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Following Faculty Engaging in Collaborative Action Research to Approach Curricular Change in Undergraduate Biochemistry

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FOLLOWING FACULTY ENGAGING IN COLLABORATIVE ACTION RESEARCH TO APPROACH CURRICULAR CHANGE IN UNDERGRADUATE BIOCHEMISTRY

by

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ABSTRACT

This study engaged in a curricular redesign of an undergraduate biochemistry course undertaken by a collaborative action research group. The initial portion of this study investigated student conceptual understanding of foundational concepts via a rigorously tested concept inventory. the impact of the redesign on the student foundational conceptual understanding was determined by comparison with a baseline data set. Findings suggest that students enter and exit the biochemistry course with little understanding of key foundational concepts. Examination of student performance after the incorporation of creative exercises showed a significant impact of the curricular changes on two of the concepts of interest. In addition to the quantitative investigation, this study explored the experiences of the faculty as they participated in the action research on undergraduate biochemistry education. Through the faculty interviews, descriptions of their experiences and reflections on the project's quantitative data provided a deeper understanding of the action based curricular design. The final portion of this study included a qualitative analysis investigated the approaches students take while working through the creative exercises via think-aloud interviews. The think-aloud interview format was also employed to explore the students' interpretations of the quantitative instrument. This portion of the study revealed a misalignment between the student interpretation of the quantitative instrument and its structure. The findings from the creative exercise interviews were used to propose a model of student approaches to solving the activity which reveals both critical and promising features such as a prevailing concern of faculty expectations and contemplating the quality of responses.

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CHAPTER 1: INTRODUCTION

Project Initiation

This dissertation follows a small group of faculty as they collaboratively alter the curriculum of an undergraduate biochemistry course in a scholarly manner. My advisor and I, as chemistry education researchers, help guide the faculty in their efforts to change their current curriculum. This guidance has included: finding a pre/posttest from the current literature on biochemistry education to probe student understanding key concepts in chemistry, suggesting course activities from literature that may help improve the faculty's courses and analyzing data collected both by the faculty and by ourselves.

It is important to note that this project was not initiated by myself or my advisor. Rather, it was the faculty who approached our research group expressing their desire to seek guidance on improving their curriculum. The initiation by the faculty was motivated by a dissatisfaction with the ability of the curriculum to elevate the students conceptual understanding. This invitation to collaborate with the faculty in order to explore and address the undergraduate biochemistry curriculum played a role how the project was approached as will be seen in the subsequent chapters of the dissertation.

Positionality of the Researcher

It cannot be denied that I have preconceptions regarding the subject matter of this dissertation. I have been enrolled and completed the undergraduate biochemistry courses offered at the institution. I have also had two of the three faculty members involved in this study as instructors of courses that I was enrolled in as a student. Furthermore, over the course of this project, I have had encounters over the years with the faculty during project meetings and occasional interactions during department events. These interactions both before and after have undoubtedly influenced my perceptions regarding the contents of this dissertation in ways that I am not fully confident that I understand. Therefore, it was imperative that I engaged in various check points within the analysis of the data to avoid unwittingly introducing my preconceptions into the conclusions of this research. These efforts have included research activities such as reflexivity journals, member check and peer analysis review. Such efforts have been included within this thesis, not only as a testament to the rigor of this research, but as means for myself to be transparent as to why I made the decisions that I did over the course of the analysis.

Project Timeline

This dissertation project was initiated during the Fall semester of 2019 and spanned to early within the Spring semester of 2023. Figure 1 provides a visual representation of the collection and the analysis of the data that was included in this dissertation. With this figure, I hope to aid the reader in understanding when the research activities occurred over the course of the project.

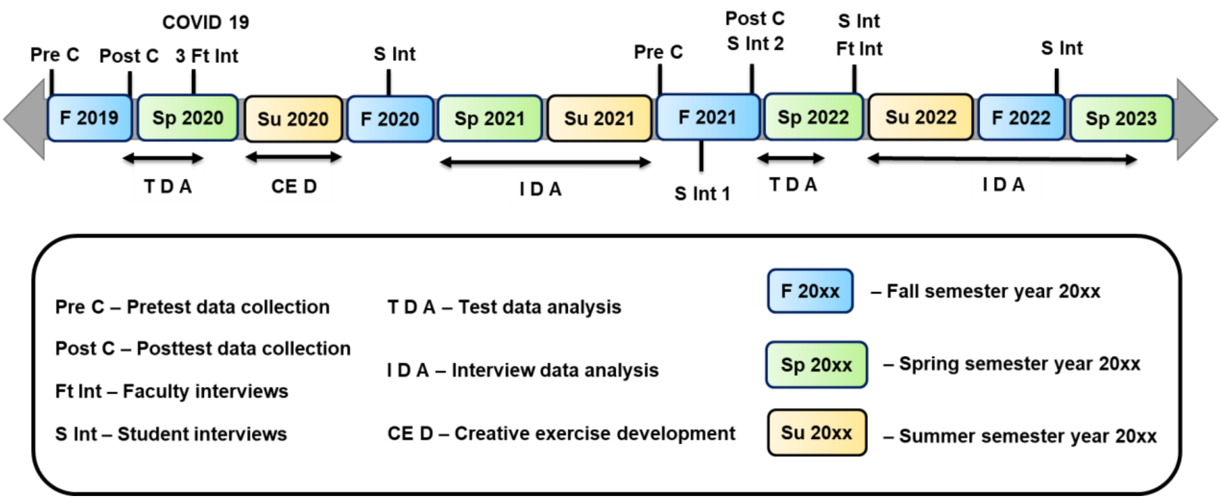

Figure 1: Project timeline map

During the project, my advisor and I interacted with the faculty through in person & virtual meetings and emails to plan and enact the project. The meetings were frequent in the early stages of the project, approximately every two weeks, and then moved to about once or twice a semester in the last year and a half. The initial focus of these meetings were to understand what aspects of the curriculum they wanted to address and what type of data was needed to guide their decisions for change. We curated chemistry education literature and related resources for the faculty to read based on the group discussions to familiarize them with the education research practices. After considering a variety of assessment instruments including self-made assessments, they became most interested in using an established concept inventory. Within this period, we also introduced a selection of evidence-based teaching practices which we felt aligned with their goals including the creative exercises they eventually selected as the intervention.

The faculty were also connected with the internal review process for educational research and the related ethical training. Our meetings involved planning to implementat the instrument within the course while maintaining the integrity of the instrument.

As we progressed through the baseline semester, the focus of our meetings moved towards finalizing the selection of an intervention. After the baseline data was analyzed and the faculty understood where the students struggled with their conceptual understanding, we began to develop the selected intervention (creative exercises as indicated on Figure 1) to focus on those struggle areas. As a group, the faculty decided how the intervention would be implemented within the course sections and the logistics involved with ensuring the faculty could be consistent with integrating the intervention in their individual cources. Subsequent meetings after the implementation of the intervention involved debriefing how the interventions were carried out, sharing how students engaged with the intervention, discussing the data collected, and making adjustments to the implementation as needed.

Impact of COVID 19

The COVID 19 pandemic began fairly early within timeframe of this dissertation as seen in Figure 1. As a result, the pandemic had a considerable and unexpected impact on the direction of this work. The primary impact of COVID on this project was on the quantitative data that we was able to collect. Due to requirements from the original developer of the quantitative instrument, we was unable to use the instrument online and we was therefore unable to gather the quantitative data via the instrument until the course returned to face-to-face classes. Additionally, the sudden shift to an online platform influenced how the interventions selected by the faculty were implemented within the course. The pandemic also provided an additional environmental strain on both the faculty and student participants of this study, which was not present for the baseline student participants. Thus, I have included this reflection of the impact of the pandemic on the details of this dissertation so that the peculiarities of data collection might be better understood by the reader.

CHAPTER 2: LITERATURE REVIEW

Over decades of chemistry education research (CER), evidence-based practices have been developed and implemented to enhance the quality of instruction and improve student performance. By evidence-based practices, I mean practices reported in the literature that benefit student learning and/or success (Eddy et al., 2015; Teo et al., 2014). Many of these practices focus on having students take an active role in the learning process, which has been shown to increase student performance over traditional passive learning formats (Freeman et al., 2014). Furthermore, these practices have had an even greater impact on underrepresented groups' performance and retention in STEM majors (Odom et al., 2021; Theobald et al., 2020; Toven-Lindsey et al., 2015).

Examples of evidence-based practices in higher education chemistry include peer-led team learning and process-oriented guided inquiry learning, both of which promote active engagement of group learners, yet differ in the manner in which the group discussion is managed(Gosser & Gosser, 2001; Moog et al., 2006). These active learning methods have received notable recognition from the CER community for introductory chemistry courses (Cooper & Stowe, 2018; Lang & Bodner, 2020; Teo et al., 2014). Additionally, these methods have been used to improve upper-level chemistry courses such as biochemistry and physical chemistry (Gosser & Gosser, 2001; Loertscher et al., 2014; Platt et al., 2008). Research in biochemistry education has examined additional interventions such as "worked examples plus practice" and "productive failure," which have had a promising impact on student performance (Halmo et al., 2020).

Despite the overwhelming number of studies that demonstrate their effectiveness, these practices are not as widely adopted as the traditional lecture-based courses that still dominate undergraduate STEM education (El-Adawy et al., 2022; Henderson & Dancy, 2007; Stains et al., 2018). Investigations into why lectures have prevailed suggest that a likely culprit has been a lack of consideration of how evidence-based practices can be adapted to fit the teaching settings of each instructor (Henderson & Dancy, 2007). A case study on faculty participation in online communities of practice suggests that practitioners can misunderstand how literature describes the way practices could be best implemented (El-Adawy et al., 2022). Furthermore, a broad examination of STEM education has found that despite faculty interest in departing from lecture-based learning, faculty often struggles with barriers in these practices' implementation (Sansom, 2019). Research has also shown that a faculty's value of and perceived ease of implementation influence their adoption of a new practice (McCourt et al., 2017). Additional research has indicated that faculty members often rely on personal experiences to inform their teaching practices over evidence presented within the literature (Andrews & Lemons, 2015). This observation may relate to faculty's struggles with understanding the available literature (El-Adawy et al., 2022).

Recently, efforts have been made to address this disparity between research and practice in chemistry instruction through a series of professional development workshops (Macaluso et al., 2021). In an after-workshop survey, participants self-reported an increased understanding of evidence-based practices (Macaluso et al., 2021). However, it remains uncertain whether these efforts alone will be sufficient and research is needed to understand how to support faculty's implementation of, and persistence in, using evidence-based practices.

The disparity in research and practice is not restricted to STEM instruction but is an issue in education as a whole (Borg, 2009; Vanderlinde & van Braak, 2010). In the field of English language teaching, Borg (2009) surveyed 505 English teachers (both at a university and non-university level) from across 13 countries and found that the majority of practitioners lacked the necessary time or understanding to read or engage in research in their fields. Similarly, Vanderlinde and van Braak (2010) found practitioners to be concerned with the practicality of research-based practices and struggling with the technical language of the education literature. In their view, so long as the practitioner's role in the educational research process is solely to apply evidence-based practices, this disconnect between research and practice will continue to prevail (Vanderlinde & van Braak, 2010). Instead, researchers are encouraged to increase the involvement of practitioners in educational research so that they can gain both the skills necessary to use evidence-based practices as well as an appreciation for their value. Leach and Tucker (2018) arrived at a similar conclusion in their study on the gap between research and practice in clinical nursing, and they advocated for greater practitioner involvement in the research process.

Since these works, a number of studies have explored approaches to introducing practices to faculty (Corrales et al., 2020; Dancy et al., 2019; El-Adawy et al., 2022; Pelletreau et al., 2018). These studies, though they differed to a degree in their methodologies, largely focused on faculty communities of practice as a tool for professional development (Corrales et al., 2020; Dancy et al., 2019; El-Adawy et al., 2022; Pelletreau et al., 2018). Communities of practice can be defined as a group of individuals who possess common interests and work together to fulfill goals related to such interests (Dancy et al., 2019). These studies also shared similar conclusions:

faculty members working together to explore and implement practices suggested by the literature tend to sustain their efforts and grow in their appreciation for educational research (Corrales et al., 2020; Dancy et al., 2019; El-Adawy et al., 2022).

Action Research

A model of research that fits the implications these studies made and the communities they explored is action research: a framework that involves practitioners examining the current needs of their courses and selecting methods they feel best address those needs (Efron & Ravid, 2019; Norton, 2009). This form of research is not restricted to practitioners managing their inquiry alone; rather, it can be a collaborative process involving other practitioners and researchers within the field (Bishop-Clark & Dietz-Uhler, 2012). Although action research is an umbrella term for a variety of research, it is based on the foundational concept of moving from observing the state of the course, through considering how to address any existing issues, to taking action (Stringer & Aragón, 2020).

Action research can be conducted in any field of study. In their recent review of biochemistry education research, Lang and Bodner (2020) described the benefits of adopting action-based research practices. Specifically, they articulated the value of practitioners' understanding of how interventions can be better applied to specific student groups rather than their universal application of an intervention (Lang & Bodner, 2020). Biochemistry is a unique upper-level chemistry class that requires students to bring together multidisciplinary knowledge from prerequisite courses. Moreover, a considerable amount of research has been conducted to implement evidence-based practices for beginning general chemistry courses, but researchers have not observed an impact of these practices on student performance in biochemistry (Lewis, 2014; Teo et al., 2014). Although providing a strong foundation in any discipline is certainly important, an excessive focus on earlier courses does little to benefit students in upper-level courses (Lewis, 2014). Hence, further research is needed to understand and support faculty efforts in implementing evidence-based practices in upper-level courses.

A frequent tactic employed within action research is self-reflection on the outcomes of an intervention by participating researchers (Leitch & Day, 2000; Magee et al., 2020). These reflection experiences and opportunities to make choices in the research process are a predominant feature of the early and late phases of collaborative action research in particular (Magee et al., 2020). Within the context of biochemistry, thus far, these particular reflections have only been examined though surveys in the published literature (Loertscher et al., 2014). Though research on biochemistry faculty experiences in action research has been quite limited, a study published as part of a PhD dissertation examined the general experiences and beliefs of faculty teaching biochemistry via a hermeneutic analysis of faculty interviews (Lang, 2018). This dissertation seeks to add to the literature by providing a closer look at faculty experiences and perceptions of students' conceptual understanding as well as their experiences engaging in the research.

Creative Exercises

Creating tools and practices to foster the development of student conceptual understanding is an area of great interest in chemistry education (Cooper & Stowe, 2018). This drive to develop new practices to target conceptual understand has been motivated by a concern that traditional practices lead only to minimal understanding in chemistry (Cooper & Stowe, 2018; Freeman et al., 2014; Lewis & Lewis, 2005). While the publications of novel practices and activities in chemistry education have shown promising results, the manner in which students engage with new practices to improve their conceptual understanding remains to be explored (Teo et al., 2014). One example of an activity that strives to enhance students engagement with their own conceptual understanding is an assessment known as creative exercises (Lewis et al., 2010; Trigwell & Sleet, 1990).

Creative exercises were initially developed by Trigwell and Sleet in 1990 as means to remove the direction from chemistry problems so that student would elicit their own understanding of the topics. These exercises provoke student understanding of chemical concepts by offering students a set of information as a prompt and asking them to give as many relevant and accurate statements about that prompt (Trigwell & Sleet, 1990). From Figure 2, it can be seen that the example creative exercise does not contain the typical problem structure of a leading question. Grading of these exercises often involves instructors setting a minimum required number of accurate and relevant statements for students to receive full credit (Lewis et al., 2010; Lewis et al., 2011). Furthermore, inaccurate and irrelevant statements do not negatively impact a student's score on a given creative exercise (Trigwell & Sleet, 1990).

