outside of the range of 0.43 and 1.81 is less than 5%.

Regression of OSIQ Data Against Recall Gain Scores

To answer the research question posed here, the three groups of OSIQ-based categorizations, high-object, low-object, and non-object, were regressed against overall gain in recall knowledge as assessed by pre-/post-recall test differences. It was observed that there was no significant relationship between learning style preference and recall gain (Table 11). Predicted Y-values (i.e., gain in recall knowledge) for each of the three categories of learning style preferences, non-object, low-object, and high-object, (0, 1, and 2, respectively) are shown in Figure 11. It is clear from the output that there was no apparent relationship between learning style group categorizations and gain in recall knowledge, as defined specifically for the purposes of this study. Thus, it was not possible to statistically predict recall gain relative to preferred learning style. Implications for lack of relationship between these variables are described further in Chapter V.

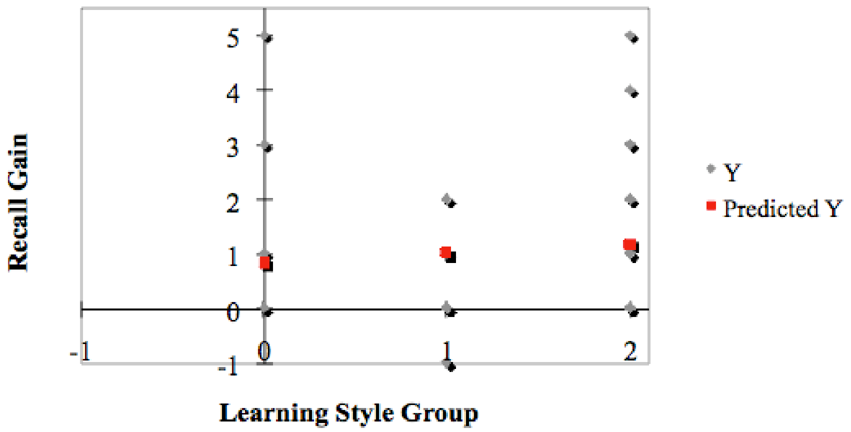


Figure 11. Predicted gain in recall knowledge ("Y") as a function of OSIQ –based learning style preference, where 0 = non-object, 1 = low-object, and 2 = high-object learning style preferences. The regression output indicates that the gain in recall knowledge (i.e., as assessed by five multiple choice questions between pre-/post-knowledge assessments) could not be predicted statistically based solely on learning style group categorization.

Table 11.

Regression of OSIQ data against recall gain scores.

Regression Statistics		*Group*		*Mean (Std.Dev)*		
Multiple R	0.084	High-Object		50.5 (3.9)		
R Square	0.007	Low-Object		61.7 (4.6)		
Adjusted R Square	-0.020	Non-Object		42.2 (5.5)		
Standard Error	1.50					
Observations	39					
ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*	
Regression	1	0.60	0.60	0.26	0.61	
Residual	37	83.30	2.25			
Total	38	83.90				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.84	0.47	1.79	0.08	-0.11	1.79
X (OSIQ)	0.17	0.33	0.51	0.61	-0.49	0.83

Research Question 3

> What features (statements, meanings, themes, or general descriptions) are found in a selection of biochemistry novice descriptions and self-explanations of relationships between molecular phenomena and macroscopic observations (i.e., frying an egg)?

This component was designed to be qualitative in nature and was designed primarily as a means for the development of a highly objective coding scheme. The data described herein were derived from student-generated descriptions, representations, and self-explanations of various dynamic processes that affect protein structure on the molecular level. The primary objective here was to sort through the data in a highly objective fashion so as to establish a basis for quantifying the qualitative data set. The nature of qualitative data analysis is such that the researcher sorts through the data with the intention of finding common themes that persist throughout the data set, and subsequent interpretations of themes. As a result of the fundamentally qualitative aspect of this technique, it is quite common for researchers to code and re-code the data set until a suitable, persistent theme has been found to which qualitative interpretive analysis can be performed. Throughout the course of data analysis, the researcher qualitatively analyzed the transfer-component using two different coding schemes, each of which revealed fundamentally similar themes, as will be established in the following section.

Initial Data Coding Scheme

Initially, data from this study were coded using a five-point rubric that was designed to simultaneously assess responses for the presence of apparent misconceptions as well as researcher’s interpretation for the level or amount of chemical detail present in the response (Table 12). Responses were split into either diagrammatic (i.e., pictorial) or written (i.e., textual) components for coding purposes. The researcher was interested in assessing student's "understanding" of a particular concept via the joint misconception/chemical-detail based rubric.

Near Transfer Student-Generated Diagrammatic Depiction (Unfolded Protein)

When students were asked to draw a representation of an unfolded protein, it was observed that out of N=56 responses, 44 were categorized by the researcher as a level "2" response. In other words, nearly 4/5 of the total responses had no apparent misconception contained within the response, however there was very little elaboration or chemical detail. It should be noted that chemical detail would include the description (either diagrammatic or written) of specific atomic or molecular detail (i.e., bonding, other types of intra- or intermolecular interactions). The remaining responses were classified as either "4" (n=5), "3" (n=5), "1" (n=1), and "0" (n=1). It was ascertained that seven responses had an apparent misconception (primarily based on the folding of the protein, purported fragmentation of the protein, or other). A total of 11 responses, out of the 56, had some attempt at revealing chemical detail.

Near Transfer Student-Generated Textual Description (Unfolded Protein)

When students were asked to describe their drawing of an unfolded protein (Appendix F), it was observed that out of N=56 responses, 21 were categorized by the researcher as a level "2" response. In other words, just over one-third of the total responses had no apparent misconception contained within the response, however there was very little elaboration or chemical detail. Note that this is much less than the corresponding diagrammatic responses. As previously indicated, chemical detail would include the description (either diagrammatic or written) of specific atomic or molecular detail (i.e., bonding, other types of intra- or intermolecular interactions). The remaining responses were classified as either “4” (n=9), “3” (n=6), “1” (n=11), “0” (n=7). There were a total of 17 responses that held an apparent misconception (primarily based on the folding of the protein, purported fragmentation of the protein, or other). A total of 15 responses, out of the 56, had some attempt at revealing chemical detail.

Table 12.

Initial Five-Point coding rubric.

Code	Description
0	Response was left blank or "I don't know".
1	Misconceptions are apparent and very little elaboration or chemical detail.
2	No apparent misconceptions but very little elaboration or chemical detail.
3	Apparent misconceptions but these students attempted to explain/describe with some elaboration or chemical detail.
4	No apparent misconceptions combined with moderate elaboration/chemical detail.

Deep Transfer Student-Generated, Diagrammatic (Step One of Heat Addition)

As part of the transfer component, participants were asked to predict, diagram, and explain what would happen to the structure of egg-white protein, ovalbumin, upon addition of heat (Appendix F). The students were provided with a snapshot from the high-resolution x-ray structure. Through analysis of this component, it was observed that out of N=56 responses, only one response was categorized by the researcher as a level

“2” response. The remaining responses were classified as either “4” (n=13), molecular level, “3” (n=15), “1” (n=5), “0” (n=23). It was observed that 19 responses had an apparent misconception (primarily based on the folding of the protein, purported fragmentation of the protein, or other). A total of 33 responses, out of the 56, had some attempt at revealing chemical detail.

Deep transfer Student-Generated, Written (Step one of heat addition)

When students were asked to characterize in both pictures and words what would happen to the two-dimensional representation of the high-resolution snapshot of ovalbumin (Appendix F), It was observed that out of N=56 responses, only one response was categorized by the researcher as a level “2”, i.e., microscopic, response. The remaining responses were classified as either “4” (n=18), “3” (n=18), “1” (n=2), and “0” (n=21). In this component, 20 responses had an apparent misconception (primarily based on the folding of the protein, purported fragmentation of the protein, or other). A total of 35 responses, out of the 56, had some attempt at revealing chemical detail.

Deep Transfer Student-Generated, Diagrammatic (Step Two of Heat Addition)

Of the diagrammatic responses provided for the deep transfer component, out of N=56 responses, only one response was categorized by the researcher as a level “2” response. The remaining responses were classified as either “4” (n=2), “3” (n=24), “1” (n=4), and “0” (n=28). In this case, 28 responses had an apparent misconception (primarily based on the folding of the protein, purported fragmentation of the protein, or other); 26 responses, out of the 56, had some attempt at revealing chemical detail.

Deep Transfer Student-Generated, Written (Step Two of Heat Addition)

When participants were asked to textually describe heat-induced denaturation, it was ascertained that out of N=56 responses, zero responses were categorized by the researcher as a level “2” response. The remaining responses were classified as either “4” (n=2), “3” (n=23), “1” (n=9), and “0” (n=24). Out of the 56 total responses, 33 responses had an apparent misconception (primarily based on the folding of the protein, purported fragmentation of the protein, or other). A total of 25 responses, out of the 56, had some attempt at revealing chemical detail.

Refined Data Coding Scheme

The same near- and deep transfer scales described above were qualitatively assessed using a refined five-point rubric whose nature, by design, was highly objective (Table 13). Responses were categorized according to discrete levels of increasing biological and chemical detail as described in Table 13. Recall that the near-transfer component consisted of two sub-components; the first component consisted of two blank squares, each associated with blank lines (Appendix F). The second component consisted of two snapshots from the animation of heat-induced protein denaturation that was shown to the participants one week prior to completion of the transfer component (Figure 13). Initially, participants were asked to draw a representation of an unfolded protein as well as a written textual response that would either describe their drawing specifically or express ideas on their perceived notions of an unfolded protein (Part A). They then completed the second part of the near transfer component (Part B).

Table 13.

Revised Five-Point Rubric for thematic analysis of qualitative transfer-component responses.

Score	Code	Description
0	Blank or "I don't know"	-
1	Macroscopic	Phenomenon described or shown is observable with the naked eye
2	Microscopic	Phenomenon described or shown is observable microscopically (no chemical detail)
3	Molecular-Level	Phenomenon described or shown consists of atomic-level details, and/or a reference to inter/intra-atomic forces
4	Integration	Response refers to at least two levels described above, excluding "0".

It was observed that misconceptions revealed in the near-transfer responses could be categorized into five distinct types. The apparent misconceptions included those pertaining to ideas of heat-induced protein fragmentation; responses that were structural in nature (i.e., protein renaturation or sequential loss of structure beginning with quaternary structure); terminology-based misconceptions; function-based misconceptions (i.e., indication of what the molecules can or cannot do); responses that were not clear to the researcher; and finally responses that were left blank or where the respondent indicated that they did not know. Responses where there was no indication of a misconception are shown (Table 14).

Near Transfer Student-Generated Diagrammatic Depiction (Unfolded Protein)

In this section of the transfer component, students drew their own representation of what they would consider an unfolded protein. It was observed that out of N=56 responses, 50 were categorized by the researcher as a level “2” response. In other words, nearly 90% of the total responses were microscopic depictions of heat-induced protein unfolding (see Figure 14, as an example). Responses categorized as microscopic would include characteristics pertaining to shape; no atomic or molecular-level details are provided. Furthermore, only four responses were categorized as level “3”, molecular level. The level of chemical detail provided would include the description (either diagrammatic or written) of specific atomic or molecular detail (i.e., bonding, other types of intra- or intermolecular interactions). The remaining responses were classified as either “4” (n=0), “1” (n=0), and “0” (n=3). For responses categorized as level “2”, seven apparent misconceptions were present, only two of which related to perceived notions of heat-induced fragmentation. For responses categorized as level “3”, two apparent misconceptions were present (i.e., 50% of level “3” responses), both of which related to perceived notions of heat-induced fragmentation. Examples of responses where there was considered to be a misconception are shown at the end of this chapter (Figures 14-18).

Table 14.

Responses that did not contain an apparent misconception in the near transfer component - written descriptions of student-generated diagrams.

Responses where the researcher assessed as misconceptions not present:
"It's completely unfolded."
"The protein is denatured and completely exposed, with limited bonds"
"This is an unfolded protein. The pleated sheet shape is coming undone and the helix is losing its shape."
"Unfolded protein formed from a sequence of amino acids."
"The protein starts as folded up then it is denatured and unwound."
"Since the protein has unfolded, it is no longer oriented in the structure of a normal protein."
"Amino acids are joined together by peptide bonds."
"Nothing has order, the protein is falling apart."
"Not folded or ordered."
"This is an unfolded protein with the line of linked amino acids it is created with."
"Here, through heat the proteins have broken its bonds and unfolded."
"The uncoiled protein in the box represents the denaturation of proteins by denaturing agents. When an agent affects the protein the amino acids unfold and will begin to disconnect to form new bonds."

Near Transfer Student-Generated Written Description (Unfolded Protein)

Students were asked to describe in words their diagrammatic representation of an unfolded protein, It was observed that out of N=56 responses, only 18 were categorized by the researcher as a level "2" response. In other words, only one-third of the total responses were microscopic depictions of heat-induced protein unfolding, much less than responses categorized as level “2” in the diagrammatic component described above. A total of 24 responses (43%) were categorized as level “3”, molecular level, a dramatic increase compared to responses categorized as level “3” in the diagrammatic component described above. The remaining responses were classified as either “4” (n=1), “1” (n=0), and “0” (n=13). For responses categorized as level “2”, three apparent misconceptions were present, two of which related to perceived notions of heat-induced fragmentation. For responses categorized as level “3”, 18 apparent misconceptions were present (i.e., 50% of level “3” responses), four of which related to perceived notions of heat-induced fragmentation. A list of examples where the researcher coded the response as having an apparent misconception are shown (Table 15).

Table 15.

Misconceptions from the near transfer component - fragmentation

Responses that indicated fragmentation:
“Pieces of the protein broken apart.”
“The peptide bonds are broken and the amino acid is no longer bonded together.”
“The polypeptide chain has been broken.”

Table 16.

Misconceptions from the near transfer component -structural

Responses that were structural in nature:
“The protein is unfolded with no bonds holding it together.”
“The protein has no structure and is just a squiggly line.”
“All the binding sites break and the protein unfolds it turns into a large straight line.”
“This is an unfolded protein. It is essentially just a polypeptide chain. It is caused by extreme heat. The quaternary structure vibrates from the heat and breaks apart.”
“The protein is held together by H- and peptide bonds.”
“Protein unfolded into 3˚ [tertiary structure].”

Table 17.

Misconceptions from the near transfer component –not clear

“Responses that were not clear in nature:
“The protein is usually folded into tight bunch.”
“When a protein is unfolded it's nonfunctional. All of the bonds have broken. This causes the protein unfold because that’s what holds it together.”
“Proteins are free floating.”
“In an unfolded protein, there are no (or very few) intermolecular forces holding the protein together. It is simply a strand of amino acids that are not reacting with each other.”
“The line represents the proteins unfolded.”
“Proteins are separated from each other.”
“A protein all the molecules are swimming around.”
“Proteins are made up of amino acids [anticodons] which bind to specific codons making the protein. A pairs with U and G pairs with C. AUG is the universal start codon.”

Near Transfer – Provision of Snapshots from Animation

After completing Part One of the near transfer component (where students provided their own diagrammatic representations of unfolded and aggregated proteins, respectively), students were provided with two snapshots from the animation that they viewed during the week previous (Appendix E). In this part, students were asked to explain what each picture represented, including the arrow separating the two pictures. As reported in this chapter, three quarters of the total responses described the pictures on the molecular level. Just 21% of the responses were based on the microscopic level. Only 4% of the respondents said they did not know what the pictures represented, and a mere 16% of respondents correctly understood what the arrow between the pictures represented (i.e., the addition of heat). Of the 30 responses that contained an apparent misconception, six were misconceptions pertaining to fragmentation. The primary misconception was that the pictures represented protein synthesis and subsequent folding of the protein into quaternary structure (24 out of the 30 had this misconception) (Tables 18 and 19).