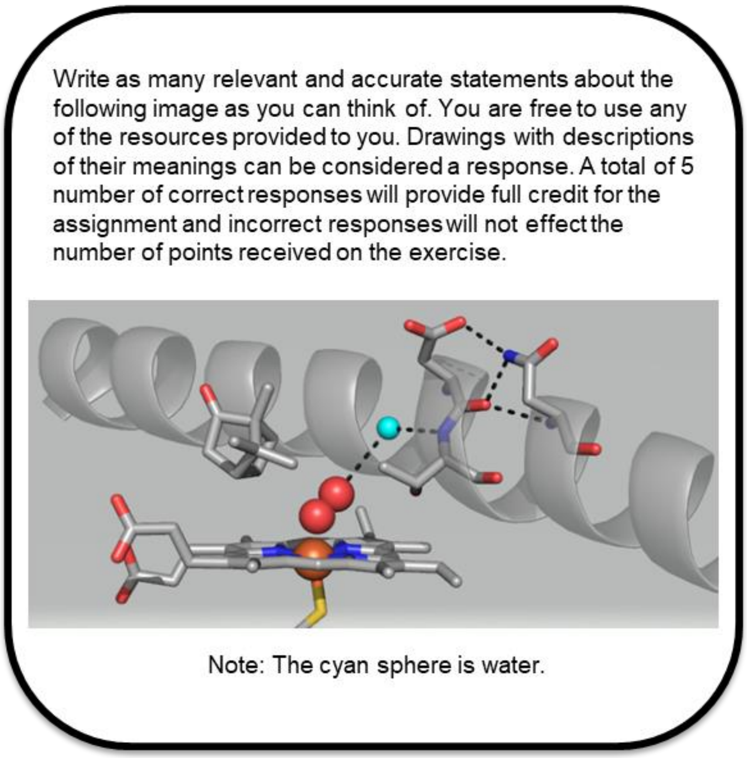

Figure 2: Example creative exercise prompt from faculty developed exercises, prompt image created by faculty using PyMol.

After their initial appearance, creative exercises remained dormant in the literature until they were revived by Lewis et al. in 2010. Within this reexamination of creative exercises, data described that the exercises received a generally positive outlook from the students, which literature suggests is critical to the successful application of new practices (DeMonbrun et al., 2017; Lewis et al., 2010). In addition to examining the potential value of creative exercises, early explorations of the creative exercises were also extended to examining the validity and reliability of these activities (Lewis et al., 2011). This early exploration of the validity and reliability indicated that the creative exercises were behaving as intended, though a few areas of validation remain to be explored by the community (Lewis et al., 2011).

Although there have been only a handful of publications on creative exercises, these manuscripts described a variety of different investigations on the value and applicability of creative exercises in chemistry education. Much of the earlier studies on creative exercises utilized these activities as individual homework assignments or test questions and were largely grounded in introductory chemistry courses (Lewis et al., 2010; Lewis et al., 2011; Trigwell & Sleet, 1990; Warfa & Odowa, 2015; Ye & Lewis, 2014). These studies noted that the exercises were able to draw out the prior knowledge of the participating students as well as explore alternative conceptions of students (Lewis et al., 2010; Warfa & Odowa, 2015). Initial attempts to correlate student performance on the creative exercises and their performance in the class did not yield significant results, though this lack of correlation was attributed to the manner to which the exercises were scored (Lewis et al., 2011).

More recent literature on creative exercises has seen a shift away from utilizing creative exercises as an individual assignment and have begun to incorporate them into classroom activities (Gilewski et al., 2019; Mai et al., 2021; Robert et al., 2016). This transition to group activities was secondary to the focus of the study (Robert et al., 2016), but later publications would see the exercises as the focus of the paper (Gilewski et al., 2019; Mai et al., 2021). Furthermore, later publications have also branched away from applying creative exercises as an intervention in introductory chemistry curricula (Mai et al., 2021; Ngai & Sevian, 2018; Warfa & Odowa, 2015). This movement away from introductory chemistry led to two publications of creative exercises in biochemistry (Ngai & Sevian, 2018; Warfa & Odowa, 2015) and most recently their application in organic chemistry (Mai et al., 2021).

Quantitative methodologies have been relied upon to approach the study of creative exercises in the available literature(Lewis et al., 2010; Lewis et al., 2011; Mai et al., 2021; Trigwell & Sleet, 1990; Warfa & Odowa, 2015). This initial focus on quantitative analysis was intended to better understand the potential impacts on learning as well as to provide evidence that the exercises were eliciting the intended responses from students(Lewis et al., 2010; Lewis et al., 2011; Mai et al., 2021; Trigwell & Sleet, 1990; Warfa & Odowa, 2015; Ye & Lewis, 2014). One of the more recent studies in creative exercises provided a substantial investigation on the their impact on student performance and showed a significant improvement in a smaller class setting (Gilewski et al., 2019). The authors of this study argued that the lack of impact of the exercises on the larger course setting may have been due more to their application than the difference in settings (Gilewski et al., 2019).

That said, a number of studies have also explored creative exercises from a qualitative lens (Gilewski et al., 2019; Lewis et al., 2010; Mai et al., 2021; Ye & Lewis, 2014). Much of the current qualitative inquiries on creative exercises have centered around response analysis and open-ended surveys on student experiences of the exercises (Gilewski et al., 2019; Lewis et al., 2010; Mai et al., 2021; Ye & Lewis, 2014). Exploration of student experiences with creative exercises in later studies were consistent with the earlier literature in that the exercises were generally viewed in a positive light, though students did note anxiety when first encountering creative exercises (Gilewski et al., 2019). As for the analysis of student responses, researchers found that students were linking prior knowledge with current topics which varied across the semester (Gilewski et al., 2019; Mai et al., 2021; Ye & Lewis, 2014).

While the literature on creative exercises have indicated that student do indeed link concepts through creative exercises and have explored the kinds of concepts elicited, the process by which the students produce their responses has yet to be investigated. This concern for how the students produce their responses to the exercises and has been a limitation of the published works and has even led to the development of an additional activity to probe this concern (Ye et al., 2015). Two works in particular call for qualitative observation of student engagement with creative exercises to address these concerns in the literature (Ngai & Sevian, 2018; Warfa & Odowa, 2015). While efforts have been made to validate creative exercises, the validity of the creative exercises, in terms of substantive and consequential validity, has yet to be fully explored in the literature (Lewis et al., 2011).

This dissertation also seeks to address the gaps indicated by the literature by observing these processes by which students engage with the creative exercises via Think-aloud (clinical) interviews., Clinical interviews also act as an additional avenue to explore the validity of the creative exercises (Arjoon et al., 2013). These interviews were conducted in the context of an undergraduate biochemistry course that has incorporated creative exercises into the curriculum.

Theoretical Frameworks of Learning

The theoretical framework which guided our selection of the creative exercises was transfer of learning. This framework defines a feature of learning known as transfer, a multifaceted term describing the variety of different movements of knowledge by a person (Lobato, 2006). This project focused on one specific form of transfer known as similarity transfer which describes the ability of a person to utilize their knowledge in a new situation (Dori &

Sasson, 2013; Larsen-Freeman, 2013). This framework was selected due to its similarity to the learning objectives of the faculty when they first approached our research group to initiate this project. The overall framework, however, has had considerable controversy over its variance of meaning depending on the form of transfer being described (Carraher & Schliemann, 2002; Goldstone & Wilensky, 2008; Lobato, 2006). Despite the controversy surrounding the framework, similarity transfer continues to have a presence in the theoretical underpinnings of educational research (Noesgaard & Ørngreen, 2015; Pai et al., 2015; Scherer et al., 2019).

As for the theoretical underpinning of creative exercises, the frameworks used to describe how and why these exercises influence learning has changed with time. Initially, creative exercises were framed by deep learning vs. surface learning framework, which distinguishes learning into a dichotomy (understanding vs. rote memorization) (Beattie et al., 1997; Trigwell & Sleet, 1990). While this may have been the goal of creative exercises at the time, literature has since perceived creative exercises as a tool to elicit prior knowledge (Lewis et al., 2010; Lewis et al., 2011; Warfa & Odowa, 2015; Ye & Lewis, 2014). This shift resulted in creative exercise researchers adopting constructivism as the guiding theoretical framework (Lewis et al., 2010; Lewis et al., 2011; Warfa & Odowa, 2015; Ye & Lewis, 2014). The constructivist theory of learning suggests that conceptual understanding is built upon prior knowledge (Fosnot & Perry, 1996; Taber, 2012). Thus creative exercise researchers argue that the activities ability to elicit prior knowledge is valuable to both the development of student conceptual understanding and the instructors observation of such learning (Lewis et al., 2010; Warfa & Odowa, 2015).

More recent studies have since adopted yet another framework in order to describe the role that creative exercises can play in enriching the learning of students. This latest framework, Ausubel's assumptive theory of learning, describes learning as a spectrum between route learning and "meaningful" learning (Ausubel, 1960; Ausubel, 1963; Gilewski et al., 2019). Meaningful learning was described by the framework as a complex understanding of a subject achieved by the linking of existing knowledge with newly acquired knowledge (Ausubel, 1960; Ausubel, 1963; Gilewski et al., 2019). Through assumptive theory of learning, later researchers have attempted to bridge together the earlier frameworks that were used to guide the construction and focus of the creative exercises. Assumptive theory of learning maintains the initial goals of the exercises (as one could argue that meaningful learning essentially describes the deep learning of the original guiding framework). Assumptive theory of learning also describes how these goals can be achieved by creative exercises, the linking of prior knowledge with new topics elicited by the exercises leads to the development of a complex understanding of the concepts. Furthermore, these frameworks are aligned with the similarity transfer and add depth to the original learning framework of the project.

Quantitative Assessment Instrument

The instrument of foundational concepts in biochemistry (IFCB) was chosen to probe students' key conceptual understandings of biochemistry. Villafañe et al. (2011a) developed this instrument as a 24-item multiple choice assessment to observe a student's understanding of eight prerequisite concepts deemed critical to success in biochemistry. The faculty associated with this dissertation selected four concepts from the modified version of the IFCB (hydrogen bonding; alpha helices; pK_a; and Gibb's energy, which was referred to as thermodynamics by the faculty), which they thought were critical for students' success in their biochemistry courses (Xu et al., 2017). Three questions, which were uniquely formatted to not be repetitive, covered each concept (Villafañe et al., 2011a). The distractors for each question were based on preidentified misconceptions students held and were consistent among the related questions. If a student answered all three related questions correctly, they were identified as understanding a concept. Subsequently, answering any one question incorrectly for a concept categorized a student as not understanding a concept. Students were identified as having a misconception if they selected the same distractor for all three related questions.

This instrument was chosen because it had undergone rigorous validation and reliability checks. In both the modified and unmodified variants, confirmatory factor analysis was employed to check the internal structure (Villafañe et al., 2011a; Xu et al., 2017). Cronbach's alpha was calculated for each concept in the IFCB, in which only pK_a was not consistently above the threshold value of 0.7 (Xu et al., 2017). Further, the IFCB is easy to administer and provides multiple avenues of analysis in terms of both the data itself and its psychometrics. The faculty selected the instrument because it covers topics that the faculty agreed were critical to understanding the course content. They also found it useful that the instrument uses distractors as a means to probe for misconceptions in the students' conceptual understanding. Although remediating such misconceptions would not ensure a genuine understanding of the concepts, leaving such conceptions unaddressed, if present, would not benefit the students and could serve as the starting place for an intervention.

CHAPTER 3: INITIAL PROJECT PHASE

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Abstract

The disparity between post-secondary STEM instruction and the practices suggested in education and cognitive research is not a novel issue. Despite evidence-based practices being available to practitioners, traditional lecture-based instruction continues to dominate higher STEM education. In this study, we explored practitioner involvement in biochemistry education research as a potential means to address the gap between research and practice. we used phenomenology as a lens through which to view faculty experiences of participating in a team-based curricular redesign. we administered a concept inventory to examine undergraduate students' understanding of key concepts and to identify misconceptions. we captured faculty perspectives and reflections on student data through semi-structured interviews, finding that faculty dissatisfaction with traditional practices were rooted in experiences from early on in their teaching careers. Their students demonstrated a lack of conceptual understanding, similar to findings of other studies in undergraduate biochemistry, and key misconceptions the student population held were identified. When examining students' conceptual understanding data, the faculty gained new insights into where students struggle in the course that they would not have gained without participation in this project. This reinforced their desire to implement curricular

change. These findings add to the available data on students' conceptual understanding in biochemistry and suggest that shared assessments like concept inventories can unify instructors as they engage in team-based curricular reform.

Research Questions

The goal of this research was to explore biochemistry faculty experiences while participating in a collaborative action-based curricular redesign as a first step towards closing the gap between research and practice. This includes soliciting faculty members' instructional experiences as well as their perspectives of students' conceptual understanding and the interplay between the two. This chapter reports findings from the beginning stages of a larger study and aims to answer the following questions.

- What experiences have shaped the way faculty approach teaching biochemistry?
- How does faculty conceptualize student performance in the early stages of curricular redesign?

Methods

Methodological and Theoretical Framework

For this project, we used a phenomenology framework because it focuses on the "lived experiences," "life world," or phenomena of a targeted community to provide insights into the challenges the population faces and the choices it makes to address such challenges (Østergaard et al., 2008; Wojnar & Swanson, 2007). Unlike methodologies such as ethnography and protocol analysis, phenomenology traditionally does not rely on frameworks existing within the community to analyze experiences; rather, phenomenological studies typically rely on inductive coding (Starks & Brown Trinidad, 2007). This study used descriptive phenomenology, which focuses on describing the core structure of a phenomenon while limiting the bias the researcher holds (Husserl, 1970; Wojnar & Swanson, 2007). While phenomenology often focuses on the collective experiences of the group associated with a given study, differences in experiences were not wholly ignored in our analysis to truly express the experiences of participants (Cibangu & Hepworth, 2016; Hasselgren & Beach, 1997).

Note that descriptive phenomenology is a distinct philosophical stance from the interpretative phenomenology Heidegger proposed, which seeks to interpret the meaning in experiences that may not be clear to participants themselves (Lopez & Willis, 2004). These distinct flavors of phenomenology also act as theoretical frameworks within the larger methodological framework of phenomenology (Lopez & Willis, 2004).

CER researchers have noted the benefits of this methodology as a means to better understand why researchers observe particular results in their quantitative inquiries (Burrows et al., 2021). For example, phenomenological analysis has been used to highlight the experiences of pre-service teachers and describe the impact of a prep course on participants' instructional choices (Kirbulut & Bektas, 2011).

One concern that needs to be addressed when applying descriptive phenomenology in the context of this study is how phenomenology can be paired with action research without conflicting with the other's philosophical assumptions. The effort to avoid such clashes in philosophical underpinning is particularly challenging when considering the broadness of action research in terms of the epistemological stances that prior researchers have assumed (Cassell & Johnson, 2006). To simplify this process, we focused on the form of action research we employed in reference to our cooperative work with the faculty. This cooperative inquiry within action research positions its researchers and its participants (in this case the faculty) not as disconnected entities but as a unit that cohesively participates in the research process (Magee et al., 2020). This particular flavor of action research entails exploring the positions of the involved participants after an initial examination of the problem they wish to address as well as the experiences of the participants after action has occurred (Magee et al., 2020). These key phases in the process are moments that the adoption of phenomenology as a research tool can aid. Ladkin (2005) suggested that phenomenology can help action researchers understand their own subjectivity and take a step back to appreciate the "other" involved in the process.

Population and Instructional Context

The participating faculty had a diverse range of teaching experiences. Table 1 details the participants' characteristics. All three faculty members were research active with ~60% of responsibility for research (focused on biochemistry) and ~30% for teaching. The remaining percentage of the faculty's responsibilities were related to administration.

Table 1: Characteristics of participating faculty at the time of the interview.

Faculty	Position	Course Section	Years Teaching Biochemistry
Instructor 1	Tenured	Biochemistry I	13 years
Instructor 2	Tenure track	Biochemistry I	5 years
Instructor 3	Tenure track	Honors Biochemistry I	1 year

The investigation took place in the Biochemistry I course for science majors in Fall 2019. Student data were collected in two large lecture sections and one smaller honors section of Biochemistry I where all sections covered the chemical structure, reactivity, and functions for the four main classes of biological compounds: carbohydrates, nucleic acids, proteins, and lipids. The two large sections (instructor 1, n = 269: instructor 2, n = 284) as well as the honors section (instructor 3, n = 23) were taught in a face-to-face format over a 16-week semester. The honors course had the same curriculum as the large lecture sections but a smaller class environment. Instructor 1 held classes twice weekly (Tuesdays and Thursdays) for 90 minutes each, whereas Instructors 2 and 3 held classes 3 times a week (Monday, Wednesday, Friday) for 50 minutes each class.

The undergraduate biochemistry sequence, as the setting for this collaborative action research, has a unique place among the upper-level courses offered by a department of chemistry. Unlike other upper-level chemistry courses, which have a student body comprised almost entirely of chemistry majors, biochemistry courses typically consist of predominantly non-chemistry majors (of which health and biomedical science majors make up the majority). Furthermore, Biochemistry I is often the last chemistry course most health and biological majors require, resulting in a rather large student roster compared to other upper-level courses in chemistry. Given the large lecture setting of the Biochemistry I course, probing individual student outcomes to determine areas for improvement can be a challenge. Additionally, any intervention applied in the course will need to be adaptable to a large class size.

This study shared both the quantitative and qualitative approaches of the early phase of the research. The quantitative data were intended to provide the motivation and context for the qualitative portion of the analysis, the faculty reflections and conceptualization of student performance, which was the primary focus of this chapter. Figure 3 shows how this investigation fits into the larger overall project, which was informed by the cyclic process that action research entails. This study will focus on the first two steps of the project, with an emphasis on faculty interviews.

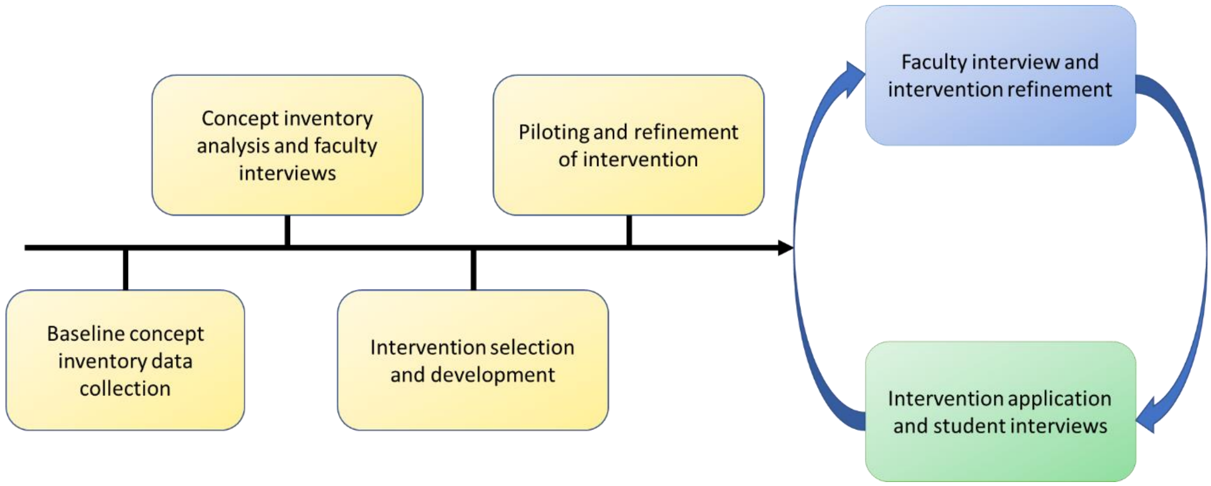

Figure 3: Diagram showing the different phases of the larger action research project

Data Collection and Instrumentation

Quantitative Instrument

The IFCB discussed in Chapter 2 was given as a pretest during the first day of each class in which the assessment was graded as an extra credit completion activity. The IFCB was given to the students again as a posttest attached to their final exam and was once again an extra credit completion activity. The decision to give the IFCB as an extra credit completion activity was to encourage participation as well as to dissuade students from cheating. Both tests were collected and hand graded in order to prevent the instrument being uploaded to websites and thus breaching the integrity of the instrument.

Student Sampling

The sampling frame (n = 553 large lecture, n = 23 honors) for this study consisted of the undergraduate students taking the two large sections and one honors section of Biochemistry I for science majors. Students were provided two opportunities to consent to participation via an online consent request sent through Qualtrics and a consent form attached to the post-test. There were 316 students in the large class, and 16 students in the honors class took both the pre-test and post-test and provided their consent. A misprint on the exam for one of the large lecture sections resulted in a question needing to be thrown out, resulting in a reduced sample of 150 student answers available for the hydrogen bonding concept items. Descriptive categorization of the data was performed on the entire consenting population. Inferential statistics was conducted with a subsample of 164 students who were randomly selected from this sample set via the Statistical Package for the Social Sciences (SPSS), which was used for the tests of associations. The sample was acquired via instructing SPSS to randomly select 50% of the participants.

Interviews

In the interest of understanding the experiences and perspectives of the instructors before making any curricular changes, the three faculty members participated in semi-structured interviews. They were interviewed in their own offices to reduce the stress and anxiety that can be associated with the interview process (Elwood & Martin, 2000). To further increase their comfort, the faculty had their choice of interviewer: the first author, a CER graduate student, or the corresponding author, a CER faculty member. The corresponding author was chosen to conduct each interview. The interviews were 30 minutes each in duration and were held the semester immediately following the student data collection. They were audio recorded via a Sony handheld recorder.

The interviews consisted of three segments. The beginning questions prompted faculty reflection on their perspectives and experiences of teaching biochemistry. Next, the faculty were asked how well they believed their students understood the target concepts. The IFCB pre- and post-test data from students in their individual courses were then provided to the faculty to view for the first time. The last part of the interview asked faculty to respond to student data and provide their perspectives. Faculty members were asked to share their ideas on possible interventions to address student learning. Table 2 shows example questions from the interview protocol (see Appendix B for the full interview protocol).

Table 2: Example faculty interview questions

Question Type	Question Example
Before data reveal question	What experiences have shaped the way you design your class?
After data reveal question	How does this information compare to your understanding of student performance in biochemistry?

IFCB Score Analysis

Student IFCB scores were processed initially in Excel to categorize the respective learning levels of correct concepts and misconceptions (i.e., Were the misconceptions retained, lost, or acquired during the semester?) (Figures 4 and 18, respectively). The inferential statistics were conducted in SPSS and R.

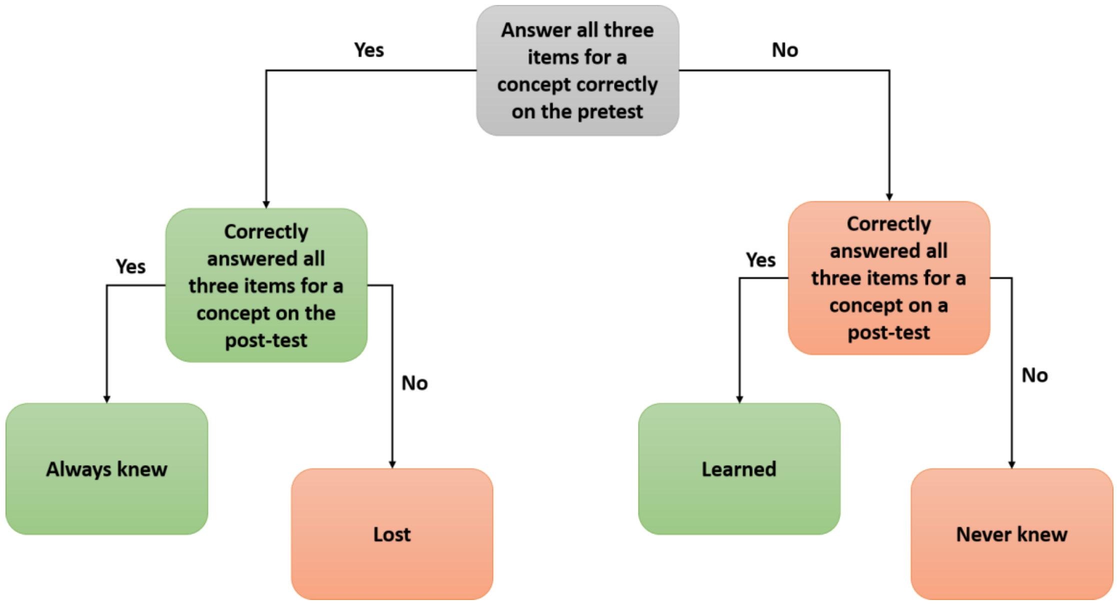

Figure 4: Flow chart showing how IFCB data were categorized into the different learning levels

<u>Chi-squared test of association</u>

IFCB data revealed that when students displayed at least one misconception at the end of the course, the concept was most likely hydrogen bonding and/or alpha helix. I conducted further analysis to determine whether the number of students with a particular misconception was tied to a specific instructor to obtain insight into how instruction may or may not perpetuate alternative understandings. To accomplish this, I used SPSS to generate a random subsample from which I could conduct a chi-squared test of association. This test was conducted only on misconceptions about the alpha helix concept because hydrogen bonding data were not available for both classes (as described in the methods section).

Instrument Validation

While the IFCB has already undergone extensive psychometric analysis, I did explore the validity and reliability of the instrument on the baseline data sample. I converted the item scores to dichotomous ordinal data (1 for correct and 0 for incorrect) which is consistent with previous methods (Villafañe et al., 2011a; Xu et al., 2017). To explore the validity of the instrument, I conducted confirmatory factor analysis via the laven function on R to examine to factor loadings. As for the internal consistency of the instrument, I utilized SPSS to obtain the Cronbach's alpha for each concept. Inter-item correlation matrixes of the concept items were tabulated when calculating Cronbach's alpha in SPSS.

Interview Analysis

Transcription

The interviews were transcribed using Otter.ai transcription services. I reviewed these rough transcripts to correct transcription errors and returned them to the faculty to further check their quality. The faculty were given an opportunity to elaborate more about a given interview topic if they believed that there was more to be noted about the topic (Sanders, 2003). The transcripts were then arranged into four spreadsheets in Excel (one spreadsheet for each primary interview question) to group different excerpts from each interview together for further analysis.

Analytical framework

I selected a modified version of Colaizzi's seven-step analytical framework (Figure 5) to analyze the faculty interviews and answer our research questions. Qualitative researchers in nursing and other medical fields frequently use this framework to guide analysis of data collected in phenomenological studies (Sanders, 2003). The appeal of this particular analytical framework over other frameworks used in phenomenology is its systematic nature and ease of use (Sanders, 2003).

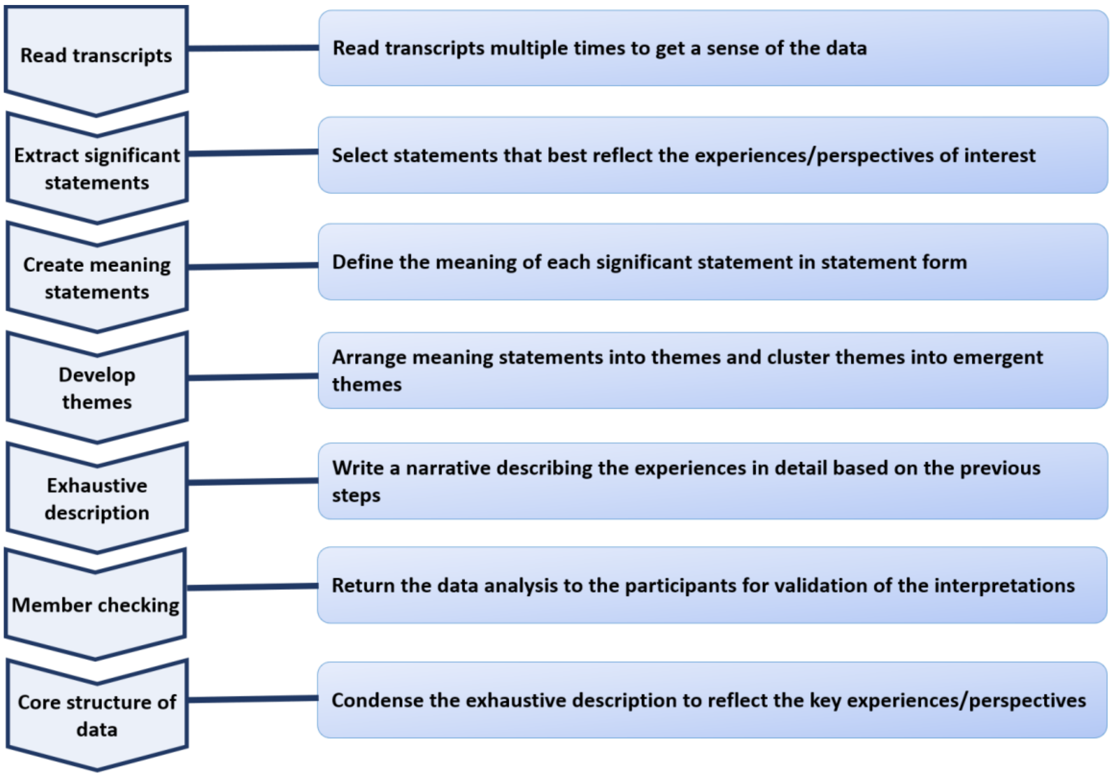

Figure 5: Modified Colaizzi's seven-step analytical framework

Although Colaizzi (1978) returned the core structure of the phenomenon to the participants, Sanders (2003) suggested that the exhaustive description should be returned to the participants instead because it would be more recognizable to the participants. I took this suggestion a step further by returning the description to the participants before I defined the core structure of the faculty experiences and perspectives. I believed this arrangement did not betray the goals of this framework and reduced the amount of backtracking should the faculty point out any inconsistencies in the analysis.

Unit of analysis

The units of dialog used in the analysis of the transcripts were statements conveying a particular point the authors deemed to be a meaningful expression of the faculty's experiences. These statements typically consisted of 1 to 3 sentences (though rarely beyond 1) within the transcript that conveyed a particular point. These statements then had their meanings defined and clustered into themes as the analytical framework directed (Colaizzi, 1978). This process is an inductive method of analyzing data and is consistent with the philosophical assertions of phenomenology.

Establishing trustworthiness

I kept audit trails for each stage of the analysis, which I returned to the participants for confirmation of their accuracy (Colaizzi, 1978). To ensure the transparency of the analysis, the first author kept a journal describing the choices made during the analysis and reflecting on the rationale for these choices (Appendix C). My Advisor, the undergraduate assistant for this chapter and I identified significant statements individually and then went through each statement together to choose by consensus which ones would be used in the analysis.

Results and Discussion

The results of the analysis included student data that provided context for faculty action research as well as faculty reflections and conceptualizations of student performance.