Table 18.

Responses that contained an apparent misconception in the near transfer component - written descriptions of researcher-provided diagrams (Part B).

Responses where the misconception was fragmentation in nature.“
“Stuck together protein fragments.”
“The separated parts aggregate with H-bonds.” [Note, “parts” appear to refer to fragmentation.”

Table 19.

Responses that contained an apparent misconception in the near transfer component - written descriptions of researcher-provided diagrams (Part B).

Responses where the misconception was structural in nature
"This protein is held together by bonds and forms shapes such as an alpha helix and beta pleat."
"The protein when formed will use various secondary and tertiary structures to hold its shape."
"This is a beta double helix of amino acids together, arranged specifically to proper function. The drawing on the left is an alpha pleated sheet of a specific arrangement of amino acids."
"As they come into contact, each protein begins to bond to one another forming the quaternary structure, or in some cases tertiary."
"In an aggregated protein, most intermolecular forces are lost, but some are still present. They are in the process of breaking."
"Proteins have formed bonds moved from 1° to 2° and 3° structures."
"The beta structures are aggregated because they were in order."
"Proteins are in their condensed form where bonds have yet to be broken. The majority are H^+."
"This is an aggregated structure. Still bound together in its quaternary form."
"These proteins have primary, secondary, and tertiary structures."
"This is a coiled protein gathered together."
"This is a functional protein because all of the bonds are intact."

Deep Transfer Student-Generated, Diagrammatic

When students completed the high-resolution component, It was observed that out of N=56 responses, only two were categorized by the researcher as a level "2" response. In other words, only 3.5% of the total responses were microscopic depictions of heat-induced protein unfolding. A total of 31 responses (55%) were categorized as level “3”, molecular level, a dramatic increase compared to responses categorized as level “3” in the diagrammatic component described above. The remaining responses were classified as either “4” (n=0), “1” (n=0), and “0” (n=23). For responses categorized as level “2”, one apparent misconception were present, that of which related to perceived notions of heat-induced fragmentation. For responses categorized as level “3”, 24 apparent misconceptions were present (i.e., 77% of level “3” responses), 19 of which related to perceived notions of heat-induced fragmentation. Please see Figures 14-18 at the end of this chapter for examples of the diagrammatic component described here.

Deep Transfer Student-Generated, Written

When students were asked to describe what would happen to a protein as heat is applied, It was observed that out of N=56 responses, four were categorized by the researcher as a level “2” response. In other words, about 7% of the total responses were microscopic depictions of heat-induced protein unfolding. A total of 30 responses (approximately 55%) were categorized as level “3”, molecular level, a dramatic increase compared to responses categorized as level “3” in the diagrammatic component described above. The remaining responses were classified as either “4” (n=1), “1” (n=0), and “0” (n=20). For responses categorized as level “2”, one apparent misconception were present, that of which related to perceived notions of heat-induced fragmentation. For responses categorized as level “3”, 22 apparent misconceptions were present (i.e., 73% of level “3” responses), 19 of which related to perceived notions of heat-induced fragmentation (Table 20). Examples of responses that represented misconceptions that were structural in nature are shown in Table 21. For the purposes of comparison, responses where there were no apparent misconceptions are shown in Table 22.

Table 20.

Responses that contained an apparent misconception in the deep transfer component - written descriptions of provided diagrams.

Responses where the misconception was fragmentation in nature
"[Heat] breaks covalent bonds."
"The proteins would come apart and bonds break."
"When even more heat is added the proteins will break apart further."
"More heat destroys a protein completely."
"The other bonds begin to break down."
"Breaks apart the amino acids."
"Further breaking and unloosening of bonds so that structure is no longer whole."
"More heat causes the bonds to break apart."
"The molecules themselves break apart."
"They break off even more with more heat."

Table 21.

Responses that contained an apparent misconception in the deep transfer component - written descriptions of provided diagrams.

Responses where the misconception was structural in nature
"As the heat continues, the proteins themselves unfold and spread out as bonds are no longer holding them together."
"The protein will continue to flatten out and lose additional structure."
"Protein is denatured - returns to 1° structure."
"Protonated [student depicted protonated amino acids]."

Table 22.

Responses that did not contain an apparent misconception in the deep transfer component - written descriptions of student-generated diagrams.

Responses where the researcher assessed as misconceptions not present:
"H-bonds would break due to heat."
"[Heat] breaks H-bond."
"As heat is applied and intensifies, the bonds between the proteins begin to break down."
"H bonds break apart, protein begins to unfold."
"As heat is applied, the bonds will weaken as molecules get excited."
"The heat initially breaks apart the hydrogen bonding."

Pictorial Representations Throughout the Transfer Study

As indicated earlier, the diagrammatic representations provided by the participants of this study were highly revealing in terms of their level of chemical detail and the misconceptions brought forth. The following images, (Figures 12-16), were strategically selected from the population of interest to portray the evolving mental models of the novice biochemistry students. Below, "Picture A" and "Picture B" represent participant diagrammatic representations of unfolded and aggregated proteins, respectively as portrayed in the Near Transfer component. The final two images represent student diagrammatic representations of heat addition to a two-dimensional representation of egg white protein, ovalbumin as requested in the deep transfer component.

The "wavy" or circular line representations in Picture A and Picture B of Student # 1106 (Figure 12) were coded as being microscopic in nature (i.e., a rubric score of 2 was assigned to these images). This microscopic nature of diagrammatic representation was the predominant theme among all of the near-transfer data analyzed. Given the visual cue as part of the deep transfer component, the vast majority of the responses were molecular-level in nature, and were considered high in chemical detail. Recall that when participants were asked to characterize, through multiple choice, what they believed would happen to a protein when heat is added in the recall component (RQ 2), just over one out of five (N=47) students indicated something other than denaturation (out of four possible options including fragmentation, vaporization, and, other). During the deep transfer component, it became clear that many students held a deeply - ingrained misconception regarding the covalent bond fragmentation of a protein upon exposure to heat.

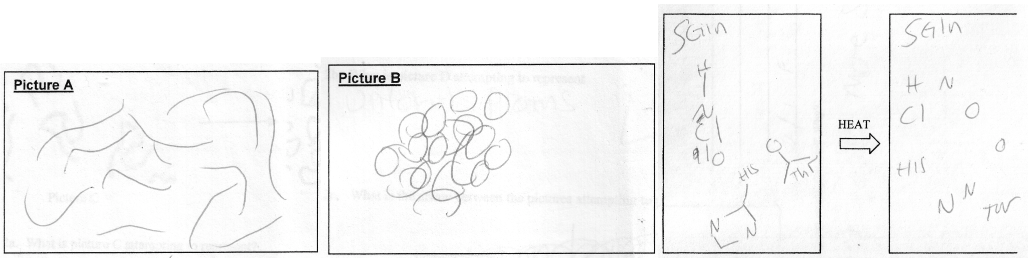


Figure 12. Student # 1106 representations of an unfolded protein, an aggregated protein from the near transfer component ("Picture A" and "Picture B", respectively. The latter two images were provided by this student in the deep transfer component. Misconceived ideas pertaining to heat-induced protein fragmentation are obvious.

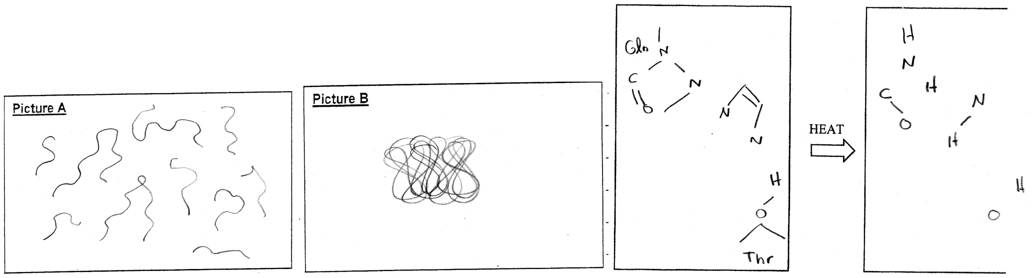


Figure 13. Student # 1109 representations of an unfolded protein, an aggregated protein from the near transfer component (“Picture A” and “Picture B”, respectively. The latter two images were provided by this student in the deep transfer component. Misconceived ideas pertaining to heat-induced protein fragmentation are obvious.

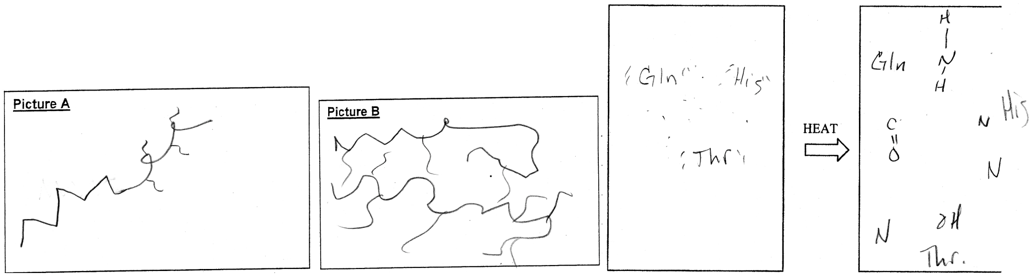


Figure 14. Student # 1117 representations of an unfolded protein, an aggregated protein from the near transfer component (“Picture A” and “Picture B”, respectively. The latter two images were provided by this student in the deep transfer component. Misconceived ideas pertaining to heat-induced protein fragmentation are obvious.

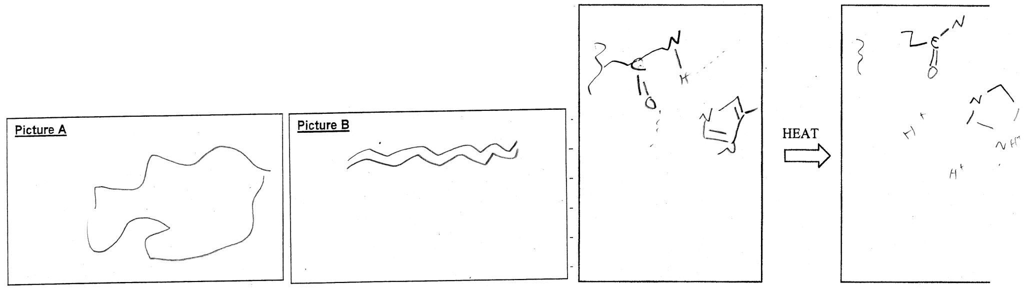


Figure 15. Student # 1136 representations of an unfolded protein, an aggregated protein from the near transfer component (“Picture A” and “Picture B”, respectively. The latter two images were provided by this student in the deep transfer component. Misconceived ideas pertaining to heat-induced protein fragmentation are obvious.

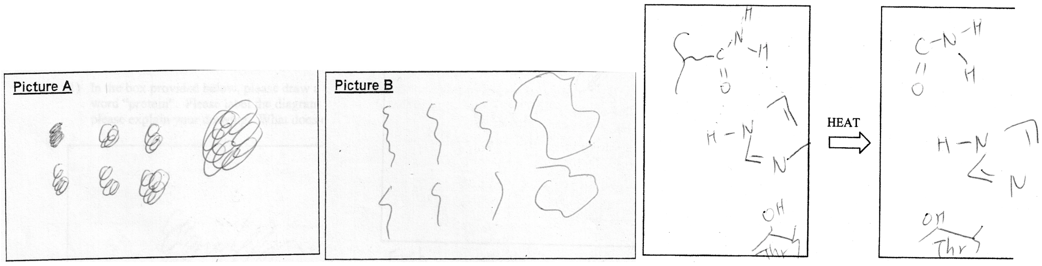


Figure 16. Student # 1168 representations of an unfolded protein, an aggregated protein from the near transfer component (“Picture A” and “Picture B”, respectively. The latter two images were provided by this student in the deep transfer component. Misconceived ideas pertaining to heat-induced protein fragmentation are obvious.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Overview

Multiple instruments were designed specifically for use in the ‘Fundamentals of Biochemistry’ population, and these were distributed in such a way so as to provide the researcher with a “window” through which the evolving mental models of the participants could be observed (Figure 17). Through the carefully crafted design of the research, the results of the research included the groundbreaking discovery of a very powerful method that allowed the researcher to identify serious misconceptions held by the novice biochemistry students. These misconceptions were not readily apparent at the outset of the study. However, when students were questioned at a deeper, more refined level (in terms of chemical detail), deeply held misconceptions were revealed to the researcher that implied an overall lack of understanding of heat-induced protein denaturation.

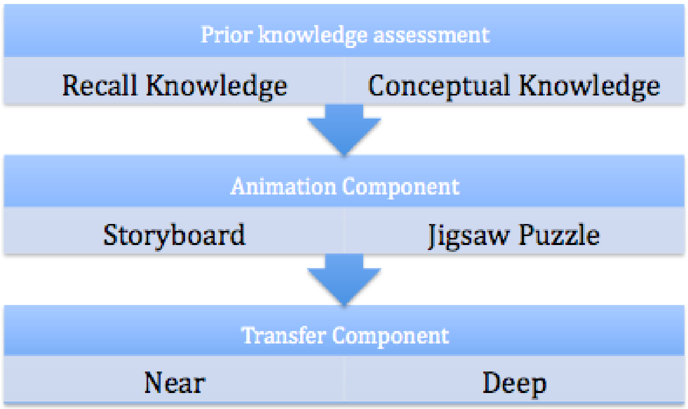


Figure 17. General theme of this dissertation research. Initially, prior to the unit on biochemistry in this GOB course, the participants were given a prior-knowledge assessment consisting of recall (i.e., multiple-choice) and conceptual knowledge components. During the biochemistry unit, participants completed an animation component consisting of each a storyboard and jigsaw puzzle component. Finally, transfer knowledge was assessed on both the near and deep transfer scales one week after the animation component.

Throughout the course of this study, it was demonstrated that a novice's conceptual understanding of dynamic protein structure and function relationships were expressed through their self-explanations. As alluded to in Chapter III, the type of data a chemist collects in an experiment is influenced by his or her choice of instrumentation. For qualitative research studies, a theoretical framework plays a role analogous to the role of the instrument. A theoretical framework is a system of ideas, aims, goals, theories and assumptions about knowledge, how research should be carried out and how research should be reported that influences what kind of experiments can be carried out and the type of data that result from these experiments (Creswell, 1998). Within a theoretical framework is the declaration of an epistemology, a description of how what is known is known. This describes in essence the nature of knowledge and how knowledge is gained. In this study, knowledge of student learning was gained primarily through qualitative means, with the assumption that all knowledge gained by the participants was constructed into their mental framework consisting of pre-conceived notions and misconceptions. This premise is based on the Piagetian notion that the learner assimilates and accommodates new information (Piaget, 1952). In other words, no objective truth is to be gained by the learner; only truths that are meaningful for the learner within the context in which they are learning the material will be gained.