Students’ Conceptual Understandings

<u>The majority of students lacked sufficient understanding of the target foundational concepts.</u>

The data were categorized into the learning levels identified by the IFCB. A large proportion of students displayed gaps in knowledge of foundational concepts on both the pre- and post-tests. As Figure 6 shows, more than 50% of students never knew each concept sufficiently enough to consistently answer the three questions on that concept correctly. Furthermore, nearly 14% of students “lost” their understanding of alpha helices, as evidenced by students answering all three questions correctly on the pre-test while having inconsistencies on the post-test. In the case of hydrogen bonding, 86% of students lacked sufficient understanding (having lost their understanding or never knowing enough to answer the three questions correctly) by the end of the course. Xu et al. (2017) obtained similar findings in which a large section of students struggled with hydrogen bonding. However, our student population had a larger proportion of students in the “never knew” category and a smaller proportion in the “lost” category.

The honors students, as Figure 6 shows, had a greater proportion of students who “always knew” the foundational concepts compared to the large lecture sections. Additionally, the honor students finished the semester with the greatest mastery of thermodynamics and pK_a (whether through always knowing or learning) compared to the students in the large sections, with a less who “never knew.” However, the honors students also struggled with hydrogen bonding, with 13% of the students scoring in the loss of understanding category and 63% of students scoring in the “never knew” category at the end of the semester. This observation between students in large sections and honors sections has not been reported in previous works.

That said, a caveat to interpreting the honors data is the sample size. Given that the sample size for the honors section is only 16 participants, any movement of the students from one category to another would result a drastic shift in the proportions as compared to the large section data. This is a limitation in the size of the honors section as the course section is typically far less populated than the large lecture sections which have hundreds of students. Therefore, any discussion of student learning level categorization must be taken with caution. Yet, the data still can provide an instructor the honors student's performance for the baseline semester.

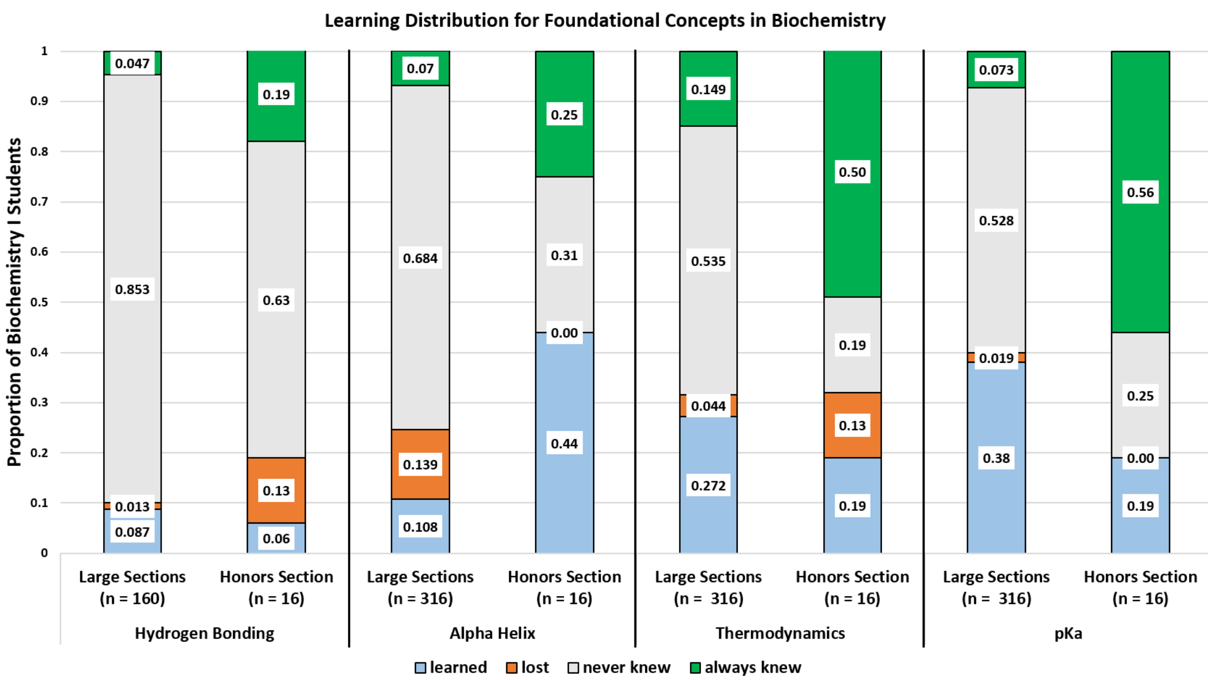

Figure 6: Learning level distributions for the four target concepts from the IFCB

The IFCB Identified Prevalent Misconceptions.

To better understand the misconceptions the IFCB measured, I analyzed students' selection of matching distractors (see Appendix A, Figure 18 for the misconception categorization scheme and Figure 17 for misconceptions identified in the IFCB). By doing so, I could see the types of misconceptions students held and how these misconceptions (or lack thereof) were involved in students' learning levels. This information was presented to the faculty members during their interviews so that they could see the range of student performance in their class.

		Misconception	% Biochemistry Students	% Honor Biochemistry Students
Hydrogen bonding	1	Hydrogens bonded to carbons can participate in hydrogen bonding	36.2%	50%
	2	Any bonding between hydrogen and another atom is a hydrogen bond	11.8%	6.2%
Alpha helices	1	The interior of the helix is composed of side chain groups (R groups)	19.3%	31.2%
	3	Molecules such as water fill the interior of the alpha helix	6.3%	0%

Figure 7: IFCB's commonly identified misconceptions within the student sample

Although a few students displayed misconceptions about thermodynamics and pK_a, the majority of student misconceptions were about hydrogen bonding and/or alpha helices. IFCB data revealed that ~25.6% of large section and 31.2% of honors section students held misconceptions about alpha helices at the end of the course. Additionally, ~67.9% and ~40% of these students respectively demonstrated misconceptions on the post-test and not the pre-test (implying that the misconceptions were formed the same semester they took the biochemistry class). Specifically, the major misconception students held was misconception 1 (Figure 7), which represented ~19% of the large lecture students and ~31% of the honors students at the end of the course.

The other target foundational concept with a large number of student misconceptions was hydrogen bonding, a concept addressed in multiple chemistry and biology courses, which are a prerequisite for the biochemistry course. A total of ~48% of large section and ~56% of honors section students held a hydrogen bonding misconception at the end of the course. From this data set, ~71% and ~67% of students respectively gained the misconception during the semester. Further, ~73% of large lecture students and ~88% of honors students identified as having a misconception consistently chose distractors tied to hydrogen bonding misconception 1. Aside from the small sample size, it is unclear why the honors students had a greater percentage of students who were identified as having a misconception compared to the large lecture. For example, it is possible that the honors students were able to identify answer patterns more readily, however more research in this area is necessary. The predominance of hydrogen bonding misconception 1 is consistent with the data reported within the literature (Kopecki-Fjetland & Steffenson, 2021; Xu et al., 2017). Prior work has also noted that the alpha helix misconception 1 was the most common misconception present among the sampled participants (Villafañe et al., 2011b). More details on the baseline misconception data relative to the learning levels can be found in Appendix A in tables 12-17.

Misconceptions present among the students were independent of instructors

Because of the high percentage of students whose IFCB data indicated they experienced misconceptions during the course, additional analysis was conducted on the data sets to determine the extent to which the frequency of misconceptions was related to a specific section of the class, which all had different instructors, times of day, and class activities. Table 3 displays the results of a chi-square test of association between the misconceptions the large section students held about alpha helices at the end of the course and the instructor of the specific section (see Appendix A, Table 18 for the contingency table used for the test). The chi-squared test of association produced a p-value that was greater than the conventional alpha value ($p = 0.154 > \alpha = 0.05$), suggesting a lack of association between the misconception data and the instructors of the course. The assumptions for this test were not met because the expected count was less than 5 for two categories (Table 18). Thus, Fisher's exact test was conducted, yielding similar results with a p-value of 0.150. This further suggested a lack of association between the instructor's section and the misconceptions students held at the end of the course.

Table 3: Statistical outputs for test of association between alpha helix misconceptions and instructor

Statistic	Value
Chi-squared p-value	0.154
Cramer's V	0.151
Fisher's exact test p-value	0.150
Post hoc power	0.39
Priori power sample size	423

The effect size was calculated via SPSS (w = 0.151, Cramer's V), which was small based on the conventional interpretation of that value (Ellis, 2010). Furthermore, a post hoc analysis yielded a statistical power of 0.39, and priori power analysis suggested that a sample size of 423 would be required to observe a significant association among the tested variables. Power is a statistical error which represents the probability that the rejection of the null hypothesis (in this case that there was no relationship between variables) would be genuine. Post hoc power analysis provides the power relative to the sample data where as priori power analysis provides an estimated sample size required to observe a significant difference at a given power. Given the low power and high sample size required, a larger sample size is unlikely to provide a valid statistical association between instruction and student misconceptions. This analysis was useful for the collaborative faculty action research because it contextualized the struggle students experience mastering the content of the course as independent of the instructor. This knowledge allows the faculty to see the struggle points in students' understanding as a group challenge rather than as the burden of one particular faculty member. Therefore statistically, the students held the same misconceptions regardless of the instructor of the course.

<u>Psychometric Analysis Revealed Issues with Thermodynamics Items</u>

Examining the results of the confirmatory factor analysis (CFA) of the IFCB presented in Table 31, the standardized factor loadings for the hydrogen bonding and alpha helix questions on both the pre and posttest data fell within the desired threshold (0.7) for representing a good fit with the model (Doll et al., 1995). Issues with the standardized factor loadings appeared within the first two questions for the thermodynamics concept (item 1 0.534 and 0.587; item 2 0.551

and 0.665) and question 2 for the pKa concept on the pretest only (0.272). For the thermodynamic questions that did not meet this desired threshold, they still represent moderate factor loading rather than a definite cause for concern (Comrey & Lee, 2013). The second pKa question factor loading on the pretest was more problematic as it did not meet the minimum accepted threshold. This issue appearing only on the pretest may be attributed to the design of the question itself relative to the others as it provides structural answers (compared to the text-based answers of the other two questions).

As for the reliability of the IFCB explored through Cronbach's alpha displayed in Table 32, once again the hydrogen bonding and alpha helix concepts performed within the acceptable threshold of 0.70 (Arjoon et al., 2013). Reflective of the CFA results were the Cronbach's alpha values for the thermodynamic and pKa IFCB concepts. Neither the pretest nor the posttest for the thermodynamics concept had a Cronbach's alpha (0.560 and 0.651 respectively) above the threshold value where as only the pretest Cronbach's alpha for pKa (0.522) did not meet the threshold. Looking at the inter-item correlation matrixes for the concepts on the pretest (shown in Tables 33 – 36) and the posttest (shown in Tables 37 – 40), low correlations are present between items 1 and 2 for the thermodynamics concept (0.190 for the pretest and 0.246 for the posttest). This indicates that the inconsistencies in the student responses for the concept are rooted between these items. Student interviews in Chapter 5 look closer into these inconsistencies.

Faculty Experiences and Perspectives on Teaching

I analyzed transcripts from faculty interviews where faculty discussed biochemistry education, and reflected on student data. I identified 12 unique themes, which I condensed into five emergent themes. The theme data (Figure 8) was not the endpoint of the analysis. Rather, the themes acted as building blocks, which I used to construct an exhaustive description of the data and, later, the core structure of the faculty teaching experiences.

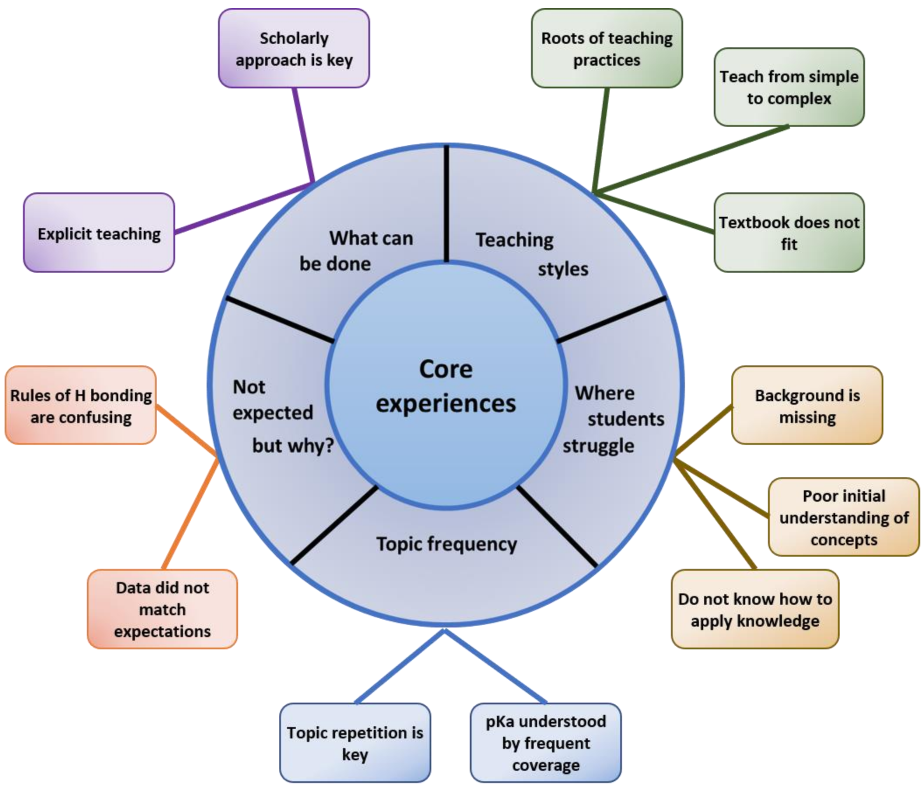

Figure 8: Theme data construct of the core structure of faculty experiences

<u>Faculty members wanted to improve instruction, but past experiences influenced their choice of focus.</u>

Regarding teaching styles, faculty shared the desire to alter the way the biochemistry content was presented. Much of the motivation for this shift from traditional approaches was derived from faculty's previous teaching experiences (notably from early within their career) or experiences as students. The nature of these experiences also shaped how faculty members felt about their current teaching deviating from what they considered to be traditional instruction. For one participant, their previous job as a tutor motivated them to focus on problem-solving as a way to gauge students' content knowledge. The faculty member noted that this experience as a tutor had the greatest impact on their teaching style. They found that by accessing students' understanding with multiple low-risk assessments, they could identify struggle points to address in a class discussion.

Instructor 3: "*So most of most of my teaching philosophy derives from my work as a tutor . . . So I'm more of a trouble-shooter than a lecturer.*"

Another participant's experience as a teaching assistant drove them to be dissatisfied with the order in which content was presented in the course. This led them to rearrange the content so that simple molecules were introduced first. From there, they moved on to more complex systems to emphasize the chemical perspective of biological systems. The faculty member felt that by starting with content that was more familiar to students and building up from there, students would have an easier time understanding the content.

Instructor 1: "*From the very beginning, I had my take on how to teach it. When I arrived, I immediately decided to teach it from chemical perspective. So, using all the background that students [were] supposed to have collected or accumulated during their undergraduate education.*"

Instructor 1: "*And from this background moving towards understanding more complex biological objects.*"

Instructor 2 adopted this approach early in their teaching career, as shown below, after an unofficial peer-to-peer conversation with instructor 1 prior to their involvement in the action research.

Instructor 2: *"I've had some experience like, for example, from Instructor 1, right, because instructor 1 was teaching it and we kind of communicated [as] to how they decided to schedule their class.*" (Changed pronouns to maintain confidence of instructor 1)

Instructor 2: "*So in this case, and I think it's beneficial, to first start with introducing the molecular um, um, like building blocks for each biopolymer, right.*"

An issue that the two participants encountered upon implementing this new curricular layout was the textbook assigned to the course. The faculty members observed a disconnect between how the text and the course content were arranged and the difficulties the students had in connecting the two. Therefore, the faculty sought to create a new textbook for the course that would align with the curriculum.