The constructivist-based epistemology described here embodies many theories, and in this case, the epistemology was the embodiment of interpretivism (Bodner, 2008 and Creswell, 1998). Within this perspective, the researcher strives to understand social reality through observation and interpretation (Creswell, 1998). This is opposed to rigidly explaining natural reality, as is often the case in physical science research. To easily assess the open-ended responses, qualitative data were re-coded to a quantitative rubric, and an objective coding scheme for the purposes of thematic analysis was developed and used as the primary means of knowledge gain by the researcher. A potential ramification of this type of qualitative design then is that the researcher is working with a pre-defined population, thus research-based interpretations and implications are limited to the group that is the researcher's focus.

A central theme of the study was the characterization of the population of interest according to learning style preferences. It was anticipated at the outset of the study that these descriptions and group categorizations would ultimately lead to an understanding in how these learning style preferences affect various factors of learning. It was not known if there would be any relationship found at all, and the null hypothesis indicated that there would be no relationship. A primary source of data came from the thematic analysis of student-derived self-explanations (i.e., their own understanding of observed phenomena). Therefore self-explanations generated by the novice participants after varying cues were provided to them gave the researcher a means through which students' understanding of complex dynamic biochemical phenomena could be recognized and understood. These student-generated self-explanations of both the textual and diagrammatic variety provided a means to which evolving mental models of participants could be understood through objective coding of their responses.

In order to elicit a transfer response, students were provided with a cognitive anchor, a depiction of a molecular-level dynamic process with observable macroscopic properties that were easy for the participants to relate to, regardless of chemistry-content background or understanding. The specific cognitive anchor used was that of a frying egg. In the animation shown, students were provided with a dual-depiction of an egg as it is cooked on a skillet, with a corresponding representation of microscopic-level events. The depiction was considered microscopic in the sense that atomic-level details were not provided in the animation, only shape-based characteristics were provided. In other words, the proteins within the egg white were represented as "lines" that were shown to unfold and aggregate as a function of heat. Intermolecular hydrogen bonding was indicated in the animation. In the following sections, implications of results will be further described and characterized. Finally, recommendations for teaching are presented.

Research Question 1

> Using the Object-Spatial Imagery Questionnaire (OSIQ), what are the predominant, preferential learning styles of novice students in a fundamental biochemistry course (object or spatial)?

Learning style preferences were classified based upon the sum of one component compared to another. A student was initially classified as having an object or spatial learning style if the score for one component was five or more points greater than the summative score for the opposing component. As expected, the object and spatial processing preferences were essentially uncorrelated (Chabris, 2006). As described in Chapter IV, the group of interest for this study, as a whole, had a strong preference for object visualization. Object and spatial visualization components were essentially uncorrelated, implying that theses learning preferences did indeed measure distinct dimensions of learning style.

The strong tendency displayed by this population toward objective-based visualization preferences reveals a strong implication for teaching. Recall that a preference for object visualization implies that the learner(s) prefer information presented to them in discrete, static, and highly detailed images or snapshots. Thus it can be assumed that for this specific population, 'Fundamentals of Biochemistry', the vast majority of students would prefer that concepts are introduced to them in static, highly detailed images or snapshots. Therein lies a conflict, however. Chemistry is a dynamic process, thus fundamental disagreement between the student's object-based learning with dynamic procedural and process-based ideas are present. The question becomes two-fold: should classroom instruction be "style-flexed" to accommodate the vast majority of students' preferred learning styles? If so, what would be the nature of this learning style-flexed classroom environment? These are questions that should be considered beyond the scope of this research.

Research Question 2

> What is the relationship between learning style preference and ability to recall specific features of protein structure?

Learning style preferences were a fundamental part of this study as part of the general characterization of the population of interest. Thus the goal of this specific research question was to understand if recall ability was correlated to learning style preference. It was of interest to the researcher to understand this due to the unique population, primarily female pre-nursing or allied health majors apparent tendency to prefer object-based learning styles. Based on the researcher's classroom observations, it was noted that the primary exam methodology was of the multiple-choice format.

Paired t-test two-sample for means analysis revealed that there was no relationship between learning style preference and recall gain (Table 6, p. 75). The population of interest was presented with only five multiple-choice questions, a relatively small sampling of recall data. Therefore, it is not clear if this lack of relationship would hold for a large-scale multiple-choice (recall knowledge) analysis. Another possibility for the lack of observed relationship may be that the population of interest was highly homogenous in terms of learning style preferences (Table 6). Thus, this research question should be further studied with a population of greater learning style heterogeneity with a larger sampling of recall data.

Finally, recall that difficulties have been encountered by learning style researchers in the past (Chapter II). It was noted that often, extraneous influences may complicate the researchers ability to detect a measurable relationship between learning style preferences and classroom performance (Price, 2004). Thus, it is possible to extrapolate this observation in relation to the current research presented here, in that it may be difficult to detect an effect between learning style preferences and knowledge gain, including the gain of recall knowledge.

Research Question 3

> What features (statements, meanings, themes, or general descriptions) are found in a selection of biochemistry novice descriptions and self-explanations of relationships between molecular phenomena and macroscopic observations (i.e., frying an egg)?

The Storyboard

The qualitative thematic analysis was applied to what will henceforth be referred to as “The Animation Component”. This component was designed in the following fashion. Initially, participants – who had recently begun the biochemistry unit during the lecture - were asked to “storyboard” their ideas of what they believe happen when an egg is fried. Within the component, participants were asked to draw what they believe happens when an egg is fried (Appendix D). Participants were then asked to provide a written explanation of their picture on the lines provided.

It was ascertained that, out of 63 participants who completed the storyboard component, 71% of the students showed a diagrammatic depiction that was based solely on the macroscopic level (i.e., a picture of an egg, skillet, and/or burner was shown). Another 24% of the students depicted both macroscopic and microscopic properties, thus these responses were categorized as an integrated diagrammatic response. Only 2% and 3% of the diagrams submitted represented solely a microscopic or molecular-level depiction, respectively. Conversely, only 47% of the students had a written description that was solely based on the macroscopic level. Less than half of the students (43%)

provided an integrated response, where their response integrated both observable macroscopic properties (i.e., “the egg turns white) with a molecular-level detail (i.e., “hydrogen bonds are disrupted”). Again, only 2% and 3% of the diagrams submitted represented solely a microscopic or molecular-level depiction, respectively. Of the responses that were categorized as either molecular-level or integrated, an apparent misconception was noted in 33% of the responses (Table 23).

The Jigsaw Puzzle

After completing the storyboard portion of the animation component, participants were asked to complete a “jigsaw”. The Jigsaw Puzzle was created from snapshots that were captured from the animation they were about to view. These snapshots, containing a dual representation of microscopic and macroscopic levels simultaneously, were placed in a random order. Students were asked to number each frame according to how it would occur in sequence of dynamic macroscopic and molecular-level events (Appendix E). They were then asked to provide a textual response under each frame, explaining why they ordered the frames as they did.

It was observed that, of the 64 participants who completed the jigsaw component, 98% of the respondents placed the frames in the correct order. It was ascertained that 59% of the students had a written description that was solely based on the molecular-level. Nearly one-third of the students provided an integrated response, where their response integrated both observable macroscopic properties (i.e., “the egg turns white) with a molecular-level detail (i.e., “hydrogen bonds are disrupted”). Only 5% of the written text-based responses referred only to the macroscopic level, and just two responses (3%) were categorized on the microscopic level (in other words, if a response was not categorized as macroscopic in nature, there was some indication of molecular-level details, i.e., specific indication of hydrogen bonding) (Table 13). Of the 90% of the responses categorized as either molecular-level or integrated, an apparent misconception was noted in approximately one-third of them.

Table 23.

Characterization of responses obtained from the Storyboard exercise from the Animation Component.

Rubric Code (Level)	Meaning of Score	Characterization of Response	Storyboard[a] (N=63)	
			Diagrammatic[b]	Text[c]
0	Blank or "I don't know"	-	0% (n=0)	5% (n=3)
1	Macroscopic	Observable to the naked eye	71% (n=45)	47% (n=30)
2	Microscopic	Shape is emphasized; "wiggly" lines or mesh network; use of generic words (i.e., "unfolds" or "denatures")	2% (n=1)	2% (n=1)
3	Molecular-level	Indication of chemical detail (i.e., hydrogen bonding or atomic structure)	3% (n=2)	3% (n=2)
4	Integrated	Consisting two or more "levels"	24% (n=15)	43% (n=27)

[a] The Storyboard component required that participants both diagram a response pictorially and explain or describe the phenomenon textually. This component was completed prior to their viewing the animation on heat-induced protein denaturation.

[b] The word "diagrammatic" indicates that the responses were pictorial representations drawn by the participants inside a blank text box provided by the researcher.

[c] The word "text" indicates that the responses were textual self-explanations or descriptions written by the participants on a space directly next to their representation.

Table 24.

Characterization of responses obtained from the Jigsaw Puzzle, provided as part of the Animation Component.

Rubric Code (Level)	Meaning of Score	Characterization of Response	Jigsaw Puzzle (N=64)
			Text[a]
0	Blank or "I don't know".	-	3% (n=2)
1	Macroscopic	Observable to the naked eye	5% (n=3)
2	Microscopic	Shape is emphasized; "wiggly" lines or mesh network	2% (n=1)
3	Molecular-level	Indication of chemical detail (i.e., hydrogen bonding or atomic structure)	59% (n=38)
4	Integrated	Consisting two or more "levels"	31% (n=20)

[a] The word "text" indicates that the responses were written self-explanations or descriptions. The Jigsaw Puzzle component did not require participants to draw or diagram a response. In this component, participants were required to place each snapshot in the sequential order to which they perceived was correct, and then they were to explain why each snapshot was placed in the order that it was. Note that 14% (n=9) of the participants ordered the snapshots incorrectly.

Upon completion of the storyboard and jigsaw puzzle components, the participants were randomly assigned an animation to view regarding heat-induced denaturation. The animation had two options – continuous with narration (no pre-set pause points) and step-through with text (including pre-set pause points). Students viewed their randomly assigned version of the animation and then responded to a variety of questions about the animation. Note, data collected from these questions will be presented in a subsequent paper as they are not relevant to the research question at hand.

Once the participants completed the post-animation questionnaire, they were asked to view the alternate version of the animation. This step was taken to ensure that all participants had equal viewing opportunity. At this point, the animation component was considered complete.

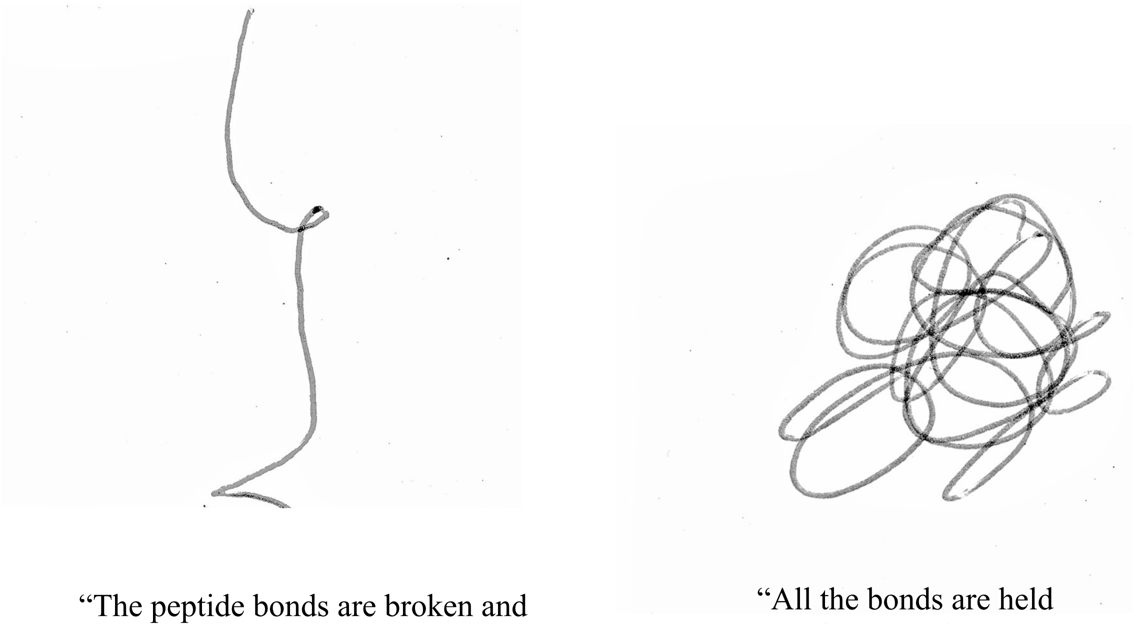
The Transfer Component

One week after completing the animation component, participating students were asked to complete the transfer component. The transfer component was designed as a means to assess novice understanding of a complex dynamic phenomenon on increasingly higher-resolved levels, as well as a means for the researcher to assess student-derived self-explanations. The primary components of the transfer component that will be presented here include the near and deep transfer portions.

Near Transfer

Recall that near transfer has been defined, for the purposes of this study, as an representation, description, diagram, or explanation of a phenomenon that is identical to that introduced in the original learning task. In a near-transfer scenario, the context is the same as that presented in the original learning task. Recall that the original phenomenon and context involved heat-induced protein denaturation upon the frying of an egg. Students were initially presented with a template consisting of two blank squares, and blank lines next to each box (Figure 21).

As reported in Chapter IV, 88% of the diagrammatic responses in this near-transfer component revealed a microscopic representation (i.e., primarily through the drawing of shape-based representations of protein structure such as “squiggly” lines). Approximately 7% of the near-transfer responses had some diagrammatic reference to molecular-level details, i.e., through the showing of a hydrogen bond or covalent linkages. Of the misconceptions detected in the written representations, only two out of the 11 total apparent misconceptions pertained to ideas of heat-induced protein fragmentation. When students were asked to describe their drawings, nearly one quarter of the written responses (23%) were left blank, or the student wrote, “I don’t know”. Nearly one third of the written (i.e., text-based) responses pertained to the molecular-level, and 43% were categorized as microscopic in nature by the researcher. Of the misconceptions detected in the written representations, only six out of the 21 total apparent misconceptions pertained to ideas of heat-induced protein fragmentation. Other misconceptions centered primarily around ideas of heat-induced protein renaturation, where students implied the formation of higher-ordered structure upon addition of heat (i.e., formation of 3° and 4° structures rather than unfolding and subsequent aggregation). Based on the descriptive summaries provided, very few students alluded to the of heat-induced protein fragmentation misconception in the first portion of the near transfer component. As described in Chapter IV, it is apparent that as students delved deeper into the transfer component, the misconceptions surrounding ideas of fragmentation began to surface, and this ultimately became the most prevalent misconception of heat-induced protein denaturation among the population of interest. Students tended to describe their microscopic diagrammatic representations on the molecular-level (i.e., only 7% of the diagrams were molecular-level; nearly half of the written explanations and descriptions were molecular-level in nature). Example responses are shown in Figure 18. A summary of the descriptive statistics for this component are shown in Table 25.