Instructor 1: "*That's why at the end of the first semesters, I got an idea to write in our own text, which is more concise and focused on concepts that I want to teach to students.*"

Instructor 2: *"So, again, because the traditional textbooks use a traditional approach of introducing the material, I had to kind of jump from section to section, and students usually feel like a little bit lost.*"

Before seeing the baseline data, faculty perceived an overall lack of student background knowledge.

When considering how students struggled with the course content, faculty member shared their frustration with the state of students' background knowledge. Two faculty members expressed their feeling that students typically lacked sufficient understanding of prerequisite course content. One faculty member noted that the lack of background knowledge in students was not an isolated view but one their supplemental instructor (an undergraduate who displayed excellent understanding of the course content and facilitated help sessions for students) shared as well. The two faculty members attributed this lack of prior knowledge to students' poor understanding in earlier courses. One faculty member felt that students abandoned knowledge that they did not perceive to be relevant to the next assessment (quiz or test) rather than understand and retain that knowledge.

Instructor 1: "*I would say more than 50% of students struggle with insufficient background knowledge that is required for biochemistry.*"

Instructor 2: "*They don't view biochemistry as that easy subject because it kind of builds up on their prior chemistry knowledge. Yes. All what they were lacking from general chemistry, organic chemistry classes, like either abandoned or didn't get, you know, out of these classes.*"

While reading the exhaustive description of the interview data, instructor 3, who taught the honors section, hesitated to claim that the students altogether lacked understanding of background knowledge. Rather, the faculty member thought students likely had sufficient knowledge but were unsure when to apply it.

Instructor 3: "*There's a lot of discussion about prior knowledge, and it's not clear to me that we are able to tell the difference between lack of prior knowledge and inability to understand when the prior knowledge should be applied.*"

Instructor 2 expressed a similar view when they suggested that students' difficulties with applying prior knowledge could contribute to their focus on memorization in biochemistry. The participant felt that the students did not know when to apply prior concepts towards current content, which led them to drop and no longer value prior knowledge.

Instructor 2: "*But then they don't use it, you know, they kind of memorize something right? And they don't apply it next time*."

Instructor 2: "*I don't think I included examples of this type of questions in my homework or in other course assignments. And so they just didn't think that it's important, right? And that's why it just slipped.*"

<u>Baseline data-initiated conversations about topic frequency and student misconceptions</u>

The faculty held some preconceptions on how students would perform, and the IFCB (the instrument they selected to examine students' conceptual understanding) either supported or challenged these preconceptions. Before and after the class data were shown to them, the faculty noted that the frequency of topic coverage influenced the number of students with positive scores. Before the class data were revealed in the interview, instructors noted that topics such as pK_a and thermodynamics were covered frequently in the course (both in the class and within office hours). The faculty believed that covering the topics more frequently throughout the course led to better retention and conceptual understanding among students. After seeing the

IFCB scores, some faculty ideas were affirmed. Specifically, in the case where more students learned pK_a, the instructors felt this made sense given how frequently the topic was covered.

Instructor 3: "*Definitely go through that a million times pK_a. So yeah, yeah, we go through pre-drill that big time.*"

Instructor 1: "*Well, about pK_a. I felt like that's what was expected. Because they had they [come] to my office and we covered this multiple times because they asked about this.*"

However, the student data challenged other faculty ideas. When reflecting on the extent to which their expectations were aligned with the data, the instructors expressed a disconnect between their preconceptions of students' understanding and what the data were telling them. This disconnect was largely oriented towards what the students understood at the end of the course rather than what content knowledge the students possessed before they entered the course. The instructors had observed (via tests and conversations during office hours) that the students understood the concept of alpha helices by the end of the course. This conflicted with the IFCB student data presented to them in the interview. One instructor noted that they had not expected students to have had any prior knowledge on alpha helices and was shocked by the proportion of the lost category for the concept:

Instructor 2: "*Surprisingly alpha helix that I felt they know so well. They don't know. Or they learned incorrectly from, from my instruction. And that's a shocking thing.*"

Instructor 1: *"Well, first of all, alpha helix, my expectation was, they didn't know anything about alpha helix because they didn't have to [interviewer: learn it in prior courses]. It was a new* *concept taught in biochemistry and as you can see, there is a significant loss [interviewer: of knowledge] instead of gain.*"

Making sense of student misconceptions was another shared experience where instructors reflected on what was happening and why in their courses. One instructor noted that students may be confusing alpha helices with DNA double helices, in which the backbone constitutes the exterior while the nucleotide base pairs (which differentiates the nucleotides as R groups differentiate amino acids) constitutes the interior of the double helix. This instructor also believed that what they described as the "tricky" nature of hydrogen bonding could easily confuse students:

Instructor 3: "*What's interesting is I wonder if they're getting confused with the interior of the interface of two helices instead of thinking about the interior of the core.*"

Instructor 3: *"The hydrogen bonding. Yeah, I could see that. That's a tough one. I think . . . I think it's tricky because there's so many rules.*"

<u>Baseline data provide the context for decisions on a curricular intervention.</u>

Finally, the instructors shared their perspectives on what could be done to address the gaps in students' understanding. Two of the faculty members mentioned a need to be more explicit about the details of the target concepts. In addition to being more explicit, one faculty member noted that including more application prompts would promote the students to value prior knowledge. The instructor felt that, currently, students did not know that they needed to apply this knowledge and hence did not see the value of maintaining a working memory of it. One faculty member stressed the importance of approaching the changes to the curriculum in a systematic way to improve the rigor of an intervention. The instructor was enthusiastic about using creative exercises, open-ended activities that required students to provide statements about a given prompt, as a tool to target the weaknesses in students' understandings of key concepts (Lewis et al., 2010; Trigwell & Sleet, 1990).

Instructor 3: "*But yeah, I don't explicitly discuss packing on there. Maybe I should.*"

Instructor 2: "*And I also think that um more um questions for the applications are needed, you know, to kind of force them to apply because that's definitely they are not applying the knowledge even if they have the knowledge.*"

Instructor 1: "*Our plan was to interfere, right [interviewer: Mm hmm] and do it in a systematic way [interviewer: Mm hmm]. I just think that we should follow our plan.*"

<u>Core Structure Insights</u>

This phenomenological study captured the lived experiences of this faculty group and gave insights into the challenges the biochemistry faculty faced before the curricular redesign. The results implied that there may be a prevalence of uncertainty among faculty as to how they can alter their curriculum in a way that is beneficial to the students. Previous attempts to make changes to the curriculum that did not noticeably yield the desired results may bolster these feelings of uncertainty. This could be seen in the faculty's efforts to change the order of materials and yet feel unsatisfied with student performance. This feeling was not unique to participants in the current study; Lang et al. (2018) examined a range of biochemistry faculty experiences, finding that faculty believed existing materials on evidence-based practices did not provide sufficient guidance to implement them effectively.

Another insight from this study was how intertwined the faculty recollections of their teaching experiences were with their perceptions of students' understanding. This was particularly true for the more experienced faculty members who frequently brought up student background knowledge when discussing their experiences. I observed within the core structure of the faculty members' experiences that this interplay between their experiences of teaching and conceptualization of students' understanding contributed to their current teaching practices. Furthermore, the faculty members' concerns about the lack of students' understanding, despite their own efforts to address the situation, may have motivated them to seek collaboration with experts in educational research. This interest to collaborate was reflected in a prior study in which a surveyed faculty group expressed the desire to obtain input from education experts during the curriculum redesign process (Loertscher et al., 2014).

Chapter 3 Concluding Remarks

My analysis of the faculty interviews identified a set of five emerging core experiences (teaching styles, where the students struggle, topic frequency, not expected and why, and what can be done) through which I could present a narrative of the faculty experiences. Regarding the experiences that shaped the way the faculty approached teaching, it can be seen that their desire to move away from traditional practices was not an impromptu one. Rather, the faculty started their current careers with a determination to break away from conventional approaches based on their earlier teaching experiences. Their own experiences with education early in their professional careers drove this determination to move away from the traditional curriculum. The literature has shown that such a feature is not unique to this faculty group (Andrews & Lemons, 2015).

Another key takeaway from this data was that the IFCB provided the faculty with a fresh perspective on the conceptual understandings of their students that may have gone unnoticed otherwise. Though the faculty had unique perspectives on how to approach the curriculum, albeit ones rooted in similar goals, the instrument provided the faculty with unifying target points by which they could collaborate to address these areas of interest. The newfound common ground could be a promising avenue for faculty members to see the benefits of collaboration with one another despite overall differences in their teaching approaches. Additionally, while prior research has used the IFCB as a tool for faculty members to target concepts that could be better addressed in their courses, this is the first study to interview the faculty as they reflected on their personal data. Prior works either used a survey to elicit faculty perspectives or did not conduct substantial discussion on the matter (Loertscher et al., 2014; Villafañe et al., 2011b; Xu et al., 2017).

The faculty believed that their concerns were legitimate because student data highlighted the need to address the current biochemistry curriculum. Indeed, a desired conceptual mastery of key concepts escaped the majority of students. This situation cannot continue if undergraduate students are to truly excel in their course of study and later careers. Furthermore, a number of students were identified as having misconceptions by the end of the course, specifically for hydrogen bonding and alpha helices. A test of association suggested that this phenomenon is not unique to the section that the students participated in, further supporting the idea that a team-based approach to curricular change may prove more effective than an individual effort.

This research has benefited not only faculty members who are determined to improve the quality of their courses but also the educational researchers who collaborated on this project. By exploring the experiences and perspectives that led to the drive for curricular redesign, the researchers better understand what evidence-based practices would lead to the best improvement in student learning, and what interventions may be most compatible with the perspectives of the instructors.

Limitations

One notable limitation of this study was our ability to describe the data corresponding to the concept of hydrogen bonding. This limitation was due to the previously mentioned printing error, which led to a reduced sample size and minimized our ability to compare student performance on this concept between sections. As mentioned previously, the sample size for the honors section was also limited, though this was largely due to the size of the course itself rather than limited participation. That said, this small sample size minimized our ability to compare the honors section with the large sections. Furthermore, given the nature of the instrument as a concept inventory composed of multiple-choice questions, the student data presented here could only provide a glimpse into the conceptual understanding of the students. The intended use of this instrument was not to gain a holistic understanding of students' conceptual knowledge, but rather to garner a general sense of knowledge related to a handful of concepts.

The instrument itself may have induced a level of bias in the faculty's perception of student performance in the course. While the data from the IFCB were generally aligned with the faculty perceptions of student foundational understanding, it was not our intention for the instrument to represent holistic learning in the overall course. Rather, I intended the instrument to bring focus to a few key areas that could be reasonably addressed in the curricular redesign. In this context, the instrument did cause the faculty to explore their preconceptions of students' conceptual understanding (i.e., that none of the students came to the course with knowledge on alpha helices).

Given the nature of action research, the generalizability of this study is limited. I did not anticipate that theses snapshots of the three faculty experiences would have broad application to other settings. Instead, I hope that by documenting these experiences and perspectives, I can encourage the field to investigate the role of practitioners in curricular redesign research. Additionally, by sharing these experiences with a broader audience, I hope to provide readers with an opportunity to consider their own experiences with teaching as well as understand how the documented experiences relate to their own experiences.

CHAPTER 4: INTERVENTION PHASE

Abstract

As a continuation of the research efforts presented within the previous chapter, we will present the findings from the intervention phase of my dissertation. Such findings will include the pre-posttest IFCB results collected from the Fall semester of 2021 as well as statistical comparison with the baseline data presented in the previous chapter. In addition to this data, this chapter presents the faculty's experiences implementing the creative exercises as well as their experiences engaging in the collaborative action research process. Statistical analysis of the IFCB data revealed a small increase in student learning after the creative exercise intervention over the baseline data. A phenomenological exploration of the faculty experiences revealed a generally positive experience with the creative exercises despite a number of challenges. The study also revealed the faculty's appreciation for the collaborative research process despite feeling uncertainty on the overall effectiveness of the creative exercises.

Research Questions

The following research questions were utilized to guide the research presented within this chapter:

- How do the creative exercises influence student performance in the beginning undergraduate biochemistry course?

- What do faculty experience as they implement creative exercises in the context of biochemistry?
- What do faculty experience as they engage in a collaborative action research project?

Methods

Methodological and Theoretical Frameworks

The methodology and theoretical framework which guided our inquiry into the faculty's experiences was once again Descriptive Phenomenology. For the details of this qualitative framework, please refer to the description provided within the previous chapter (page 20).

The quantitative methodology for this chapter was a quasi-experimental design using a pre-posttest with a control group. The distinction from a quasi-experimental and an experimental approach being that the course enrollment was not randomly preassigned (White & Sabarwal, 2014). Furthermore, this research design also aligns with the typical practice of collaborative action research in education (Efron & Ravid, 2019). Quasi-experimental designs also are not an unfamiliar approach in chemistry education research as a number of studies within the field have relied on this methodology in their research (Chan & Bauer, 2015; Fringer et al., 2022; Liu, 2006).

Project Intervention

Exercise design

While there are existing, published creative exercises within the context of biochemistry (Warfa & Odowa, 2015), the faculty involved in the project set about to develop their own exercises. This effort was motivated by data they collected in order to address areas where their students struggle (particularly hydrogen bonding and alpha helices) which they observed in the groundwork stages of the larger project. The faculty hoped that by providing the students prompts tailored to these weaker areas, the students would have an opportunity to engage and confront these difficult conceptual areas of foundational biochemistry. An example of one of the creative exercises developed by the faculty can be seen in Figure 2.

To ensure the quality of the creative exercises before their implementation within the course, the exercises developed by the faculty were piloted in clinical interviews with two participants. These piloting interviews revealed aspects of the prompts that needed to be and were adjusted so that the information that the images were intended to convey would be clear to the viewer.

Implementation

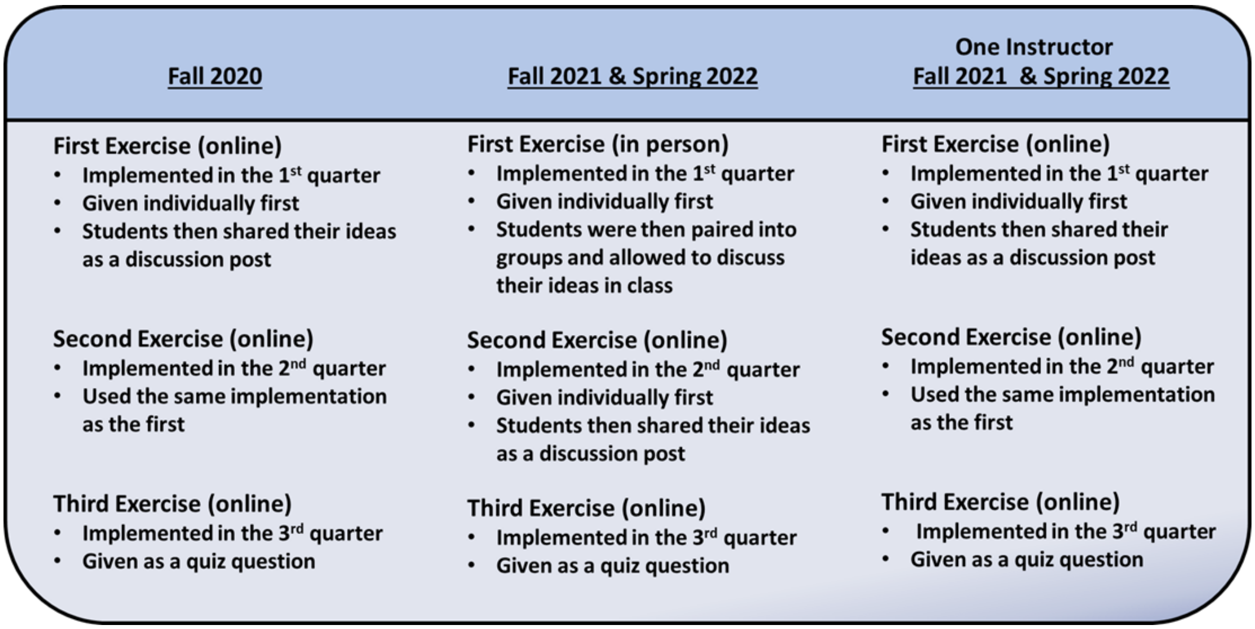

Figure 9: Differences in creative exercise implementation over time.