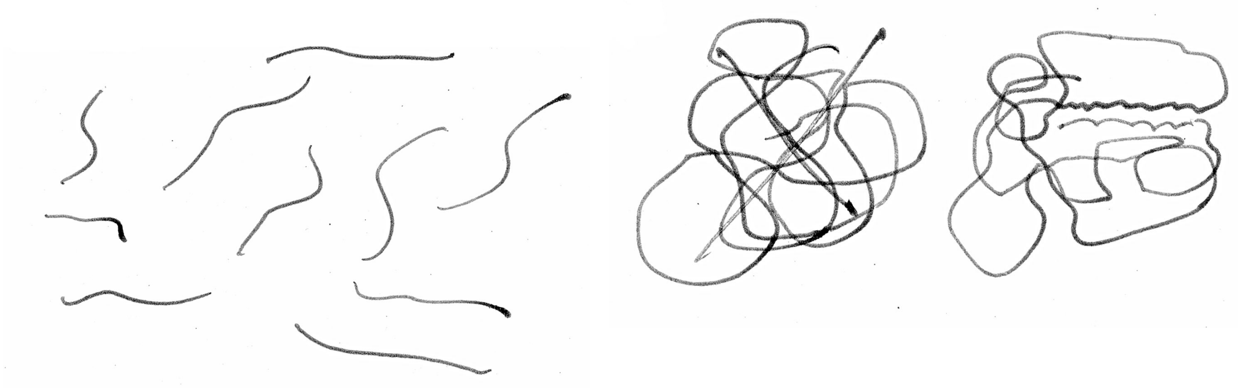


“The peptide bonds are broken and the amino acid is no longer bonded together” Participant 1118

(a)

“All the bonds are held together.” Participant 1118

(b)



“Multiple primary sequences that have been synthesized yet not combined.” Participant 1131.

(c)

“As they come into contact, each protein begins to bond to one another forming the quarternary structure or in come cases, tertiary.” Participant 1131

(d)

Figure 18. Example responses from the near transfer component with corresponding written descriptions provided by the participants. Top row: Participant # 1118 a) representation of an unfolded protein; b) representation of protein aggregation. Bottom row: Participant 1131 c) representation of an unfolded protein; d) representation of protein aggregation.

Deep Transfer

Within the context of this study, a novel and unique term has been introduced called deep transfer. Please note that this term refers to the representation, description, or explanation of a phenomenon that is identical to the one introduced in the original learning task but is associated with a more complex, high-resolution scale. This transfer scale, which to the researchers knowledge, has not been coined in the literature until now, is ideally suited for physical science education research, where concepts often rely heavily upon molecular, atomic, or sub-atomic depths of understanding.

Table 25.

Summary of Near Transfer data.

Level of Description	Meaning of Score	Characterization of Response	Near Transfer (N=56)	
			Text	Diagram
0	Blank or "I don't know".	-	23% (n=13)	5% (n=3)
1	Macroscopic	Observable to the naked eye	0%	0% (n=0)
2	Microscopic	Shape is emphasized; "wiggly" lines or mesh network	32% (n=18)	88% (n=49)
3	Molecular-level	Indication of chemical detail (i.e., hydrogen bonding or atomic structure)	43% (n=24)	7% (n=4)
4	Integrated	Consisting two or more "levels"	2% (n=1)	0%

In this component, students were provided with a high-resolution x-ray crystallographic snapshot of egg-white protein. This image was converted to a two-dimensional form that it was assumed the participants were familiar, based on researcher observations of the lecture and laboratory components of the course (Appendix F). The students were asked to depict both diagrammatically and textually what they thought would happen upon continued addition of heat. Two blank frames were provided for participant use (Appendix F).

Up until this point, the general trend of the animation and transfer components were that responses provided by the novice participants were increasingly on the molecular-level. Note, in the storyboard, the vast majority of responses were macroscopic in nature. With the cognitive anchor provided in the storyboard, the majority of responses were either molecular-level or an integration of the molecular level with macroscopic observations. Near transfer responses were primarily microscopic or molecular-level in nature, however, as students were attempting to transfer their knowledge, an increasing number of blank or "I don't know" responses were apparent. It was noted for the deep transfer component, the novice students tended to describe heat-induced protein denaturation on the molecular level textually, however 41% of students could not draw a diagrammatic representation of the heat-denatured unfolding process. Just over one third (36%) could not explain what happens to a protein as heat is applied. Of students that did respond to this component, the vast majority of responses were molecular-level in nature. Only a minority of the responses were considered to be microscopic in nature. These data are summarized below (Tables 26 and 27).

Table 26.

Summary of the Deep-Transfer component.

Level of Description	Meaning of Score	Characterization of Response	Deep Transfer (N=38)	
			<u>Text</u>	<u>Diagram</u>
0	Blank or "I don't know".	-	36% (n=14)	41% (n=16)
1	Macroscopic	Observable to the naked eye	0%	0%
2	Microscopic	Shape is emphasized; "wiggly" lines or mesh network	8% (n=3)	4% (n=2)
3	Molecular-level	Indication of chemical detail (i.e., hydrogen bonding or atomic structure)	54% (n=20)	55% (n=21)
4	Integrated	Consisting two or more "levels"	2% (n=1)	0%

It was noted in preliminary studies that of those participants from the 'Fundamentals of Biochemistry' who could adequately draw a depiction of a protein, few of these students could explain their drawings (Chapter I). It was observed in the current research that these students had a tendency to describe or explain dynamic chemical phenomena on the molecular-level textually, but – unless they were provided with a visual cue – they tended to depict these phenomena on the microscopic or macroscopic levels throughout the animation and near transfer components (Table 27). With regard to the storyboard, nearly ¾ of the responses that were characterized as being macroscopic in nature by the researcher, only approximately half could explain their diagrammatic depiction with an integrated response consisting of both macroscopic and molecular-level explanations or descriptions. The other half of respondents described their macroscopic drawing with a textual, macroscopic response. As the participants were encouraged to respond with increasing molecular and chemical detail in the near transfer component, participants' diagrammatic depictions were overwhelmingly on the microscopic level. Conversely, nearly half (43%) of the textual descriptions and explanations were molecular-level in nature.

There is an implication that these participants, who, in general, preferred object-based learning styles, tended to struggle to depict an unfolded protein with any chemical detail, but were able to describe these phenomena in words. This observation may be related to the idea of recall knowledge, where these novices tended to understand the "right words to say" (i.e., see Chapter IV, Research Question Two), but may not have understood what they were saying *visually*. Upon provision of a visual cue in the deep transfer component, these same students provided diagrammatic representations and textual descriptions that were equally molecular-level in nature (Table 27). Thus, these students may reply to questions regarding dynamic chemical phenomena with responses that are highly similar to explanations and descriptions provided in the original learning task.

Table 27.

Summary of Animation Component categorizations.

Level of Description[a]	Storyboard (N=63)		Jigsaw Puzzle (N=56)	Near Transfer (N=56)		Deep transfer (N=38)	
	Text	Diagram	Text	Text	Diagram	Text	Diagram
0	0%	0%	0%	23%	5%	36%	41%
1	50%	71%	5%	0%	0%	0%	0%
2	2%	2%	0%	32%	88%	8%	4%
3	3%	3%	62%	43%	7%	54%	55%
4	45%	24%	33%	2%	0%	2%	0%

[a] 0=blank; 1=macroscopic; 2=microscopic; 3=molecular level; 4=integrated

Throughout all of the components describe thus far (i.e., the animation and transfer components), the researcher noted instances when misconceptions were apparent in a response. These misconceptions were tabulated and thematically analyzed. Of particular interest to the researcher were misconceptions alluding to heat-induced fragmentation of a protein. Note that data obtained from the recall component revealed that the majority of students correctly chose that multiple-choice option that heat would denature a protein (84%; Chapter IV). By choosing this response, students directly indicated that heat would not fragment a protein (i.e., break the covalent bonds).

It was revealed by thematic analysis of self-explanations that, as students progressed through the transfer component, apparently deeply-held misconceptions pertaining to heat-induced protein fragmentation gradually began to emerge. In the storyboard and jigsaw puzzle components, approximately one third of the responses held an apparent misconception, as judged by the researcher. The predominant misconceptions here were structural in nature (i.e., renaturation-based). Very few of the misconceptions revealed here were within the realm of fragmentation. Note also that responses from these components tended to be macroscopic in nature. As students progressed through the transfer component, the self-explanations appeared to become increasingly based on molecular-level explanations. At the same time, the number of apparent misconceptions identified by the researcher also began to increase. It was noted that as students progressed through the transfer component, the presence of apparent misconceptions increased as shown in Table 28.

Table 28.

Presence of apparent misconceptions in the animation component.

Level of Description[a]	Storyboard (N=63)		Jigsaw Puzzle (N=56)	Near Transfer (N=56)		Deep Transfer (N=38)	
	Text[b]	Diagram[c]	Text[b]	Text[b]	Diagram[c]	Text[b]	Diagram[c]
3	3%	3%	62%	43%	7%	54%	55%
4	45%	24%	33%	2%	0%	2%	0%
Apparent Mis-conceptions[d]	33% (Fragmentation-based: 0%)		31% (Fragmentation-based: 0%)	37% (Fragmentation-based: 80%)		54% (Fragmentation-based: 86%)	

[a] 3=molecular level; 4=integrated
[b] The word "text" indicates that the responses were textual self-explanations or descriptions written by the participants on a space directly next to their representation.
[c] The word "diagrammatic" indicates that the responses were pictorial representations drawn by the participants inside a blank text box provided by the researcher.
[d] Apparent misconceptions revealed within the responses as assessed by the researcher.

Implications for Teaching

The research presented herein describes the revelation of deep-seated misconceptions held by novice participants as these students progressed through the transfer component. When students were initially presented with a question asking them to describe their thoughts regarding an observable macroscopic event (i.e., the frying of an egg), the vast majority of students portrayed the dynamic events primarily on the macroscopic level (Table 21). Once the participants were provided with a visual cue alluding to events on the deeper level (i.e., from the jigsaw puzzle exercise), approximately two-thirds of the responses transitioned to the molecular-level, with the remaining one-third of responses consisting of an integration of both the non-observable molecular-level events and corresponding macroscopic visual phenomena (Table 22). When the participants were provided with a high-resolution x-ray crystallographic representation of the molecular-level detail associated with the observable macroscopic event, over half of the respondents depicted the heat-induced dynamic process on the molecular level. The remaining participants indicated that they did not know what happened to the protein upon addition of heat when presented with a highly-detailed, molecular-level representation of egg-white protein. Few responses included an integration of the molecular-level events with observable macroscopic observations. Interestingly, as student written descriptions and diagrammatic representations progressed through high orders of complexity, in other words from macroscopic to microscopic, and ultimately molecular-level, the sheer number of misconceptions increased similarly.

Misconception-Based Teaching

Thus, one possible implication for teaching would be from the perspective of misconception-based teaching. In such a classroom scenario, students would be presented with an apparently common misconception (i.e., the misconception that the proteins will fragment upon exposure to heat), and taught backwards from this point. This concept, originally considered a novel concept unique to this research, has been recently reported as an effective teaching strategy in the physics education literature (Muller, Bewes, Sharma, and Reimann, 2008). The basic premise of misconception-based teaching is to present novice students with a common misconception which they must refute. Using the technique of self-explanations, students would explain why the information presented to them is in error, and propose an acceptable alternative. Muller, *et al.* showed that misconception-based teaching was effective in producing significantly greater learning gains in a first-year undergraduate physics course. The learning gains were also significantly greater for low prior-knowledge learners, relative to high prior-knowledge learners. The authors concluded that multi-media resources could be useful in promoting conceptual change in novice learners through direct presentation of misconceptions. The students in the population of interest in this study have very little prior chemistry in general, thus the misconception-based teaching strategy may be a beneficial addition to the curriculum for these low-prior knowledge learners. It has been noted that self-explanations provided by novices have yielded significant effects on mental model repair (Chi, 2000; Uttal, *et al*., 2006), and transfer effects (Atkinson, *et al.,* 2003). Once students are presented with fundamental and foundational conceptual knowledge as introductory material, students may be able to critically assess misconception-containing materials as a form of mental model repair.

Teaching from the High-Resolution to Application

The order of the data collection during the transfer component was such that an application was presented, and students were subsequently asked to provide descriptions, explanations, and representations of events of increasing molecular levels. This order is reminiscent of the traditional order that science courses are taken in typical high school environments, that is where students often take biology initially, followed by chemistry, and then in some cases, physics. Given the research described thus far, it may be beneficial to study course attrition rates as influenced by so-called “reverse-science teaching”. For example, students may be introduced to molecular-level understanding initially, and the concepts put forth here would be gradually linked to more observable, application-based properties. This would allow students to grasp fundamental, ground-laying concepts at the outset so that they have an appropriate foundation with which to apply larger-scale phenomenon (i.e., observable, macroscopic properties). Though the affect of such a methodology is not known, it is a useful consideration as a result of the implications provided in this research. This is not the first time this idea has been proposed. Rhode Island educators, for example, have proposed a pilot program where high school science courses are taught in reverse, that is from physics to chemistry to biology (Needham, 2005). Similarly, Nobel Laureate Leon M. Lederman, known casually in the physics community as “The Godfather of Physics First”, has also proposed similar reverse-science teaching ideologies (Holtzman, 2006). Other scientists and educators have proposed the reverse-science teaching strategy from independent studies, as well (Bell, 1999; Mervis, 1998). A potential challenge to the reverse science method would lie in populations where students are primarily concrete reasoning and nonmathematical students, characteristics that may be associated with pre-nursing populations. Students within these populations may encounter difficulty with the mathematical abstractness of physical science-based concepts, thus prior knowledge and learning style preferences should be accounted for prior to employing this novel technique so as to style-flex the classroom appropriately.

Future Research

The research described above can be thought of as the metaphorical “tip of the iceberg” for deep transfer research. It is the researcher’s intention that results from this study will lead to a variety of sub-studies to further elucidate correlations between learning style preferences and knowledge transfer within the chemistry context, as well as further elucidation of the role of intermediate transfer in the global process of transfer.

Learning Style Preferences

It was noted in the current research that learning styles were not distinguished in the population of interest. The vast majority of participants in this study were object visualizers, an indication that the students preferred static, highly detailed images as opposed to moving, dynamic and highly schematic process depictions. This finding was further validated during the animation component of this study. Students were randomly assigned to initially view an animation as either a text version with pre-designated pause points or a continuous, narrated version with no pre-designated pause points. It was observed that the students in this population had a slight, yet significant preference for the text/step-through version of the animation over the continuous, narrated version ($r - 0.222$, $p = 0.017$). Thus, the object visualizers may have preferred the step-wise with text version of the animation because the concepts of dynamic chemical phenomena were presented through a series of detailed snapshots. To further understand this observation, it would be useful to understand if, in a more heterogeneous population, there is a correlation between learning style preferences and gender, major, prior chemistry background, cumulative grade point average, and math/science grade point average. These relationships were difficult to establish here, given that the vast majority of the population were of similar learning style preferences. The vast majority (84%) of the participants were female, and 75% of the total population was pre-nursing majors. The majority of the remaining 25% of the population were composed primarily of sport and exercise science majors. The average self-reported cumulative GPA was 3.16 (+/- 0.54), and less than 2/3 of the population had previously taken a chemistry course in high school, though high school chemistry is a prerequisite for the course. It should be noted here that there was a correlation between learning style preferences with gender ($r = 0.222$, $p < 0.05$) and with course grade ($r = 0.200$, $p = 0.022$). It is known that the majority of students in this population were female, thus it is not possible to say if this correlation is really an indication that females tend to be object visualizers, or if the apparent relationship is due solely to the inherently large percentage of the population that were both female and object visualizers. Furthermore, it is difficult to say conclusively if there is a true relationship between learning style preferences and overall course performance. To study this further, it would be ideal to assess the potential relationship between learning style preferences and course performance within a population consisting of a greater degree of population heterogeneity in terms of learning style preferences.