The faculty associated with this project selected three creative exercises to implement within their courses. The three exercises were chosen to be implemented across each course. As displayed in Figure 9, there was variation in the implementation of the exercises amongst the semesters of the study. The initial uniformity of online implementation was largely due to the COVID-19 pandemic. However, upon the movement to return to in-person courses, two of the faculty moved the first creative exercise to an in-person discussion activity. This was done by the instructors to explore the student preferences of the creative exercises as an in-person activity vs. an online activity. Though one of the instructors chose to keep the shared exercises as an online activity, they also incorporated additional creative exercises as class discussions.

To avoid confusion and anxiety about the creative exercises noted to be present in early interactions (Gilewski et al., 2019; Lewis et al., 2010), a video explaining the details of creative exercises was included in the course modules for the students. The video included a description of the assignment, a clip of students working through the activity to provide example responses and an explanation of how the exercises would be graded. The example responses were provided by members of the research group, whom consented to be included in the video, on an example creative exercise that was not implemented in the course.

Student Participant Sampling & Data Collection

Implementation and collection of the IFCB pre and posttests were carried out in a similar fashion as the baseline collection. The pretest was offered at the beginning of the semester as an extra credit completion grade (in order to avoid cheating). The posttest was included with their final exam at the end of the exam. A logistics error related to the number of printed tests reduced the number of participants available in one section during the Fall semester of 2021.

The student participants from the fall semester of 2021 were sampled from a sample frame of ~600 students in which 327 students consented to the research. Consent was acquired at the beginning of the semester as a consent sheet at the end of the pretest which was submitted in a separate pile to be given to myself or my advisor. Consistent with the baseline data collection, participants were offered the pretest on the first day of the semester and the posttest was offered to the students at the end of the semester. One setback within the data collection for this semester was an insufficient number of pretests printed for one of the course sections. Of the students who consented to the research, 171 students provided both pretest and posttest data.

While efforts were made to collect data from the honors section as well, there was an insufficient number of posttests collected. Thus, I was unable to provide any meaningful analysis of the data.

Faculty Interviews

Once again, we had the faculty involved in this project participate in semi structured interviews after the fall semester of 2021 concluded. Instructors 1 and 2 participated in the interviews online via Zoom while Instructor 3 participated in an in-person interview (Though Zoom was also used to record the interview). As seen in Table 4, the length of the interviews ranged from ~40 minutes to ~80 minutes.

Table 4: Characteristics and interview length of the participating faculty after the intervention phase.

Faculty	Position	Course Section	Years Teaching Biochemistry	Interview Length
Instructor 1	Tenured	Biochemistry I	15 years	~40 minutes
Instructor 2	Tenured	Biochemistry I	7 years	~50 minutes
Instructor 3	Tenure track	Honors Biochemistry I	3 years	~80 minutes

The interview followed a similar layout to the first interviews, where the faculty were asked their experiences with the intervention semester followed by an opportunity to reflect on the IFCB data. Instructors 1 and 2 were shown their personal class data from both the fall 2019 baseline data and the fall 2021 intervention semester data. Since there was insufficient data collected from the honors section, Instructor 3 was shown the overall class aggregate data for the large lecture sections. This likely did not have a noticeable impact on the experiences that instructor 3 could share during the interview as they have also taught the large lecture section before and after the exercises were introduced into the course. The last part of the interview had the faculty discuss their experiences with the project. The faculty were all interviewed by my advisor as they felt more comfortable being interviewed by a fellow faculty member. The full details of the interview protocol can be seen in Appendix B.

Analysis

Quantitative Analysis of the IFCB Data

The IFCB data was initially in Excel in order to categorize the student data in terms of the learning levels and the misconceptions identified by the instrument. The learning level data was subsequently transferred into SPSS in order to conduct chi square tests of association for each of the 4 concepts. Also, random subsamples of both the baseline data set ($n = 249$) and the intervention data set ($n = 139$) were acquired in order to meet the assumption of independent responses for the inferential statistics. An additional subsampling had to be carried out for the hydrogen bonding concept due to the smaller baseline sample set (baseline subsample, $n = 119$; intervention subsample, $n =120$). The statistical software package R was also utilized to conduct Fisher's exact tests in cases where it was necessary.

Qualitative Analysis of the Faculty Interviews

For the faculty interviews, I continued to use Colaizzi's seven step method to guide my analysis. For the full details of why I chose this analytical framework and what this framework entails see Chapter 3.

Transcription

The Interviews were transcribed via the integrated Otter.ai transcription software utilized by Zoom cloud recording. I then cleaned the automated transcripts and transferred them to a word document for the analysis, rather than transfer them to Excel as in the previous chapter.

Unit of analysis

The units of analysis acquired from the transcripts were 1 to 3 sentence statements which provided a meaningful expression of the faculty's experiences. The statements were rephrased to describe the meaning of each unit identified within the data. I then clustered the meaning statements into themes as well as clustering these themes into larger major and emerging themes.

Establishing trustworthiness

In addition to the efforts for establishing trustworthiness engaged in with the previous chapter, I also did individual theming of the data along with the undergraduate assistant working on this project at the time of the analysis. These themes were then compared and discussed until agreement was reached. Additionally, I then had my advisor go over the agreed upon themes to give further feedback on the veracity of the themes. All these efforts were made to further ensure that my position within the research did not significantly impact the constructed narrative of the faculty experiences.

Results And Discussion

Quantitative Data

Descriptive Statistics

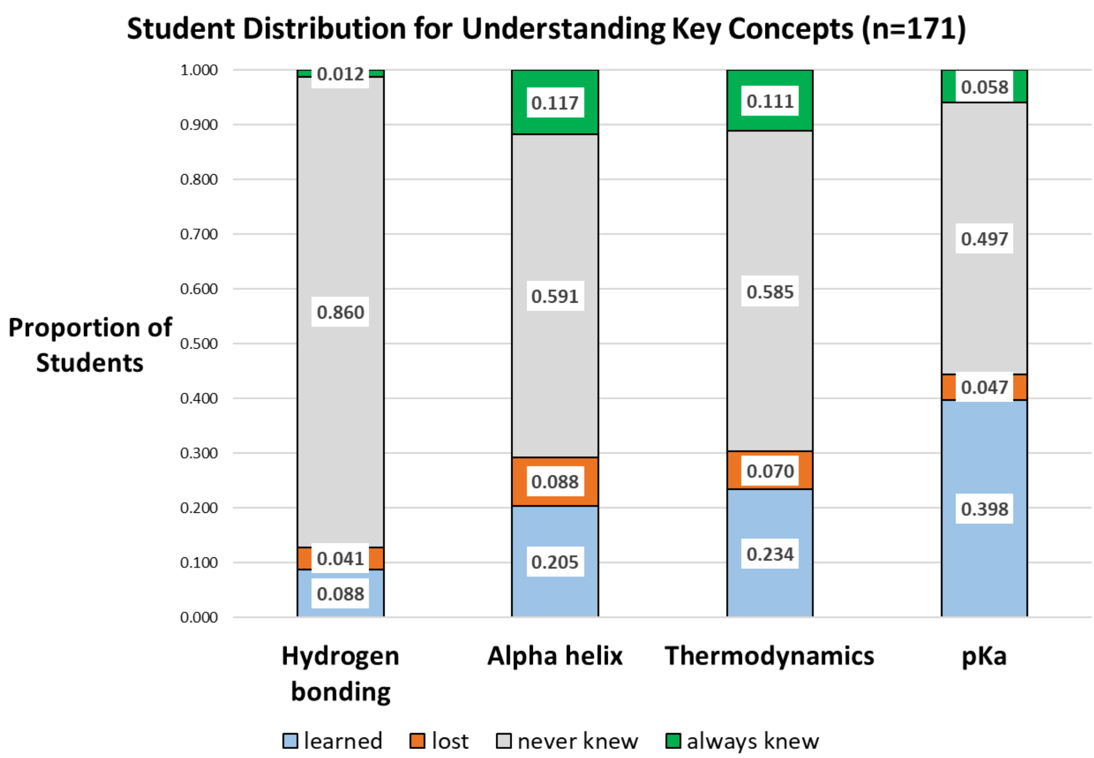

Figure 10: Distribution of Student learning levels for each key concept from the IFCB for the fall semester of 2021.

Just as in the previous chapter, I represented the learning level data as bar graphs as seen in Figure 10. Within the figure, it can be seen that the majority of the participants were coded as never knew for each of the IFCB concepts except for pKa (though the majority of students still did not know the concept at the end of the semester. The data appears largely unchanged from the baseline data, though the inferential statistics shed better light on any existing distinctions.

		Misconception	% Students baseline	% Students intervention
Hydrogen Bonding	1	Hydrogens bonded to carbons can participate in hydrogen bonding	36.2%	39.2%
	2	Any bonding between hydrogen and another atom is a hydrogen bond	11.8%	11.7%
Alpha Helices	1	The interior of the helix is composed of side chain groups (R groups)	19.3%	18.1%
	3	Molecules such as water fill the interior of the alpha helix	6.3%	5.3%

Figure 11: Common misconceptions tracked during the intervention and baseline

Similar to what was seen within the learning level data, the extent to which the creative exercises effected the student's misconception data was difficult to discern. Figure 11 provides the percentages of participants from both the baseline and intervention semesters for a side by side comparison. The percentage of students identified with Misconception 1 of hydrogen bonding saw an increase of 3 % for the semester of the creative exercise implementation. However, Misconception 1 and 2 for alpha helixes dropped by ~1 % each during the intervention semester. Additional information pertaining to the misconception categorization of the students in relation to their learning level categorization can be seen in Appendix A, Tables 19 – 22.

Chi Square Tests of Association

Table 5: Statistical output for the learning levels chi square test of association (* p values acquired from Fisher's exact test).

Sample	SPSS output	*p*-value (2 tailed)	Crammer's V	Sig. Standardized Residuals	Post Hoc Power
Random sample	pKa	<0.001	0.221	-2.1 (baseline) 2.9 (intervention) learned category	0.97
	Alpha Helix	0.017	0.162	none	0.77
	Hydrogen bonding	0.343 (0.3771*)	0.118	none	0.30
	Thermodynamics	0.363	0.091	none	0.29
Total sample	pKa	<0.001	0.193	-2.1 (baseline) 2.9 (intervention) learned category	0.97
	Alpha Helix	0.003	0.171	2.2 (intervention) learned category	0.90
	Hydrogen bonding	0.129 (0.1415*)	0.133	none	0.49
	Thermodynamics	0.298	0.087	none	0.33

Based on the data presented in Table 5, 2 of the 4 IFCB concepts targeted by the faculty saw a significant association between the learning level distribution and the semester, pKa and alpha helices. Both of these concepts had a p-value below the standard alpha value of 0.05. Hydrogen bonding and Thermodynamics had p-values below that of the standard alpha value and, therefore, there was no significant association between the learning levels and the semester of participation. Hydrogen bonding also failed to meet the assumption made by the chi square test in which the expected count (the number of participants for each variable if the no difference exists) was at least 5 (See Appendix A, Tables 23 - 30 for contingency tables). Therefore, I had to conduct separate Fisher's exact tests in R to determine if the differences were indeed nonsignificant. The exact tests for these concepts were consistent with the chi square tests.

To check whether or not I made a false rejection of the null hypothesis (no association between semester of participation and the learning levels), I conducted a post hoc power test for each concept via G*power. From the concepts, only pKa met the standard threshold of 0.80 (power = 0.968) for the random sample and therefore can confidently say that a significant association does exist between the tested variables.

In order to better understand how the learning levels were associated with the baseline and intervention semester, I had SPSS include the standardized residuals for each contingency table. Through these values, I was able to see which learning level was dependent on the semester as well as in what direction. Only pKa had consistent significant standardized residuals for one of the learning levels, learning, in which the standardized residuals exceeded the threshold value of $\pm$ 1.96 (Hahs-Vaughn & Lomax, 2013). In this case, the number of participants in the learned category were lower than expected for the baseline semester and higher than expected for the intervention semester. The effect size for the pKa chi square test was small (random sample $w = 0.221$; total sample $w = 0.193$, Cramer's V) based on the standard conventions of chi square effect sizes (Ellis, 2010). Thus, while there was an increasing in learning for the pKa concept as identified by the IFCB, the scale of this increase was small.

Upon examination of the total sample chi square test of association for the alpha helix learning level vs. semester comparison, there was an improvement in the post hoc power, as expected, to meet the acceptable level. The standardized residual for the learned category during the intervention semester did indicate a significant positive relationship as shown on Table 5. The remaining concepts did not have any changes of significance for the total population.

This application of the creative exercises within the undergraduate biochemistry course adds to the body of literature regarding the student impact of creative exercises. While recent exploration on the impact of creative exercises in general chemistry only saw significant benefits when applied in smaller course sections, this analysis provides evidence that such activities can aid students in courses with larger student populations (Gilewski et al., 2019). Furthermore, previous work on creative exercises in biochemistry have yet to explore such impacts on students conceptual understanding (Ngai & Sevian, 2018; Warfa & Odowa, 2015).

In addition to the creative exercises, this project’s he use of the IFCB to track the impact of the interventions also add to the growing body of literature. The original instrument development team saw more noticeable shifts in the learning level distributions for their population than the results reported in this dissertation (Xu et al., 2017). However, Xu et al. acknowledge that they accomplished changes in student understanding via direct discussion of the correct responses. They further noted that this was not a recommended approach to address weaknesses in the student understanding (Xu et al., 2017). An separate study utilizing the IFCB to probe changes in students conceptual understanding, albeit for smaller course sizes, also examined hydrogen bonding and pKa concepts (Kopecki-Fjetland & Steffenson, 2021). The investigators use of tactile activities for hydrogen bonding displayed a significant improvement in the students' understanding of the concept (Kopecki-Fjetland & Steffenson, 2021). Such hands- on activities with tactile manipulatives may be an additional avenue for the participating faculty to explore in the future to address the student understanding of hydrogen bonding.

Faculty Experiences

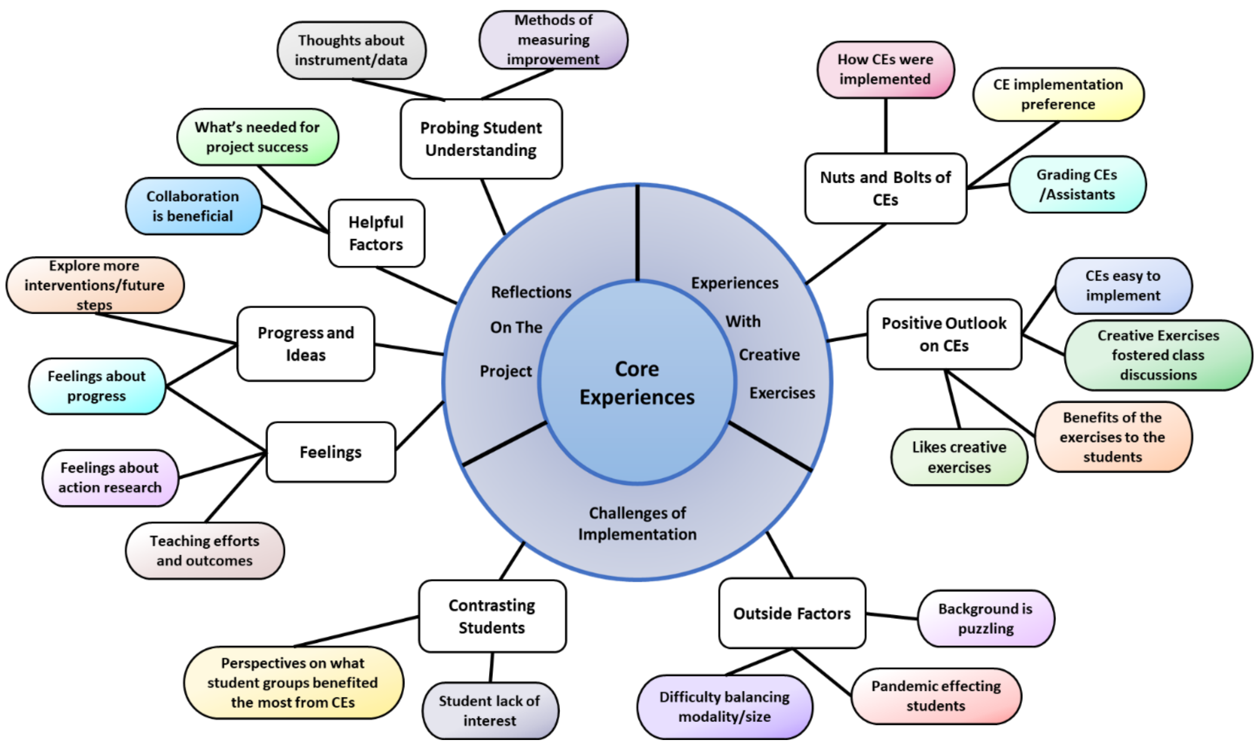

Figure 12: Themes identified within the summer 2022 faculty experiences.

Figure 12 displays the subthemes, major themes and emerging themes that were used to construct the description of the faculty experiences. The subthemes displayed in the figure use the same colors that I used to keep track of the different themes during the analysis. Note that the subtheme feelings about progress was interwoven between two major themes. This decision was made as I and the undergraduate research assistant were unable to place the theme within just one of the two specific major themes.

Description of Faculty Research Experiences

The instructors' experiences engaging in the research at the intervention phase of the project begins with their recollection of the creative exercises. These recollections typically began with their generally positive outlooks on the creative exercises. The faculty found that the exercises were fairly simple to implement in terms of integrating the exercises within the curriculum. Two of the instructors explicitly noted that they liked the creative exercises as an activity for biochemistry. Instructor 2 did not explicitly mention this within the interview, though the instructor noted that they enjoyed the discussion aspect that these exercises brought to the classroom. This appreciation for the discussions that the creative exercises brought to the course was not exclusive to instructor 2, but was shared amongst the faculty. Instructor 1 noted that they liked that the discussion of creative exercises led students to confront their understanding of the exercise concepts. Instructor 3 brought to attention the community building that the exercises brought to the students.

"I in general like the idea of the exercises, it's type of open questions when student can ... pretty much demonstrate their knowledge outside of the given ... given already predetermined answers by ... test Creator, alright." (Instructor 1)

"Yeah, I mean, it was a good place to exchange ideas, and again I wasn't doing, before this, I wasn't doing creative exercise, so I think it's a useful tool, so ... especially for biochem." (Instructor 3)

"And so, when they come into this class, it was you know that nice humming with discussions environment in the classroom, so I think they themselves enjoyed a lot of discussion with peers" (Instructor 2)

Beyond the discussion aspects of the creative exercises, the faculty noted that the exercises provided other beneficial experiences for the students. Instructor 1 noted that the open nature of the exercises allowed them to discuss their understanding of the related concepts beyond what was covered in the classroom. Furthermore, instructor 2 felt that the exercises provided the students with an opportunity to strengthen their problem skills and learn new strategies for engaging with the course content. Instructor 3 noted that they were impressed by the connections that the students were able to make when only given the information of the prompt and saw an improvement in the course for those who did well on the exercises.

"And it took me some time to realize I think, they're actually talking about hydrogen bonding actually, something like that. You know at first, I was like that was good, but wait no that's pretty good [...] So they were connecting things. So that was good." (Instructor 3)

"that's the purpose of the creative exercise is to develop such a strategy to respond to whatever you are asked, right, and that can be used for your even formal assessments like exam and that's what I want them to learn, the strategies to succeed, you know, to show your real knowledge on assignments" (Instructor 2)

In addition to the impressions that the exercises left on the faculty, the instructors also shared their personal methods of implementation. While the faculty included the same three creative exercises within their courses, the manner of their implementation differed between the instructors. Instructor 1 noted that two of the exercises were given as individual assignments to then be used for group discussions while the third exercise was an individual assignment. The instructor also had the students submit a reflection on how their responses changed based on the discussion. This was similar to Instructor 2's implementation of the exercises, though instructor 2 used online discussions for the second exercise. Instructor 3, who taught the honors section, kept the three shared exercises online, but also included personally made exercises as ungraded class discussion points.

Two of the faculty also described their preferences for the structure of the activities that led to their unique implementations. Both of these preferences were tied to the discussion aspect of the exercises. Instructor 2 noted that the in-person exercises were better due to the face to face discussions that they felt the students enjoyed. Instructor 3 noted by having the discussions online, this encouraged students to build a community and meet with their fellow classmates. The instructor also felt that in-person discussions would be constrained by the time allotted to the class and also considered the effort involved with collecting the exercise responses.

"Yeah definitely. Definitely in-person is better because of the discussion component that can be done in like, how we call, we call life, right? Because I guess that's the benefit of creative exercises, not, not the statements, but moments of discussion." (Instructor 2)

"Like I said, in a virtual environment, it gives it a chance to build community. It gives them a chance, like instead of just, if they do come to class, instead just the people sit around, right, it, like, forces them to know at least ten people or nine people I guess, plus themselves because you have to know yourselves." (Instructor 3)

In line with how the exercises were implemented, the faculty also described their experiences with the grading process to an extent. Instructor 3 noted that when they taught the course in the spring (large lecture) they had an undergraduate assistant to help grade the exercises, though the assistant was shared with instructor 2. In contrast, instructor 1 graded the exercises personally which required time on their part to grade, but the instructor was used to grading free response assignments. Instructor 1 also described the point distribution in which the submission after the discussion represented the bulk of the credit. The instructor did caution this point distribution as it led to students skipping the initial submission. Instructor 2 did not discuss the details of the exercise grading, though they noted that in the future they may explore peer grading or not require submissions.

"Well, what was good about last semester, was um, we had some undergraduate TAs, so we were actually able to grade them quickly, so they got back some feedback much faster than if it was just." (Instructor 3)

"Well, no, I didn't ask for help ... even though I had undergraduate TAs, but I graded myself" (Instructor 1)

"I would definitely keep the element of creative exercises, maybe not with submissions, maybe I'll ask them to submit, but we can do like peer grading because the grading is kind of difficult" (Instructor 2)

Along with sharing their general experiences with the creative exercises, the faculty also discussed the challenges that were intertwined within these experiences. The focus of these challenges was on the factors outside of the exercise design that were difficult to control and the student behaviors towards the exercises. In terms of outside factors, two of the instructors noted that they had difficulty with balancing the modality and class size. Instructors 2 and 3 expressed that they had trouble splitting their interactions between the Zoom and in-person attendees for the discussion. Instructor 2 also felt that students who attended in-person office hours benefited more than those who attended via Zoom as the instructor had access whiteboards and the students had more peer interactions in-person. Instructor 3 wished to move course content back to in-person, but they felt that exams needed to transition first before creative exercises assignments. Both instructors noted a challenge with the scale of the large lectures. Instructor 2 felt that it was difficult to reach all the students of a class of its scale. Instructor 3 felt the lack of one on one engagements kept them from understanding how the students were interacting with the exercises.

"I had to do zoom of lectures, like normal format and then zoom, and so I guess some students who decided to jump in remotely, they of course would miss, you know, that kind of interaction, interactive kind of moment of the class because I wasn't able to efficiently, you know, do that on two platforms" (Instructor 2)

"You know I want to get back towards more, towards more in-person stuff for that exact reason. But I doubt that, I'm almost certain its not going to be creative exercises. It is gonna be exams again first." (Instructor 3)

Along with these concerns, the faculty noted that in some cases the students' background knowledge was still puzzling to them. This discussion was centered around the concept hydrogen bonding, one of the foundational concepts investigated by the IFCB. Instructor 1 was concerned about the lack of improvement that students had for hydrogen bonding, a concept they felt had considerable coverage both in class and in prior courses. Instructor 2 noted that there have been many controversies surrounding hydrogen bonding as the exact nature has still been under research. Given this dialogue on hydrogen bonding, some of the incorrect responses on the IFCB could be correct if the right circumstances are met (something instructor 3 noted in the first set of interviews). That said, the instructor noted that it was unlikely that the students were exposed to the related literature to be aware of the matter. Instructor 3 noted that the lack of understanding on hydrogen bonding could be a shortcoming of general chemistry, in which the instructor was unsure how that might be addressed.

"Also, I have to say that hydrogen bonds they should be taught all over the courses ... chemistry like ... in all chemistry courses at UCF hydrogen bonds should be covered, more or less, including organic chemistry and I'm surprised 90% students ... don't ... know never learn this concept." (Instructor 1)

"*Hydrogen bonding, it's, it's a very controversial topic today because it's still in progress of figuring out, you know, like, for example, we teach them already established facts, but some new research, like, for example, some, in some new data, they actually found the, that hydrogen bonds can be formed when you have carbon hydrogen, and then hydrogen is bonded, depending on the environment, right, I am not sure that they learned the literature right"* (Instructor 2)

Two of the faculty also discussed the effects of the pandemic on the students and the class in general. Instructor 2 observed that the students were struggling the most at the beginning of the semester as they were adjusting from a predominately online courseload. The instructor felt that the students likely relied on learning “crutches” which were no longer available and were hesitant to engage with in-person assignments. The instructor also noted that the students were more comfortable with the course as the semester progressed. Instructor 3 also noticed the students struggle with movement to the hybrid format of the Fall 2021 semester as well as the students’ adjustment over the course of the semester. Instructor 3 also contemplated the role that societal issues sparked by the pandemic as well as those that exist in general might have played on the academic performance of the students.

“And that the problem was also the students were not used to in class exams so they would say in that oh it's okay for tools for, like, one or even more than one year, they would have all the online exams and they didn't know how to, you know, catch up with time” (Instructor 2)

“How much the pandemic had affected students, how much they knew, I totally noticed this first.” (Instructor 3)

Another challenge that the faculty faced was the different levels of engagement the students had towards the exercises which two of the faculty often contrasted. While instructor 1 discussed their issue of students not submitting their initial responses, instructor 2 and 3 described the traits of students whom would make the best use of the creative exercises as well as the attitudes towards the exercises that limited their impact on learning. Instructor 2 noted that success for both engaging with the exercises and the course required a willingness to participate and engage with the material, rather than simply intelligence. Instructor 2 noted that the students who excelled in the course would be the most engaged in the course and the discourse of the creative exercises. Instructor 2 contrasted the success students had with the exercises with the students who were not engaged with the exercises and lacked interest would not see the same benefits. Instructor 3 expressed their fear that some students may have simply used other students' responses to the exercises instead of their own ideas. Instructors 1 and 2 felt that perhaps the lack of interest in the exercises may be due to the students focusing more on the grade of the class rather than the learning biochemistry.

"It's not, it has nothing to do with your kind of intellectual property or something, or like your academic performance overall. It's about your approach to like, okay I'm here to learn I'm going to take whatever I'm given, I'm going to try everything, that kind of mentality and those, of course, succeed, succeed more often than same kind of background students, but who don't try" (Instructor 2)

"Some of them pretty much ignored, some of them would ignore the first stage, because it was ... It cost only two points, and the second stage cost eight points, so they sort of ignored this stage, and they would collect only eight points." (Instructor 1)

"But on the other hand, there's no, you know, call response, right, like I don't get to preview them, just view. It is the likely possibility that they discuss with others and then put those answers down so I'm not really getting their thoughts." (Instructor 3)

Past the challenges that were faced during the implementation of the creative exercises, the faculty also reflected on their experiences with the research. Such reflections included their experiences with the IFCB and its associated class data. In terms of the data collected using the IFCB, the faculty were concerned about the lack of improvement for the hydrogen bonding concept. Instructors 2 and 3 speculated as to why the performance on hydrogen bonding was low, of which instructor 2 felt that this did not align with their experiences during the semester of interest. Instructor 3 felt that perhaps the hydrogen bonding questions may be misleading as the questions required students to recognize implicit hydrogen bonds.

"And hydrogen bonding to improve ... and I cannot say ... it was much worse, but definitely didn't improve ... at all." (Instructor 1)

"for example, some, in some new data, they actually found the, that hydrogen bonds can be formed when you have carbon hydrogen, and then hydrogen is bonded, depending on the environment, right, I am not sure that they learned the literature right but, it's kind of difficult to know to conclude anything, right." (Instructor 2)

"You know, I still (unclear), I didn't know what to expect and still is (unclear, confusing to) me never knew hydrogen bonding is so high. [That] doesn't, doesn't make sense in the context. What I see in the class doesn't make any sense whatsoever." (Instructor 3)

The faculty were also concerned about the student's performance as well, though to varying degrees. Instructor one noted an increase in performance for their students' alpha helix concept scores which the found to be encouraging. Instructors 2 and 3 noted that the performance on alpha helices was not a noticeable gain and considered whether the instrument may not be capturing what they see in the students understanding. Instructor 3 felt that the questions for alpha helices were not focusing on critical components of the secondary structure. Instructor 2 felt that perhaps the instrument was too foundational to fully understand the students conceptual understanding.

"I already see that the Alpha helix is better now [mm hmm] based on the bar graphs." (Instructor 1)

"And now there are some critical aspects to the part where there's no space for there is tight packing in the middle, though I don't understand why that's a critical piece of knowledge." (Instructor 3)

"So definitely how people test, tests do not assess, like, learning or like mastery of the material in a broader understanding of that. Those are just kind of fundamental, some certain fundamental concepts that we have tested them on." (Instructor 2)

These concerns about the IFCB not providing a clear enough picture on the student understanding led the faculty to discuss potential alternative methods of measurement. The faculty were keen to explore additional tools to gauge the student understanding of the concepts that they are targeting. Instructor 3 was also interested in kinetics as an additional concept to explore, especially since they noticed that students are intimidated by the related math.

"Or maybe some other instruments, not only like that formal kind of instrument that assesses you know that number, maybe, something that refers, more to comprehension" (Instructor 2)

"So um, kinetics, this is probably the most important (unclear). Because, it's because thermodynamics is only half the story, right. So that's probably, what I'd say is completely missing." (Instructor 3)

That said, the faculty do not feel that the IFCB and the associated data held no value in probing student understanding. Instructor 3 felt that the instrument could still be improved and that they agreed with the mentality behind the instrument. Instructor 2 noted that the data may not be as unencouraging as they may have first considered. The instructor stated that, given the trends in student performance that they have seen during the pandemic, the fact that the student performance did not drop was encouraging.