Intermediate Transfer

A key component of the transfer study not presented here was that of intermediate transfer. Intermediate transfer, by definition in this study, referred to a phenomenon that was identical to that presented in the original learning task (i.e., heat-induced protein denaturation) but with a different context. The context here, rather than the frying of an egg, was instead the dynamic molecular-level events that may unfold in a physiological presentation of a long-term high-grade fever, and potential ramifications of such a medical scenario on structure and function of proteins, and how these ramifications would affect observable, macroscopic phenomena (i.e., patient well-being). Preliminary inspection of the intermediate transfer data revealed that students had a tendency to utilize more macroscopic or microscopic-based explanations. It appeared, through preliminary analysis, that responses were very rarely based on the molecular-level.

Common misconceptions observed in the intermediate transfer component include responses such as a prolonged high physiological temperature “damages protein synthesis”, “causes cancer”, and “fries the brain”. Future research of the intermediate transfer component would likely yield transitional shifts in novice understanding of the relationship between observed macroscopic phenomena (i.e., high-grade fever, seizures, and overall ill-health) and underlying molecular-level phenomena.

Conclusions

The research presented here described a novel approach for assessing the evolving mental models of a pre-allied health population within the context of the biochemistry portion of a ‘Fundamentals of Biochemistry’ course. Within the realm of this research, students were asked to generate diagrammatic depictions and representations and, in most cases, corresponding textual descriptions and explanations of dynamic chemical phenomena. As alluded to in Chapter II, the richness of student-derived self-explanations is fundamentally Piagetan in nature; the acquisition of knowledge on fundamentally different scales (i.e., through the transfer of recall knowledge) is mechanistically based on the integration of new knowledge within the pre-exiting framework of knowledge. The very act of student-generated responsiveness not only promotes the active facilitation of new knowledge integration into the novice’s cognitive framework, but allows for an objective means for the researcher to gauge the depth and nature of deep-seated misconceptions held by the novice population as a whole. Ultimately, the themes uncovered within the realm of this research has led to a greater, and a fundamentally cognitive, understanding of the population of interest. Though much more research is needed within this population to further elucidate factors that affect transfer ability, what has been gained is a fundamentally new, novel, and unique measure of knowledge transfer that is applicable specifically to physical and chemical science research in the form of deep transfer.

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APPENDIX A

OBJECT-SPATIAL IMAGERY QUESTIONNAIRE

Blajenkova, O., Kozhevnikov, M., Motes, MA. (2006). Object-Spatial Imagery: A New Self-Report Imagery Questionnaire. *Applied Cognitive Psychology*, 20, 239-263.

This self-report questionnaire is about people's preference to use mental imagery versus verbal representations. Mental imagery is the ability to mentally represent things in the mind (especially visible objects), not by direct perception but by memory or imagination. Mental images are not what we see directly, they are the pictures that we often have in mind while we think about things. In order to complete this questionnaire, please read the following statements and rate each of them on a 5-point scale. Use rating "5" to indicate that you absolutely agree with the statement that describes you and rating. Use rating "1" to indicate that you totally disagree with the statement. Use intermediate values to indicate intermediate degrees of how the statements describe you. It is very important that you answer on all the items in the questionnaire. There is a **10-minute** time limit to complete this questionnaire. Please remember to mark your questionnaire with your four-digit confidentiality code.

There are no right or wrong answers for this questionnaire so please be as honest as possible.

Thank you very much for your cooperation!

1 – you absolutely disagree with the statement
2 – you partially disagree with the statement
3 – you are neutral to the statement
4 – you partially agree with the statement
5 – you absolutely agree with the statement

Four Digit Confidentiality Code___ ___ ___ ___

		Totally disagree ↓				Totally agree ↓
1.	Architecture interests me more than painting.	1	2	3	4	5
2.	Essay writing is difficult for me and I do not enjoy doing it at all.	1	2	3	4	5
3.	I am a good Tetris player.	1	2	3	4	5
4.	I am always aware of sentence structure.	1	2	3	4	5
5.	I am better at manipulating equations and numbers than pictures and diagrams.	1	2	3	4	5
6.	I am good at visualizing the direction that a pool ball might travel in.	1	2	3	4	5
7.	I can close my eyes and easily picture a scene that I have experienced.	1	2	3	4	5
8.	I can easily imagine and mentally rotate three-dimensional geometric figures.	1	2	3	4	5
9.	I can easily remember a great deal of visual details that someone else might never notice. For example, I would just automatically take some things in, like what color is a shirt someone wears or what color are his/her shoes…	1	2	3	4	5
10.	I can easily sketch a blueprint for a building that I am familiar with.	1	2	3	4	5
11.	I enjoy being able to rephrase my thoughts in many ways for variety’s sake in both writing and speaking.	1	2	3	4	5
12.	I find it difficult to imagine how a three-dimensional geometric figure would exactly look like when rotated.	1	2	3	4	5
13.	I have a photographic memory.	1	2	3	4	5
14.	I have better than average fluency in using words.	1	2	3	4	5

15.	I have difficulty expressing myself in writing.	1	2	3	4	5
16.	I have excellent abilities in technical graphics.	1	2	3	4	5
17.	I memorize material mostly by the use of verbal repetition.	1	2	3	4	5
18.	I normally do not experience many spontaneous vivid images; I use my mental imagery mostly when attempting to solve some problems like the ones in mathematics.	1	2	3	4	5
19.	I prefer schematic diagrams and sketches when reading a textbook instead of colorful and pictorial illustrations.	1	2	3	4	5
20.	I remember everything visually. I can recount what people wore to a dinner and I can talk about the way they sat and the way they looked probably in more detail than I could discuss what they said.	1	2	3	4	5
21.	I tell jokes and stories better than most people.	1	2	3	4	5
22.	I usually do not try to visualize or sketch diagrams when reading a textbook.	1	2	3	4	5
23.	I was very good in 3-D geometry as a student.	1	2	3	4	5
24.	If I were asked to choose among engineering professions, language arts or visual arts, I would choose language arts.	1	2	3	4	5
25.	If I were asked to choose between engineering professions and visual arts, I would prefer engineering.	1	2	3	4	5
26.	If I were asked to choose between studying architecture and visual arts, I would choose visual arts.	1	2	3	4	5
27.	In high school, I had less difficulty with geometry than with art.	1	2	3	4	5
28.	My graphic abilities would make a career in architecture relatively easy for me.	1	2	3	4	5
29.	My images are more like schematic representations of things and events rather than like detailed pictures.	1	2	3	4	5
30.	My images are more schematic than colorful and pictorial.					

		1	2	3	4	5
31.	My images are very colorful and bright.	1	2	3	4	5
32.	My images are very vivid and photographic.	1	2	3	4	5
33.	My mental images of different objects very much resemble the size, shape and color of actual objects that I have seen.	1	2	3	4	5
34.	My mental pictures are very detailed precise representations of the real things.	1	2	3	4	5
35.	My verbal skills are excellent.	1	2	3	4	5
36.	My visual images are in my head all the time. They are just right there.	1	2	3	4	5
37.	Putting together furniture kits (e.g., a TV stand or a chair) is much easier for me when I have detailed verbal instructions than when I only have a diagram or picture.	1	2	3	4	5
38.	Sometimes my images are so vivid and persistent that it is difficult to ignore them.	1	2	3	4	5
39.	When entering a familiar store to get a specific item, I can easily picture the exact location of the target item, the shelf it stands on, how it is arranged and the surrounding articles.	1	2	3	4	5
40.	When explaining something, I would rather give verbal explanations than make drawings or sketches.	1	2	3	4	5
41.	When I hear a radio announcer or a DJ I've never actually seen, I usually find myself picturing what he or she might look like.	1	2	3	4	5
42.	When I listen to people describe their experiences, my vivid imagery always supports their stories; I try to imagine that I was there.	1	2	3	4	5
43.	When reading a textbook where things are clearly described in words, I find illustrations distracting because they interfere with my ability to focus on the material.	1	2	3	4	5
44.	When reading fiction, I usually form a clear and detailed mental picture of a scene or room that has been described.	1	2	3	4	5
45.	When remembering a scene, I use verbal descriptions rather than mental pictures.	1	2	3	4	5

APPENDIX B

DEMOGRAPHICS FORM

Four Digit Confidentiality Code: ___ ___ ___ ___

Year in College ________________________________ (example: Freshman)

Declared Major ____

Current GPA ___________

Previous Chemistry Courses (including High School):

________________________________ ________________________________

________________________________ ________________________________

________________________________ ________________________________

Previous Chemistry Laboratories (including High School):

________________________________ ________________________________

________________________________ ________________________________

________________________________ ________________________________

What do you hope to get out of this course?

____

____

____

____

What are your career goals?

____

____

____

____

____

APPENDIX C

PRIOR-KNOWLEDGE ASSESSMENT

Four-Digit Confidentiality Code ___ ___ ___ ___ Lecture Instructor: HYSLOP

4) In the box provided below, please draw a diagram of what you think of when you hear the word “protein”. Please label the diagram freely and clearly. On the lines provided below, please explain your drawing. What does each component represent?

2) What functional feature makes one amino acid unique from all other amino acids? Please circle the ONE answer you feel is the most accurate.

   a. The N-terminal

   b. The C-terminal

   c. The R-group

   d. The peptide backbone

3) In the box provided, please draw the structure of any generic amino acid. Please include labels where necessary. Please then describe your drawing in words on the lines provided underneath the box. Indicate – either in your description or your drawing, what functional group(s) are common to all amino acids.

4) How do you understand the process of the joining of amino acids by peptide bonds? Please draw how you view this process in the box provided below, and describe the chemical process in your own words on the lines beneath your picture.

5) Explain your understanding of the difference(s) between a peptide, a polypeptide, and a protein?

6) Due to hydrogen bonds that form between the backbone amino hydrogen of one amino acid with the carbonyl oxygen of another, the protein or polypeptide obtains the three-dimensional form of an alpha-helix or a beta-pleated sheet. This best describes a protein's:

a. Primary structure

b. Secondary structure

c. Tertiary structure

d. Quaternary structure

7) In some cases, such as with hemoglobin, multiple subunits (or polypeptide chains) interact together to form:

    a. The primary structure

    b. The secondary structure

    c. The tertiary structure

    d. The quaternary structure

8) The sequence of the amino acids in the protein is determined by the original DNA sequence of the gene for the protein. This protein sequence describes the protein's:

    a. Primary structure

    b. Secondary structure

    c. Tertiary structure

    d. Quaternary structure

9) What initially happens to the structure of a protein when you heat it?

    a. The protein breaks into fragments

    b. Nothing – the structure is not affected by heat

    c. The protein unfolds

    d. The protein becomes part of the vapor phase

10) Please draw a representative enzyme reaction in the box provided. Use the spaces below the box to explain your picture. Use labels in the picture as freely as you would like.

11) Please describe anything you know about enzymes in the spaces provided below.

12) Why are enzymes necessary physiologically?

APPENDIX D

STORYBOARD

Spring 2007

Dear Research Participant:

Thank you so much for your time and valuable input into this research.

On the following pages, please "storyboard" the process of frying an egg. By using the term "storyboard", I am asking you to draw pictures of what you imagine happens when you add a raw egg to a hot frying pan. The boxes on the left side can be used to draw your pictures. The lines on the right can be used to explain your drawing. Please use as much detail (molecular and macroscopic) as possible.

Sincerely,

Jacqueline L. Hilsenbeck-Fajardo
hils9369@blue.unco.edu
University of Northern Colorado
Ross 3530

1

2

3

APPENDIX E

LAB ANIMATION TUTORIAL

Background

Remarkable advances in science and technology over the past several decades have led to vast advances in the medical and biomedical sciences. Diagnosis, treatment, and prevention of human ailments, both common and rare, have improved drastically during this information age. Pharmacological treatments are becoming more and more specific, effective, and less invasive. How are these recent medical advances accounted for in science and technology? Scientists have developed technologies that help them represent what a molecule looks like.

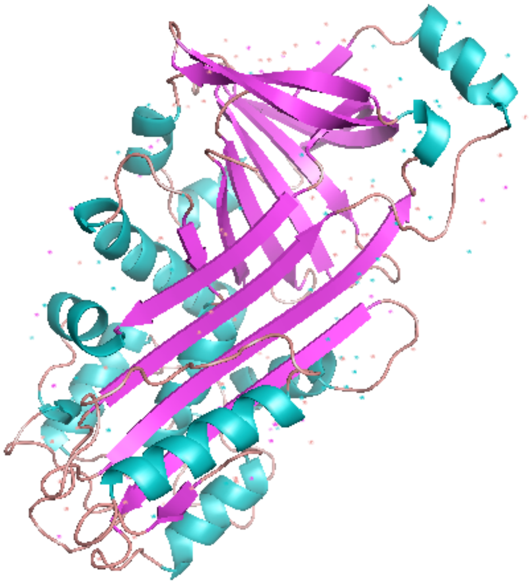


Figure 1. Ribbon diagram of the structure of ovalbumin as determined by x-ray crystallography at at 1.95 Å resolution. Stein, P.E., Leslie, A.G., Finch, J.T., Carrell, R.W. J.Mol.Biol. v221 pp.941-959, 1991.

The picture to above (Figure 1), for example, is a representation of the egg white protein *ovalbumin* at high resolution. Water surrounding the protein is shown as small spheres. Beta strands that make up the various beta-pleated sheets are shown as “arrows”. The alpha helices are shown as coils. This picture was generated using x-ray crystallographic data collected at 1.95 Å resolution. Scientific data from x-ray diffraction patterns and electron density maps can be visualized by incorporation of artistic means. This process makes up a beautiful mix of science, art, and learning!

The types of representations such as that depicted in Figure 1 help scientists and medical personnel understand the structure and molecular-level details of proteins and other biomolecules at resolutions never known before in the history of man. Proteins such as ovalbumin are very large molecules. To understand the magnitude, consider the fact that ethanol is composed of 9 atoms and has a molecular weight of 46 g/mol, whereas ovalbumin is composed of 11,522 atoms and has a molecular weight of 45,000 g/mol! Ovalbumin is composed of 385 amino acid residues covalently linked through peptide bonds. The illustration shown in Figure 1 gives us a global idea of what this protein looks like. Remember, though, that advances in medicine depend on *detail*. Let's zoom into the albumin illustration to see more detail (Figure 2, below). Recall that hydrogen bonding occurs between hydrogen and oxygen ("O") or nitrogen ("N") atoms. In this snapshot, dashed lines represent hydrogen bonds. Oxygen atoms and nitrogen atoms are shown. Note that hydrogen atoms are not shown, but implied. It is important for you to understand this in order to accurately interpret the visual representation. In Figure 2, hydrogen bonds exist between the amino hydrogens of histidine (His, center) with the side chains of glutamine (Gln, upper left) and threonine (Thr, lower right). A two-dimensional interpretation is shown (Figure 3).

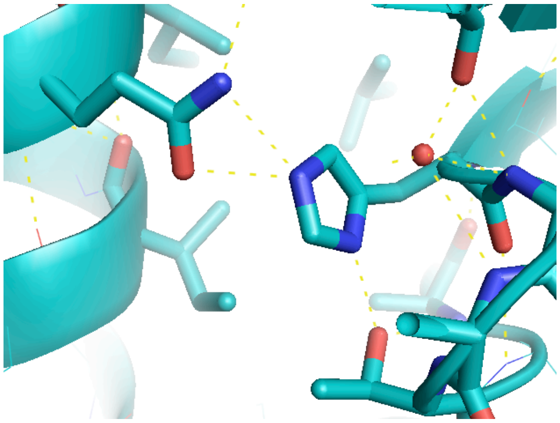


Figure 2. A region stabilized by hydrogen bonding in egg-white protein, ovalbumin.

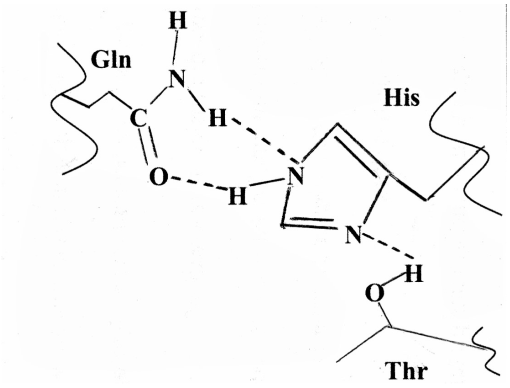


Figure 3. A two-dimensional representation of the illustration shown in Figure 2.

Applicability to You

Why is it important for professionals in the medical and biomedical sciences to understand the molecular-level details depicted in Figures 1, 2 and 3? Procedural guidelines of common drug treatments are often dictated by such structural detail. Narcotic agents such as codeine and hydrocodone act as pain relievers by inhibiting pathways within the central nervous system through specific binding interactions with calcium and potassium ion channels. They are not as effective if administered after severe pain has set in.

Similarly disulfram is used a common treatment of alcoholism. Ethanol is metabolized in the liver through a metabolic cascade. It is oxidized to acetaldehyde, which is further oxidized to acetic acid and subsequently to carbon dioxide and water. Disulfram binds to and inhibits acetaldehyde dehydrogenase so the metabolic cascade is inhibited, and the concentration of acetaldehyde therefore increases. The effects of increased amounts of acetaldehyde are so unpleasant that the treatment has been very successful for alcohol abuse. As you can see, the common thread in these varying treatments is knowledge of drug-protein interactions. Thus, to understand treatments, one must understand molecular-level structure and structural interactions. Specific instructions for the animation laboratory will be provided to you at the beginning of your regular laboratory session.

Thank you very much for your time and valuable input into this research.

ANIMATION LAB INSTRUCTION SHEET

April 2, 2007 – April 5, 2007

3) Please work individually
3) Identify ALL work with your personal four-digit confidentiality code (provided with your lecture Exam II results page)
3) Procedure
    a. Complete and turn in storyboard
    b. Collect an animation worksheet
    c. Complete jigsaw puzzle
        i. Please DO NOT modify the jigsaw puzzle once you view the animation
    d. View your <u>assigned</u> version of the animation
    e. Answer questions on the worksheet indificually
    f. View alternate version of the animation
    g. Answer questions on worksheet;
    h. Turn in all materials (be sure all materials are identified by your four-digit confidentiality code)

Please note worksheets are front and back

Frying Egg Jig-Saw Puzzle

The next page consists of four still pictures that depict the process of frying an egg. The pictures are in a random order. Your job is to:

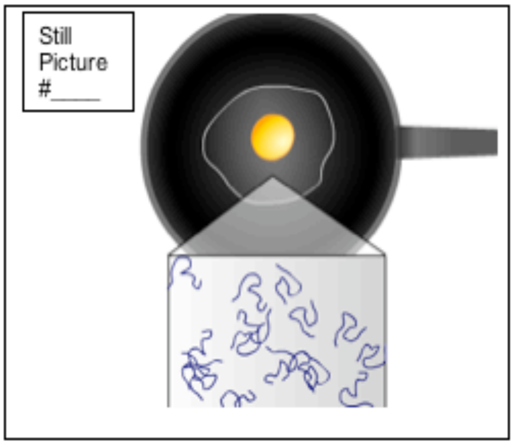
1. Order the pictures such that the process of frying the egg is accurately depicted.

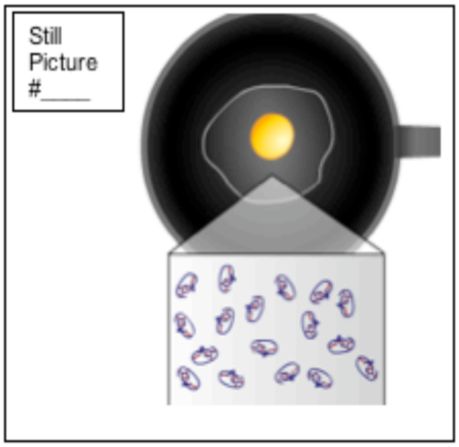
2. Write the order number in the box provided in the upper left-hand corner of each picture (e.g., 1 would indicate the first step in the process).

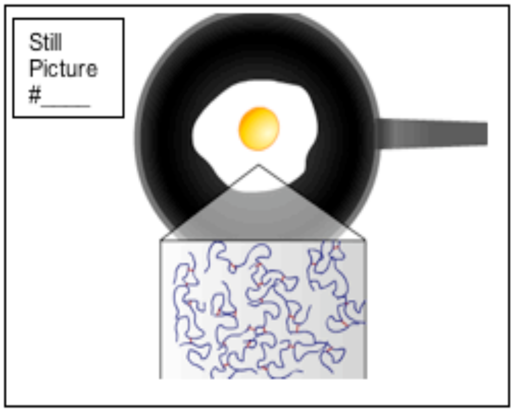
3. Beneath each picture, on the set of lines, please write a description of what you believe is happening in that particular frame.

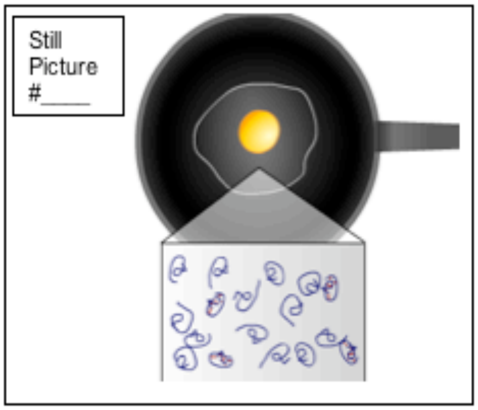
4. Include as much detail as possible in your description. Label your jigsaw puzzle with your four-digit confidentiality code (provided on your Exam II results). After you have made your jigsaw puzzle, move on to Part 3 – Animation Viewing.

Four-digit Confidentiality Code ____ ____ ____ ____









Animation Viewing - Narration

1. After you have ordered the pictures depicting the process of frying an egg, open the "Frying Egg" animation: (http://www.sumanasinc.com/webcontent/anisamples/nonmajorsbiology/proteinstructure.html).
2. You have been randomly assigned to view the "NARRATION" version first.
3. Once the tutorial has loaded, select the "NARRATION" option. Please wear headphones.
4. Proceed through the animation at your own pace.
5. You may repeat the "NARRATION" version of the animation as many times as you wish. Please do not view the "step-through" version of the animation yet. You will have an opportunity to go back and view the "step-through" version shortly.
6. After you have viewed the "NARRATION" version of the animation, move on to Part 4 to (*without* viewing the "step-through" version of the animation yet).

Post-Animation Questions - Narration

1. Did you have to pause the animation at any point(s)? YES NO
    a. If yes, where in the animation did you pause it? Specify as best as you can.
    b. How many times did you pause the animation?
2. Did you replay the animation? YES NO
    a. If so, how many times did you replay it?
3. What was the animation representing on the molecular level?
4. Did the animation affect your view of molecular-level events during the process of frying an egg? If so, how?
5. In your own words, why does an egg turn white during the frying process?
6. Are the changes that occur during the frying process reversible? Explain why or why not.
7. Was the animation useful for you as a learning tool? Why or why not?
8. Was anything that was portrayed in the animation surprising or questionable to you in any way? Please describe.
9. Do you still agree with the order of your jigsaw puzzle? If not, explain how you would modify it.
10. Please return to the animation and view the “STEP-THROUGH” version of the

animation. Please describe the features you either liked or disliked about each version.

	Features you LIKE	Features you DISLIKE
Step-Through		
Narration		

11. Overall, what was your favorite version of the animation?
12. Do you still agree with the order of your jigsaw puzzle? If not, explain how you would modify it.

Animation Viewing – Step-Through

1. After you have ordered the pictures depicting the process of frying an egg, open the “Frying Egg” animation: (http://www.sumanasinc.com/webcontent/anisamples/nonmajorsbiology/proteinstructure.html).
2. You have been randomly assigned to view the “STEP-THROUGH” version first.
3. Once the tutorial has loaded, select the “STEP-THROUGH” option.

4. Proceed through the animation at your own pace.
5. You may repeat the “STEP-THROUGH” version of the animation as many times as you wish. Please do not view the Narration version of the animation yet. You will have an opportunity to go back and view the Narration version shortly.
6. After you have viewed the “STEP-THROUGH” version of the animation, move on to Part 4 to (*without* viewing the Narration version of the animation yet).

Post – Animation Questions – Step-Through

1. Were the built-in “pauses” helpful or distracting to you? Please explain.
2. How would you modify these pause points?

   i. Delete them
   ii. Add more
   iii. Keep them the same
   iv. Other__________________________

1. What was the animation representing on the molecular level?
2. Did the animation affect your view of molecular-level events during the process of frying an egg? If so, how?
3. In your own words, why does an egg turn white during the frying process?
4. Are the changes that occur during the frying process reversible? Explain why or why not.
5. Was the animation useful for you as a learning tool? Why or why not?
6. Was anything that was portrayed in the animation surprising or questionable to you in any way? Please describe.
7. Do you still agree with the order of your jigsaw puzzle? If not, explain how you would modify it.
8. Please return to the animation and view the “NARRATION” version of the animation (with headphones). Please describe the features you either liked or disliked about each version.

	Features you LIKE	Features you DISLIKE
Step-Through		
Narration		

9. Overall, what was your favorite version of the animation?

10. Do you still agree with the order of your jigsaw puzzle? If not, explain how you would modify it.

Concluding Remarks

Thank you very much for taking part in this animation trial. Please note that the heat-induced denaturation of a protein is biochemically complex. Specific details of the unfolding and subsequent aggregation pathway are emerging in the literature. The exact structural details of unfolding and aggregation processes are beyond the scope of this exercise. The heat-induced aggregated structural states observed with egg white ovalbumin have been found to be markedly similar to the aggregated "structures" observed in many diseases such as Alzheimers, Parkinson's, and prion diseases. Understanding the molecular-level processes of one event (i.e., frying an egg) may help us understand the processes occurring in other events (i.e., prion diseases). Thus, knowledge is always transferable and useful in one way or another.

Please make sure all of your materials are labeled with your four-digit confidentiality code (on your exam two results). Staple your labeled jig-saw puzzle and Part 3 (question and answers) together and hand them to your TA. Feel free to contact the primary researcher, Jackie Fajardo, in Ross 3530 or at hils9369@blue.unco.edu if you have any questions about the research or if you would like feedback on the materials you have submitted so far. Jackie will select students for a 60-minute sit-down interview to occur in April or May. The selected interviewees will receive a $10 Barnes and Noble gift card.

APPENDIX F

TRANSFER OF KNOWLEDGE

Near Transfer

1) Please draw a diagrammatic representation of an unfolded, disordered protein in the box below on the left labeled “Picture A”. Use the space on the right to explain your drawing. Use the reverse side of the page if you need additional space to write.

Picture A

4) Please draw a pictorial representation of an aggregated structure of proteins in the box below labeled “Picture B”. Use the space on the right to explain your drawing. Use the reverse side of the page if you need additional space to write.

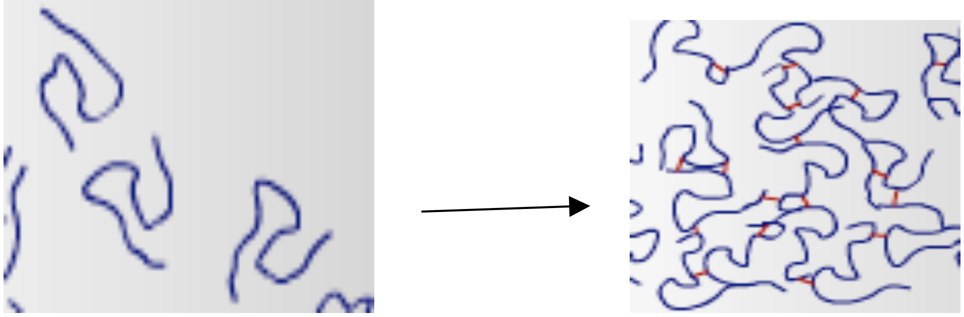
Picture B

3) Which picture, A or B, would represent the most stable structure? Why?

LEGEND

Blue lines: Protein backbone

Red lines: Hydrogen bonding



Picture C

Picture D

4) What is picture C attempting to represent?

5) What is picture D attempting to represent

6) What is the arrow between the pictures attempting to represent?

7) Which picture, C or D, would represent the most stable structure? Why?

8) Is the process depicted exothermic or endothermic? Why do you say so?

TRANSFER OF KNOWLEDGE

Intermediate Transfer

Please read each of the italicized passages prior to answering each question:

> *Recent published studies have shown that the structures of some proteins are affected by microwave radiation. These studies indicate that proteins exposed to microwaves lose structure over time of exposure. Typically, microwave radiation induces H_2O molecules to vibrate much the same as heat. Ultimately the proteins exposed to microwave radiation form an aggregate (a large structure formed by intermolecular attractions).*

1) Using this information, describe – in pictures and words – how you think microwave radiation affects protein structure.

2) Cell phones emit microwave radiation. Could there be a cause for concern over their prolonged use? Explain why or why not.

3) Assuming normal body temperature is 98.6˚F (37˚C), and temperature greater than 101.5˚F are considered high-grade fevers, why can prolonged high-grade fevers be potentially detrimental? Explain with as much detail as possible

TRANSFER OF KNOWLEDGE

Deep Transfer

1) Figure 1 is a high-resolution, three-dimensional snapshot of a region within ovalbumin at pH 7. Water (H_2O) is shown as a red sphere. Glutamine, histidine, and threonine are identified. Oxygen is "red" and nitrogen is "blue". Hydrogen atoms are not shown. Yellow, dashed lines depict intramolecular hydrogen bonds. Hydrogen bonding occurs between hydrogen and nitrogen or oxygen atoms.

2) Figure 2 is a two-dimensional "re-creation" of the image shown in Figure 1. You may be more familiar with this representation of intramolecular hydrogen bonding. Symbolic representations of H, O, N, and C are used rather than color. As in Figure 1, water is shown in red and intramolecular hydrogen bonds are depicted as yellow, dashed lines.

3) Imagine that you begin to apply heat to this protein. How will the structure of the region depicted in the high-resolution snapshot be affected by heat? In the box marked "Figure 3" draw a picture to represent any structural changes that are induced by heat.

4) Explain your drawing in words on the lines provided berneath the box. Please use the reverse side of the page if you need additional space.

5) Imagine that you continue applying heat to this protein. Draw a picture to represent any subsequent structural changes that are induced by further addition

of heat in the box marked “Figure 4”.

6) Explain your drawing in words on the lines provided underneath the box. Please use the reverse side of the page if you need additional space.

Deep Transfer Component

Page 6 of 6

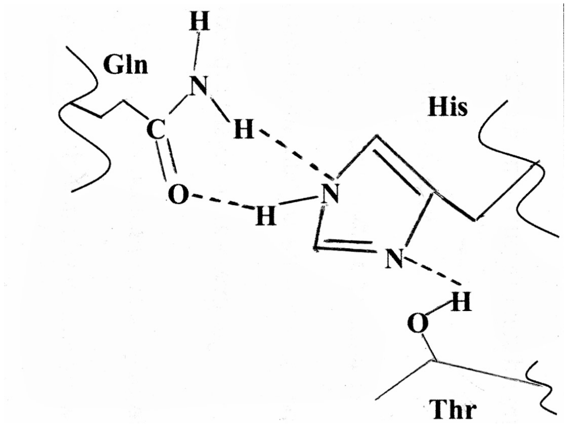


Figure 2. Re-representation of the high-resolution snapshot of ovalbumin at pH 7.

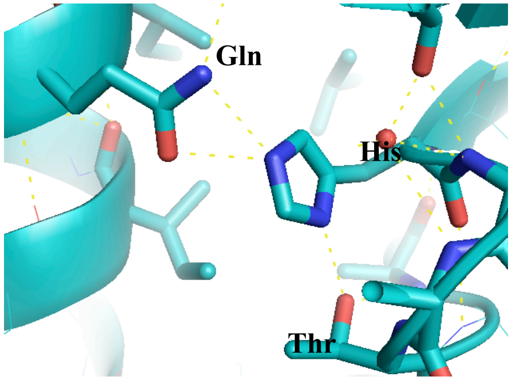


Figure 1. High-resolution snapshot of ovalbumin at pH 7.

HEAT

Figure 3.

HEAT

Figure 4.

APPENDIX G

BIGGS REVISED STUDY PROCESS QUESTIONNAIRE

This questionnaire has a number of questions about your attitudes towards your studies and your usual way of studying.

There is *no right* way of studying. It depends on what suits your own style and the course you are studying. It is accordingly important that you answer each question as honestly as you can. If you think your answer to a question would depend on the subject being studied, give the answer that would apply to this course, Chemistry 281.

Please fill in the appropriate circle alongside the question number on the ScanTron Sheet that you have been provided with. The letters alongside each number stand for the following response.

A - this item is *never* or *only rarely* true of me

B – this item is *sometimes* true of me

C – this item is true of me about *half the time*

D – this item is *frequently* true of me

E – this item is *always* or *almost always* true of me

Please choose the *one* most appropriate response to each question. Fill the oval on the ScanTron sheet that best fits your immediate reaction. Do not spend a long time on each item: your first reaction is probably the best one. Please answer each item.

Don't worry about projecting a good image. Your answers are CONFIDENTIAL.

Thank you for your cooperation.

1. I find that at times studying gives me a feeling of deep personal satisfaction.
2. I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.
3. My aim is to pass the course while doing as little work as possible.
4. I only study seriously what's given out in class or in the course outlines.
5. I feel that virtually any topic can be highly interesting once I get into it.
6. I find most new topics interesting and often spend extra time trying to obtain more information about them.
7. I do not find my course very interesting so I keep my work to the minimum.
8. I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.
9. I find that studying academic topics can at times be as exciting as a good novel or movie.
10. I test myself on important topics until I understand them completely.
11. I find I can get by in most assessments by memorizing key sections rather than trying to understand them.
12. I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.
13. I work hard at my studies because I find the material interesting.
14. I spend a lot of my free time finding out more about interesting topics, which have been discussed, in different classes.
15. I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.

16. I believe that lecturers shouldn’t expect students to study significant amounts of time studying material everyone knows won’t be examined.
17. I come to most classes with questions in mind that I want answered.
18. I make a point at looking at most of the suggested readings that go with the lectures.
19. I see no point in learning material that is not likely to be on the examination.
20. I find the best way to pass examinations is to try to remember answers to likely questions.

APPENDIX H

INFORMED CONSENT FORM

UNC INSTITUTIONAL REVIEW BOARD

Application Cover Page for IRB Review or Exemption

Select One: X___Expedited Review _____Full Board Review ____Exempt from Review
Allow 2-3 weeks Allow 1 month Allow 1-2 weeks

Project Title: Assessing Recall, Conceptualization, and Transfer Capabilities of Novice Biochemistry Students Across Learning Style Preferences as Revealed by Self-Explanations

Lead Investigator Name: Jacqueline L. Hilsenbeck-Fajardo

Department: Chemistry and Biochemistry

Telephone:

Email: hils9369@blue.unco.edu

Research Advisor Name: Jerry P. Suits, Ph.D. / Richard Hyslop, Ph.D.

Department: Chemistry and Biochemistry /Chemistry and Biochem.

Telephone: /

Email: jerry.suits@unco.edu / richard.hyslop@unco.edu

Complete the following checklist, indicating that information required for IRB review is included with this application.

Included Not Applicable

X_____ ______ Copies of questionnaires, surveys, interview scripts, recruitment flyers, debriefing forms.

X_____ ______ Copies of informed consent and minor assent documents or cover letter.

Must be on letterhead and written at an appropriate level for intended readers.

______ X_____ Letters of permission from cooperating institutions, signed by proper authorities.

CERTIFICATION OF LEAD INVESTIGATOR

I certify that this application accurately reflects the proposed research and that I and all others who will have contact with the participants or access to the data have reviewed this application and the Procedures and Guidelines of the UNC IRB and will comply with the letter and spirit of these policies. I understand that any changes in procedure which affect participants must be submitted to SPARC (using the Request for Change in Protocol Form) for written approval prior to their implementation. I further understand that any adverse events must be immediately reported in writing to SPARC.

Signature of Lead Investigator Date of Signature

CERTIFICATION OF RESEARCH ADVISOR (If Lead Investigator is a Student)

I certify that I have thoroughly reviewed this application, confirm its accuracy, and accept responsibility for the conduct of this research, the maintenance of any consent documents as required by the IRB, and the continuation review of this project in approximately one year.

Signature of Research Advisor Date of Signature

Date Application Received by SPARC: ____________________

SPARC/09/03

University of Northern Colorado

INSTITUTIONAL REVIEW BOARD

Application for Expedited or Full Review Guidelines

Section I – Statement of Problem / Research Question

The central objective of the proposed research is to understand the role that learning style preferences have on novice chemistry students enrolled in an undergraduate "fundamentals of biochemistry" course that covers basic topics in general chemistry, organic chemistry, and biochemistry. Consistently, semester after semester, there is a combined dropout and failure rate of 20% - 25% in this course. The purpose of this study is to describe the population of interest according to preferred learning styles based on a self-described preferential continuum of spatial to object to verbal. Once the learning styles have been determined, the preferred learning styles will be correlated to ability to recall knowledge (memorization), to conceptualize (understand), and to transfer knowledge (on near, intermediate, and deep scales). The research questions are as follows:

Q1. Using the Object-Spatial Imagery Questionnaire (OSIQ), what are the predominant, preferential learning styles of novice students in a fundamental biochemistry course (object, verbal, or spatial)?

Q2. What is the relationship between learning style preference and ability to recall, conceptualize, and transfer specific features of protein structure?

Q3. What features (statements, meanings, themes, or general descriptions) are found in a selection of biochemistry novice and expert self-explanations of relationships between molecular phenomena and macroscopic observations (i.e., frying an egg)?

Q4. How do these features described in Research Question 3 vary across learning style preference?

Q5. How do novice written explanations compare with novice diagrammatic representations in descriptions of various aspects of protein structure and function?

Q6. What do written self-explanations reveal about the degree to which novices of certain preferred learning styles are able to transfer new knowledge on the following transfer scales:

a. Near-transfer application involving the same phenomenon and same surface-level context,

b. Intermediate-transfer application involving a similar phenomenon but different surface-level context,

c. Deep-transfer application involving a similar phenomenon but atomic level context.

Section II – Method

Proposed instruments include the following:

7. Object Spatial Imagery Questionnaire

   The questionnaire is designed to assess whether students prefer to be presented with information verbally or visually. The visual preferential learning style is further classified into self-reported spatial and object preferred learning styles. The total questionnaire length is 45 questions, using pre-defined clusters consisting of 15 questions each for the three groups (verbal, visual object, and visual spatial) and must be completed in 10 minutes or less. Scores are based on the Likert-scale, where 1 indicates "strongly disagree" and 5 indicates, "strongly agree" (Appendix A).

8. Demographics / Information form

   The demographics form, Appendix B, will provide descriptive information about the participants. The participants will be asked to provide their gender, year in college, major, self-reported GPA, and previous chemistry courses. Prior / delayed post-knowledge assessment

9. Prior / delayed post-knowledge assessment

   The knowledge assessment, Appendix C, was developed by the researcher (J. Fajardo) during the Spring of 2004 at the University of Northern Colorado Two course instructors and one chemical educator with a biochemistry background validated the questionnaire content. The instrument was designed to include measures of conceptual understanding and measures of recall understanding. A total of ten questions are considered measures of conceptual knowledge and four questions considered measures of recall knowledge. The questions considered measures of conceptual knowledge consist of both diagrammatic and open-ended written components, and are designed to be measures of understanding. All four diagrammatic components have an associated written component. Two open-ended written questions considered conceptual in nature do not have an associated diagrammatic component. In the four questions with concurrent diagrammatic and open-ended components, students are instructed to explain their diagram using the open-ended written component. All questions on the knowledge questionnaire involve protein structure or enzyme action in some way. Recall questions are all multiple-choice questions (with only one correct response) and are all based on protein structural hierarchy. The recall component was designed to test ability to remember information. It is not a measure of understanding.

10. Frying egg storyboard (student generated)

    The storyboard template, Appendix D, will be given to the participants prior to viewing the animated tutorial (Appendix D). They will be asked to storyboard, using both pictorial representations and written explanations, the process of frying an egg. Data will be coded according the structure-behavior-function theory, and the pictorial and written components will be compared to assess the level of consistency.

11. Self-paced frying egg animation tutorial questionnaire based on the following online animation: *http://www.sumanasinc.com/webcontent/anisamples/nonmajorsbiology/proteinstructure.html*

    The animation questionnaire, Appendix E, will be distributed to all students during the 7th week of laboratory (Appendix E). This lab session was chosen for two main reasons. First, the students will have had instruction during lecture on fundamental protein structure concepts and will be familiar with the content of the animation. Second, the lab is typically complete within one and one half hours; thus, there is ample time to incorporate the animation tutorial. The tutorial questionnaire was designed to foster the generation of self-explanations or self-explanation inferences from the students. It has been noted that many students attempt to establish a causal relationship between continuous, dynamic events, a process called naïve reasoning (Goodwin and Johnson-Laird, 2006). Questions from the questionnaire can be classified as recall, conceptual, evaluation (regarding features of the animation), or transfer.

12. Near, intermediate, and deep transfer assessments

    The transfer component, Appendix G, consists of assessments designed to measure transfer of knowledge as near, intermediate, and deep. Students' ability to transfer knowledge will be measured and categorized using these scales. For the near-transfer application, students will answer a series of questions based on knowledge gained by viewing the animation. Ultimately, the students must generate a self-explanation(s) to justify an answer.

1. Participants

   a) The participants are adults (18 years and over) and are not considered vulnerable (e.g., prisoners, illegal immigrants, pregnant, cognitively impaired, financially destitute).

   b) Participants from two sections of Chemistry 281 will be solicited for participation. The same instructor, Richard Hyslop, Ph.D. is a co-advisor of the project and teaches both sections.

   c) The primary researcher (J. Fajardo) will introduce herself to both sections of Chemistry 281 during the first month of Spring 2007. She will also hand out consent forms that describe the project in terms of purpose, time needed for participation, research methods, goals, and reimbursements.

   d) The primary researcher (J. Fajardo) will emphasize that participation is not mandatory, however each persons' individual results will be fully available to the student at any time. They will be able to learn what their primary learning style is and how that influences their ability to understand fundamental dynamic principles of biochemistry. The data will be coded using the first 8 characters of their bearmail email address for confidentiality purposes.

e) Confidentiality of the data will initially be maintained through a character-coding scheme (the first eight characters of the participants bearmail email address). There will not be one piece of data collected that has the participant's full name. The first eight characters of the bearmail email address consists of the first four letters of the participants last name followed by four randomly generated numerical characters.

After data are collected, each bearmail identification number will be converted to a code, thus maximizing confidentiality. This code will be formatted as the following: "section number_three random digits". The three random digits will be selected using a random numbers table. After the bearmail identifications are converted to this code, the top part of each page containing the bearmail identification provided by the student will be sliced off and shredded.

All data, including signed consent forms, questionnaire responses, and audio tapes, will be separated and stored in two separate locked file cabinets in the Chemistry Department at the University of Northern Colorado. The office numbers where the data will be locked and stored are Ross 3526 and Ross 3580 (the offices of the primary research advisors).

f) The informed consent form is attached (Appendix H).

g) There are no special arrangements needed to protect the safety of the participants.

h) Participants my visit the primary researcher (J. Fajardo) at any time in Ross 3530 to be debriefed of their individual results or anything pertaining to the research. The primary researcher (J. Fajardo) may ask if they are surprised by the results (particularly on the learning style preference questionnaire or the revised Biggs study process questionnaire.

2. Procedure

a) Approximately 100 students enrolled in two sections of a "fundamentals of biochemistry" course at a mid-sized western university will be solicited for participation. The expected participation rate is 70%-75% of the combined enrollment from each section, based on pilot study participation rates. The sections were selected on the basis of instructor – the instructor is the same as that in the exploratory and pilot studies, thus minimizing a potential instructor effect.

b) Ideally, students will be solicited for participation during the first month of the semester during the lecture component. However, due to inherent time constraints in lecture, solicitation could be scheduled during the laboratory component. The OSIQ will require 10 minutes to complete. The IRB consent form should take no more than 5 minutes to review and sign. The demographics form should take no more than 10 minutes to complete.

Approximately one-quarter way through the semester, prior to starting the unit on biochemistry, students in the selected sections will be asked to complete an "advanced organizer" on protein-structure related material (this will be the pre-assessment). All participants will be required to complete the pre-assessment for further participation in the research. Near the end of the semester (several weeks after the conclusion of the protein structure unit), participants will have the opportunity to make modifications on their own copy of the pre-assessment (they will make modifications on a photocopy of their original pre-assessment using either a purple or green pen). Ideally, the pre- and post- assessments should be completed during the lecture component. If unforeseeable time constraints dictate, the pre- and post-assessments will be distributed in the laboratory. The post-assessment will be used to assess knowledge gain after completing all components of the research. The goal of this test is to assess the typical students knowledge and understanding of fundamental concepts of biochemistry before and after they have received lecture on the material through the professor and after viewing an animation aimed at connecting macroscopic observations with microscopic phenomenon. The primary research (J. Fajardo) will use a rubric for evaluating written responses and student-drawn pictorial representations to numerically evaluate each student response. The rubric ranges from 0 to 4, with 0 indicating blank or nonsense; 1 indicating significant misconception present; 2 indicating apparent surface-knowledge present but little deep understanding; 3 indicating apparent understanding on a deeper level; 4 indicating expert-like deep conceptual understanding. Near the end of the semester, students will be asked to modify their pre-assessment to the best of their ability (this will be the post-assessment). Pens of a different color will be provided.

Approximately midway through the biochemistry unit, students will complete a questionnaire pertaining to a frying egg animation that they will view during the laboratory component. Initially, students will be asked, "What happens to a protein when you heat it", and will be given several options (changes shape, breaks into pieces, denatures, other). They will also be asked to explain why having a prolonged high fever is potentially detrimental. Students will be informed that this prior knowledge assessment will not be graded and will be used solely for the purposes of the research. Data from students who are not participants in the research study will not be used.

Students will then complete a storyboard about what goes on when you fry an egg, using pictorial representations and written explanations. This storyboard will serve as a prior knowledge assessment of their understanding of protein denaturation and aggregation. Students will then re-order a jigsaw puzzle composed of 4 snapshots taken from the animation they are about to see and they will explain their choices for ordering in a textbox provided below each snapshot. Students will then view an animation of frying an egg. The selected animation was chosen because it incorporates macroscopic and surface-level observations with global dynamic molecular-level events. Due to the global familiarity of the context (frying an egg), the animation may provide a cognitive anchor for the students, as well as a comfortable setting.

Two versions of the animation will be used; continuous play with narration and step-through with text and built-in pauses. Students will be randomly assigned to each version, such that approximately half of all participants view one version, and the other half of all participants view the alternate version. After viewing the animation, students will answer the post-animation questions (recall, conceptual, transfer, and evaluation-type questions) and turn in the entire questionnaire to their laboratory instructor. At least two experts in biochemistry will be solicited to view the animation; one expert will view the step-through version and another will view the narrated version. The experts will also be asked to complete the post-animation questionnaire.

All students will receive a laboratory grade for the tutorial, however only the reports of those who are participants in the research study will be collected by the researcher, photocopied, and used for research purposes. The original reports will be promptly returned to the students.

Ideally, the transfer component would be completed during the lecture component after they have completed the frying egg animation tutorial. Due to the time constraints, however, it could be distributed during the laboratory component the weeks following animation week (weeks 8 or 9). The transfer component typically takes students 15-30 minutes to complete, so it could be incorporated into one of the gel electrophoresis labs if necessary.

A group of students will be selected to participate in a one-on-one interview session where they will provide verbal explanations to their written responses. Students chosen for the interview portion of the study will be selected using a purposeful sampling technique (Creswell, 1998). Interview participants will be selected on the basis of their learning style preferences and pre-assessment performance. I anticipate having three groups initially: high object / low spatial; high spatial / low object; undifferentiated (equal object and spatial); I will then sub-classify these three groups according to performance on the pre-assessment (high or low) for a total of six groups (a minimum of two students in each group will be sought). I will give each interview participant the Vandenberg mental rotations test to include in the descriptive profile of each student.

c) No deceptive practices of any kind will be used in the course of the proposed research study.

d) Copies of all instruments to be used in data collection are provided (Appendices A-G. The interview questions are not standardized, and the types of questions will be based on data collected by the researcher. Topics to be covered are interpretation of the written and pictorial data (does the student agree with the primary researcher's interpretation), learning style results, and Biggs study style results. The interviews will be recorded on an audio tape recorder, and the participant will be identified by the last four numerical characters of their bearmail email address for confidentiality. Tapes will be destroyed following transcription.

3. Proposed data analysis:

Data analysis, generally speaking, will be both qualitative and quantitative. Initially over 100 pre-assessment surveys will be collected from the Chemistry 281 students. These will be scored using a rubric based on two components – a verbal (written) component and a pictorial (diagrammatic) component. The rubric will consist of a range of levels from 0 through 4, where 0 is no conception or nonsense, and 4 is full understanding. Each question in the survey will be assigned a "score" consisting of a numerical component and a "type" component. An example is 1V_2D, which would indicate the student had both a verbal and diagrammatic component to their response, with a slightly better understanding diagrammatically than verbally. Correlations will be sought between learning style preference and other facets of the data, including demographic information, gain in conceptual written scores, gain in conceptual diagrammatic, gain in recall scores, and ability to transfer knowledge on the three pre-defined scales.

Qualitative Analysis

Qualitative data analysis will be categorical in nature. Survey responses and interviews will be organized into the following categories: nonsense or no conception (0), direct reproduction with no understanding (1), some conception prevailing with misconception (2), partial understanding with some misconception (3), and full understanding - expert (4). Qualitative data analysis will consist of an interpretive analysis of written, diagrammatic, and verbal responses as well as detailed analyses of self-explanations and descriptions for themes. The researcher, i.e., J. Fajardo, will look for relationships between corresponding written and diagrammatic components to look for features that are present or not present in pictorial versus written explanations or descriptions.

Qualitative data will also be categorized according to keyword (descriptive, action, matter), misconceptions (poor understanding of concept, absence of concept, or appropriate use of concept), as well as knowledge integration. Here, data coding will initially be focused on macroscopic (non-salient) versus microscopic (salient) features of student-generated drawings, representations, written explanations, and written descriptions. These features will then be categorized according to whether they describe matter, an event, or an abstraction. How these components are integrated can then be assessed. A recently published article provides a reasonable foundation for using written self-explanations and drawings to understand mental model organization (Uttal, Fisher, Taylor, 2006). Also, strategies for comparing student-derived pictorial representations have been described (Panagiotaki, Nobes, and Banerjee, 2006).

Quantitative Analysis

The OSIQ data will be quantitatively analyzed through ANOVA to find significant mean differences among the three learning style groups (verbal, visual spatial, and visual object). Additionally, principal component analysis (PCA) will be conducted to verify that the three factors are actually present within our sample. Finally, discriminant analysis will be performed to classify each individual into the well-defined populations of spatial, object, or verbal.

Once it is known what the global and individual learning style preferences are, multiple linear regression will be used to determine if there are any correlations between preferred learning style (the independent variable) and dependent variables such as gain in recall knowledge, gain in conceptual knowledge (both written and pictorially), degree of transfer on each transfer scale, as well as other variables as indicated on the demographics information form. Each data set will also be analyzed descriptively. A summary of data collection and analysis procedures is provided according to research question below:

1) Using the Object-Spatial Imagery Questionnaire, what are the predominant, preferential learning styles of novice students in a fundamental biochemistry course (object, verbal, or spatial)?

and

2) What is the relationship between learning style preference and ability to recall, conceptualize, and transfer specific features of protein structure?

   a. During week 1 of Spring 2007, students enrolled in two sections of Chemistry 281, Fundamentals of Biochemistry, will complete the Object Spatial Imagery Questionnaire (OSIQ) (10 minutes).

b. The overall learning style preference for the participants will be determined (the grand mean for each category).

c. Just prior to starting the unit on biochemistry, students in the pre-selected sections will be asked to complete a prior knowledge assessment of protein-structure related concepts.

d. Based on the established rubric, the conceptual component will be evaluated for each participant. Each written description and/or explanation, as well as each diagram or pictorial representation will be assigned a score in accordance with the established rubric.

e. In a quantitative fashion, the individual learning style preferences established from the OSIQ will be correlated to a) the overall individual pre-assessment performance and b) to each written or diagrammatic description or explanation (10 per individual).

3) *What features (statements, meanings, themes, or general descriptions) are found in biochemistry novice and expert self-explanations of relationships between molecular phenomena and macroscopic observations (i.e., frying an egg) and how do these features vary across learning style preference?*

- Approximately midway through the biochemistry unit, students will complete a questionnaire regarding a frying egg animation during the laboratory component.
- The questionnaire is designed to foster the generation of self-explanations or self-explanation inferences from the students.
- The self-explanations will initially be thematically coded for content (according to the presence of constituent knowledge and descriptions of macroscopic observations and microscopic phenomena in their explanations).
- Initially, a 2x4 matrix of data will be arranged and data coded accordingly (with examples provided); the integration will be assessed both horizontally and vertically.

Table 2. An example of how data will be initially categorized using the structure-behavior-function theory.

	Matter	Event	Abstraction	Integration
Macroscopic	▪ Egg ▪ Burner	▪ Turns White ▪ Heat added	▪ Kill bacteria	▪ Yes/No
Microscopic	▪ Protein ▪ H-bond	▪ H-bonds break ▪ Aggregation	▪ Energy ▪ Thermo.	▪ Yes/No

4) *How do novice written explanations compare with novice diagrammatic representations in descriptions of various aspects of protein structure and function?*

This research question will be addressed by conducting a quantitative comparative analysis of individual diagrammatic or pictorial representations and the corresponding written description or explanation (Johnstone, 1993). The established rubric will be used to assign a score to each picture or written statement that will be comparable to each corresponding written component. The scores will be compared using data from the following instruments:

1) Prior-knowledge assessment
2) Post-assessment
3) Frying egg storyboard

5) *What do written self-explanations reveal about the degree to which novices of certain preferred learning styles are able to transfer new knowledge on the near, intermediate and deep transfer scales?*

a. This research question will be addressed by conducting a quantitative comparative analysis of individual diagrammatic or pictorial representations and the corresponding written description or explanation.
b. Based on a rubric similar to that described for research question 1, the transfer component will be evaluated for each participant. Each written description and/or explanation, as well as each diagram or pictorial representation will be assigned a score in accordance with the established rubric.
c. In a quantitative fashion, the individual learning style preferences established from the OSIQ will be correlated to a) the overall transfer performance and b) to each written or diagrammatic description or explanation.

The quantitative components are designed to be inferential in nature. Thus the following hypotheses are established below.

Research question 1. The null hypothesis states that there are no significant differences between the means of spatial, object, and verbal learning preferences. The alternative hypothesis is that at least one of the means is significantly different from the other means. Discriminant analysis will be used to place each individual into one of 3 previously defined groups. Significance of group mean differences will be determined using ANOVA

Research question 2. The null hypothesis states that there is no relationship between learning style preference and ability to recall, conceptualize, and transfer specific features of protein structure. The alternative hypothesis is that at least one significant relationship will be found between learning style preference and ability to recall, conceptualize, and transfer specific features of protein structure. Multiple Linear Regression (MLR) between rubric scores and individual learning style preference; the rubric scores will be assigned qualitatively.

Research question 3b. The null hypothesis indicates that there are no significant variations in thematic features of self-explanations according to learning style preference. The alternative hypothesis is that at least one significant variation exists in thematic features of self-explanations according to learning style preference. Data gathered for part (a) will be coded qualitatively as described in the Methods. MLR between scores determined qualitatively and individual learning style preferences will be used to assess part (b).

Research question 4. The null hypothesis indicates that there are no significant differences between written and diagrammatic components of the same concept. The alternative hypothesis is that there will be at least one significant difference between diagrammatic and written components (from the same conceptual question). Written and diagrammatic components will be coded qualitatively according to a rubric. Significance of overall mean differences between pre- and post- assessment for each component will be determined using ANOVA.

Research question 5. The null hypothesis states that thematic analysis of the open-ended written self-explanations will reveal no features that can be correlated to learning style preference on all of the transfer scales. The alternative hypothesis is that thematic analysis of open-ended written self-explanations will reveal features that can be correlated to learning style preference on at least one of the transfer scales. Ability to transfer will be coded qualitatively and assigned a score(s). This rubric score(s) will be correlated to individual learning style preference using MLR.

Section III – Risks/Benefits and Costs/Compensation to Participants

There are no anticipated risks to participants. Benefits include the offer of free tutoring to volunteer participants as well as the added benefit of new insights regarding their understanding of fundamental biochemistry concepts.

Light refreshments will be provided to all participants, and \$10.00 gift cards to Barnes and Noble will be given to participants who complete the interview portion of the research.

Section IV – Grant Information

Portions of the study (payment of OSIQ license and \$10 Barnes and Noble gift cards will be provided by the Chemistry department Chemical Incentive Fund.

Section V – Documentation Please see the attached appendices, A-H.

University of Northern Colorado

Project Title: Assessing Recall, Conceptualization, and Transfer Capabilities of Novice Biochemistry Students Across Learning Style Preferences as Revealed by Self-Explanations

Researchers: Jacqueline L. Hilsenbeck-Fajardo, Doctoral student in the chemistry education program

Phone number:

Research Advisor: Jerry P. Suits, Ph D., School of Chemistry, Earth Science, and Physics, UNC

Phone Number:

Research Advisor: Richard Hyslop, Ph.D., School of Chemistry, Earth Science, and Physics, UNC

Phone Number:

Purpose: Section I – Statement of Problem / Research Question

The central objective of the proposed research is to understand the role that learning style preferences have on novice chemistry students enrolled in an undergraduate "fundamentals of biochemistry" course that covers basic topics in general chemistry, organic chemistry, and biochemistry. The purpose of this study is to describe the population of interest according to preferred learning styles based on a self-described preferential continuum of spatial to object to verbal. Once the learning styles have been determined, the preferred learning styles will be correlated to ability to recall knowledge (memorization), to conceptualize (understand), and to transfer knowledge (on near, intermediate, and deep scales). The research questions are as follows:

1. Using the Object-Spatial Imagery Questionnaire (OSIQ), what are the predominant, preferential learning styles of novice students in a fundamental biochemistry course (object, verbal, or spatial)?
2. What is the relationship between learning style preference and ability to recall, conceptualize, and transfer specific features of protein structure?
3. What features (statements, meanings, themes, or general descriptions) are found in a selection of biochemistry novice and expert self-explanations of relationships between molecular phenomena and macroscopic observations (i.e., frying an egg)?
4. How do these features described in Research Question 3 vary across learning style preference?

5. How do novice written explanations compare with novice diagrammatic representations in descriptions of various aspects of protein structure and function?
6. What do written self-explanations reveal about the degree to which novices of certain preferred learning styles are able to transfer new knowledge on the following transfer scales:
    a. Near-transfer application involving the same phenomenon and same surface-level context,
    b. Intermediate-transfer application involving a similar phenomenon but different surface-level context,
    c. Deep-transfer application involving a similar phenomenon but atomic level context.

Procedure:

1. January 2007 – the following materials will be completed
    a. Internal Review Board (IRB) consent form (lecture or laboratory – 5 minutes)
    b. The object-spatial imagery questionnaire (OSIQ) (lecture or laboratory - 10 minutes)
    c. The demographics form (lecture or laboratory - 10 minutes).
2. March 2007
    a. Complete the prior-knowledge assessment (lecture or laboratory – 15 minutes)
    b. View the "Frying Egg' animation and complete questionnaire (laboratory – 30 minutes)
    c. Frying egg animation transfer component (laboratory – 20 – 30 minutes)
3. April 2007
    a. Complete the post-knowledge assessment (lecture or laboratory – 20 minutes)
    b. Solicitation for interview participation (30-60 minutes, outside of class)

Risks and Benefits to Participants:

There are no anticipated risks to participants. Benefits include the offer of free tutoring to volunteer participants as well as the added benefit of new insights regarding their understanding of fundamental biochemistry concepts.

Compensation:

The primary researcher will provide $10.00 gift cards to Barnes and Noble which will be given to participants who complete the interview portion of the research. In addition, any participant (interviewee or non-interviewee) may seek tutoring from the primary researcher, J. Fajardo, during the course of the Spring 2007 semester. You may request a time to meet at hils9369@blue.unco.edu or stop by Ross 3530 to request assistance.

Confidentiality: Confidentiality will be maintained during the course of data collection and analysis. Signed consent forms will be stored separately from the data so that names cannot be linked to the information collected. Additionally, we will use pseudonyms rather than participants' names in all reports of our findings. Audio-tapes of interviews will be transcribed with pseudonyms replacing participants' names. The first eight characters of the participants email address will be used for identification, where the first four characters are the first four letters of the last name, and the last four characters are randomly assigned numerical values.

Questions: If you have any questions about the design or results of this study, or about the nature of your participation, you may ask now or at any time during the course of the data collection and subsequent analysis. You may also contact my advisor or myself at the phone numbers indicated at the top of this form.

Thank you for considering participation in our research.

Sincerely, ________________________

Participation is voluntary. You may decide NOT to participate in this study and if you do begin participation you may still decide to stop and withdraw at any time. Your decision will be respected with no coercion or prejudice. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Sponsored Programs and Academic Research Center, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1907.

Print name_______________________________________

____ __________________

Participant's Signature Date

____ __________________

Researcher's Signature Date

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(Please initial here to indicate that you have read the IRB consent form)