"I think it's fine, [referring to the assessment approach] you have to set up a starting point, you make a mess and then you clean it up, that's fine. I am totally with that sort of philosophy" (Instructor 3)

"(Discussing COVID's impact on student performance) Yeah, yeah, exactly because maybe the, it dropped, right, but now, with our intervention kind of level, right? [It leveled it out] So maybe in this case, we need to continue for another year, to see if there is a progression up." (Instructor 2)

Rooted throughout their reflections on the project were their feelings on the matter. The faculty provided their thoughts on action research in terms of its role in the project as well as the impact that it had. Instructor 1 noted their feeling of motivation to engage in the research process as it gave them an opportunity to explore their course in a "scientific way". The instructor further noted that they were more comfortable with the quantitative data collected as this was more familiar to them. Instructor 1 also felt that such efforts to research and develop the curriculum should be obligatory for all members of the department and beyond. Instructor 2 enjoyed engaging with the research with the experts in education research as they felt this helped them expand their understanding of new teaching methods. The instructor further noted that they felt impressed with the how engaging in the research helped them and the other faculty to develop new exercises for the biochemistry 2 course. Instructor 3 also appreciated how the research placed value on improving biochemistry education and fostered an environment that promotes this goal. That said, the instructor also felt overwhelmed at times by all the different facets of education research. Instructor 3 expressed that they would love to explore these different aspects more, but they are unsure how to do so and would need to seek guidance on the matter.

"Perhaps it should be, of course, considered by administrator, but I would I would vote for this to be ... obligatory for for all ... units, for all ... departments." (Instructor 1)

"And another thing is when you or Chris share with us the results and, like, we discussed what this or that, you know, value, or criterion means. That educates me, it broadens my understanding of how education, research in education, works" (Instructor 2)

"We are all curious, that's why we're here, bringing this to your yard, you know, it's like I would love to invest the time in the delve into student learning to the college and have a little bit of background, I'd love to expand that but it's also kind of like, help!" (Instructor 3)

In addition to their feelings about the research, the faculty also shared their impressions on their teaching efforts and outcomes. Instructor 2 felt that their efforts providing examples to the students regarding the concept of pKa was what lead to the students learning the topic. However, the instructor was disappointed with the alpha helix concept results as they felt they emphasized the concept in their instruction. The instructor also expressed that they were unsure how to promote more engagement in the class and was hesitant to enforce mandatory attendance to the class. Instructor 3 felt that they were doing well in their instruction, particularly in regards to serving the higher performing students. The instructor also noted that while they would like to see more improvement in their teaching outcomes, they realize the perfection is not feasible. Instructor 3 also stated that they wished to strike a balance in their teaching between the effectiveness of the curriculum and avoiding burning out from the workload. Instructor 1 noted that they gave a significant amount of coverage for hydrogen bonding and therefore did not expect the results of the IFCB to remain stagnant.

"I was expecting a better performance on hydrogen bonds honestly because, um, I give some significant time in my course to teach hydrogen bonds, that was my impression, but obviously it's not true." (Instructor 1)

"I think in the fall of 2021 one based on that previous experience I maybe spent, like, give more of the examples and whatnot so that's why it makes sense for me now that they learned" (Instructor 2)

"But, you know, again, it's, it's again how much how far am I want to push myself to just being overwhelmed." (Instructor 3)

Another aspect of the faculty's reflections on the research that ties in with their reflection on probing student understanding was their progress in the project as well as ideas for the future. The faculty expressed their feelings about the progress that they made over the course of the project. Instructor 1 stated that beyond their experiences with student performance on the instrument, they were able to meet their goal of establishing a group dedicated to enhancing their teaching. The instructor also held the goal of having a way to observe the students learning in the class which they felt that they had also achieved and this motivated them to improve their teaching. Instructor 2 felt that they had improved in that they gained more teaching experience and have better understood the importance of certain concepts towards the overall course vision. However, the instructor felt that their goal to reach as many students as possible in terms of their learning had not yet been achieved. Instructor 2 expressed their concern that a strategy to reach ~80% of the students might not exists. At the same time, the instructor does acknowledge that the results of the study may be skewed by the impact of the COVID pandemic. Instructor 3 had a similar feeling about the intervention, in that it was not enough to achieved the desired increase in learning, but noted that the exercises were a good starting point. Instructor 3 noted that the project did lead to an improvement in their teaching methods. Furthermore, the instructor also noted that having all the students achieve the material of the course perfectly may not be an entirely feasible goal.

"First, and ... very important goal that we actually already achieved is, uh ... building a team of, uh ... interested instructors, instructors who are interested in improving that teaching." (Instructor 1)

"I'm still in doubt if a strategy exists that helps me to reach out to, like, maybe 80% of my student population." (Instructor 2)

"I think I'm doing well, doing, I'm doing good, like I'm not maximized but, though, as far as diminishing returns are going, I could shoot for perfection, but again I've got to ration the time." (Instructor 3)

Tied with the faculty's feelings about their progress was their perspective on where they would like to take this project moving forward. The faculty were keen to discuss their ideas as to what they would like to target in the curriculum as well as their thoughts on how they might achieve these efforts. Instructor 1 hoped to further explore the implementation of the creative exercises and would also seek to explore adding new practices to the undergraduate biochemistry curriculum. The instructor wishes to use these practices to target the students' retention of the knowledge they acquired during the course. Instructor 1 also hopes to target all of the concepts of interest with these interventions and in order to understand which concept they will have the most impact on. Furthermore, the instructor hopes to examine the students conceptual understanding across chemistry as well as seeks to integrate new practices within the program. Instructor 2 also noted that they plan to stick with their current teaching methods as they feel that reaching every student may be unreasonable. Despite this sentiment, instructor 2 shared the interest in exploring additional interventions, possibly to target students' critical thinking and or data analysis skills. Instructor 2 felt that additional statistical analysis on the IFCB would also paint a clearer picture on how the intervention and baseline data sets compare. Instructor 3 was also interested in exploring more interventions, but cautioned that the external factors effecting the student success may still linger. Instructor 3 also felt that shifting the focus of the alpha helix concept towards other structural characteristics may prove more beneficial to the students.

"So, if you can think of any instrument or any assessment or any kind of project that helps to track the development or progression of how their critical thinking skill develops, that would be another interesting aspect that gets how to understand the student population best and what they need, you know." (Instructor 2)

"Yeah, and then another goal is to make, maybe try several different ... interference and learn how to implement them in class ... So creative exercise is something that I learned from this

effort, and maybe we can explore some interferences and uh, I will be glad to learn this too." (Instructor 1)

"Because again I think it's helpful. Yeah, I mean, again what I want to know is what is the core of those gray bars? And I strongly, strongly suspect the core of those gray bars at this university are not teaching style, you know, we can move the needle on ... but I suspect, what I would, what I would want to know is, you know, once we de-convoluted those bars, how much that is because they were working forty hours and how much of it is because they're missing sleep, because there are other stressors." (Instructor 3)

The last aspect of the faculties reflections on the project was what they found to be helpful in carrying out the research efforts. The faculty felt that collaboration with between themselves and the researchers was a key beneficial feature of this project. The faculty stated that the project meetings were an excellent place to share ideas and gain insights from the other faculty members experiences in the course. Instructor 1 was pleased to have this collaborative environment as these interactions constituted one of their goals for the project. Instructor 2 noted that they were impressed by what they were able to accomplish through their collaboration as tasks that they felt were intimidating (such as the biochemistry 2 exercises development) were achieved within the desired time. Instructor 2 noted that the collaboration with the other faculty also helped them to reflect and give quality feedback to the students. Instructor 3 greatly appreciated the way in which members of this project collaborated as they felt that goals were set and met during the project. Instructor 3 noted that they felt that their time spent towards teaching was valued in this environment. The instructor noted that both positive features of the project collaboration were not always present in past experiences.

"What's really nice about this compared to like some committees is that things get acted upon very, like uh, [we] consistently come up with some sort of plan, enact it, to the point, like there's manuscripts you know, like you know, things are instead of, like, it being a, you know, pontificating session which certain communities tend to fall into, a philosophical thing." (Instructor 3)

"So that's good. It's not like some places where they are like, 'why, why do you spend time on teaching stuff?'" (Instructor 3)

"First of all, I find that, um, talking with colleagues, biochemistry instructors, discussing, it's itself very beneficial for establishing like ... collegial atmosphere in the department." (Instructor 1)

"(Discussing biochem 2 exercise development) Yeah you mentioned it, sorry. I didn't mention that but yeah, you reminded me of, that's interesting, because I really enjoyed that, and you know, at first, when we had this stuff to do, I'm like, oh my gosh. How we're going to accomplish that? But then you know slowly, slowly with discussion, it ended up a very good product, right." (Instructor 2)

Adding to their thoughts on the benefits of the project collaboration, the faculty discussed what features they felt were key to the success of this kind of project. Instructor 1 noted that gathering data on the students' conceptual understanding is a helpful motivator for faculty to grow in their teaching and understanding of educational research. Instructor 1 also stressed that thorough records of any data collected is another key component of a successful project. Instructor 2 stated that knowing the purpose of the research was a key frame of mind to have in order to successfully engage in the project. Instructors 1 and 3 both felt that faculty commitment in the project is critical for a similar project to be successful. Instructor 3 felt that in addition to the commitment of the faculty, the faculty should also believe in the value of the project.

“Definitely to explain the purpose, right. If it takes some kind of collaborative effort, what is the purpose? Clearly formulate the purpose” (Instructor 2)

“I think that ... instructors should be motivated to ... should be motivated to change the way ... To improve, they should be motivated to improve their uh ... result of their teaching, I mean the students learning in the class” (Instructor 1)

“And it can't just be, "Oh, we should do this," and then everyone leaves and no one does it. Because there has to be, you know, buy in is one thing, buy in can just be there, one is to get to talk talks that's really helpful for the good or there's something always have a plan of action that gets done and everyone is committed to doing it.” (Instructor 3)

Chapter 4 Concluding Remarks

In this chapter, I covered the data collected from the intervention phase of my dissertation which included the IFCB results and the faculty experiences after the semester of exercise implementation. In terms of the influence of the creative exercises on the student performance, I determined that the creative exercises had a small, positive, significant impact on the students understanding of pKa and alpha helices based on the IFCB. However, I cannot confidently claim that the creative exercises had a noticeable effect on the other concepts examined by the IFCB. That said, the dosage of the exercises within the course was not what the literature would consider high (Gilewski et al., 2019), and therefore the minimal impact of the exercises may change with a greater frequency of implementation within the course. Furthermore, this study only viewed the student learning in terms of the IFCB, which only provides one view of the student learning in the course.

As for the faculty experiences with the exercises, I observed the faculty as having a generally positive view of the exercises. The faculty appreciated the ease to which the exercises were inserted within the curriculum and found that the exercises were a good tool to facilitate discussions. The faculty did note that they had challenges balancing the modality of the classes when integrating the exercises into the lesson and expressed difficulty with garnering the interest of the large classes in the creative exercise activities. The faculty also viewed the exercises as a starting point from which to build upon further.

In terms of the faculty's experiences with the collaborative action research process, I noticed that the faculty greatly appreciated the opportunities the research process afforded them through interacting with myself, my advisor and each other. The faculty found these interactions to aid in their understanding of teaching practices and education research. In addition, the faculty appreciated that the action research efforts fostered an environment that values teaching. Despite expressing discouragement over the lack of change in the IFCB scores during the intervention semester, the faculty still discussed and exhibited interest in exploring additional interventions as well as taking encouragement form not seeing decreases in performance despite the pandemic. The faculty expressed a persistence in the project that literature has noted to be key for long term curricular refinement (Casper et al., 2019). The faculty also recognized that such dedication was critical to the success of educational reform.

CHAPTER 5: EMBEDDED QUALITATIVE EXPLORATION OF INTERVENTION

Abstract

In this chapter of my dissertation, we would like to shift to focus of the qualitative inquiry towards the students as it was embedded within the project. This embedded qualitative inquiry was centered around the research material that the students interacted with as a part of this project: the creative exercises and the IFCB. While studies have reported the impact of creative exercises on learning and the kinds of student responses generated, how the students engage with these exercises has yet to be explored. Therefore, this study seeks to fill in this gap within the literature by exploring student approaches to the creative exercises, within the context of biochemistry, through semi-structured, think-aloud interviews. In terms of the IFCB, through engagement with the faculty experiences, we were inspired to interview students as they verbally responded concept inventory. This chapter reports the findings from 10 participant interviews from undergraduate biochemistry students actively and verbally engaged with creative exercises. This chapter also reports the findings of 6 participant student interviews in which they verbally engaged with the IFCB. These findings showed a range of variation in how the participants approached the creative exercises as well as the role of the modality of the exercises played in shaping the student approaches. The findings also revealed aspects of the IFCB questions which led to inconsistent responses.

Research Question

In order to understand how the students engaged with the creative exercises as well as how the students reasoning aligned with the IFCB structure, we utilized the following research questions:

- What protocols do students use to solve creative exercises?
- How are the students' approaches to the creative exercises shaped by the modality of the exercises?
- How do students interpret the IFCB questions?

Methodology

To answer our first two research questions, we chose to employ protocol analysis as the guiding methodology of this study. Protocol analysis is a qualitative methodology which focuses on understanding the approaches and thought processes that a individuals employ to achieve a task (Bainbridge & Sanderson, 1995). Protocol analysis often employs think-aloud, also known as clinical, interviews in order to elicit these processes and approaches in the moment (Fox et al., 2011; Trickett & Trafton, 2009). However, the methodology is not restricted to these forms of interviews and researchers may also employ interviews which call for the participants to give a retrospective account on how they approach a particular task (Kuusela & Paul, 2000; Van Den Haak et al., 2003). While there is debate on which particular method of interviews within protocol analysis yields the best results, both approaches are generally accepted (Kuusela & Paul, 2000). Additionally, it has even been suggested that incorporating aspects of both retrospective and concurrent examinations of participants engagement in a task can provide a beneficial diversity of observation (Kuusela & Paul, 2000).

Protocol analysis, particularly think-aloud interviews, has been by no means an unfamiliar methodology to chemistry education research. Chemistry Education studies have utilized this approach, though not always explicitly defining the methodology, to describe students chemical reasoning when engaging in activities or problem solving (Davenport et al., 2014; Nakhleh & Krajcik, 1993; Popova & Bretz, 2018). With this data, researchers have then been able to develop activities that promote students to adopt mental scaffolds that could help address struggle points in their mechanistic reasoning seen in previous research (Caspari et al., 2018; Graulich et al., 2012). Ironically, these same think-aloud interviews that help develop these activities are often then used to examine the efficacy of the scaffolding activities (Arjoon et al., 2013; Graulich et al., 2012).

As for my last research question for this chapter, we continue to borrow the aspects from protocol analysis, though we did not emphasize approaches as we had with the creative exercises. Rather, the focus of the data collection was to gauge whether the IFCB was understood by the students or if there were features of the exercises that confused the student. This decision to qualitatively explore the IFCB questions was inspired by both my own investigation into the validity and reliability of the instrument discussed in chapter 3 as well as the faculties concerns about the students' interpretations of the hydrogen bonding questions. Therefore, we decided to conduct these interviews to better understand how students were interpreting the questions in relation to their construction. Such an effort had yet to be undertaken within the literature and therefore adds weight to the importance of this inquiry (Loertscher et al., 2014; Villafañe et al., 2011a; Villafañe et al., 2011b; Xu et al., 2017).

Methods

Setting

This study was conducted as a part of a larger collaborative effort to reform the curriculum of an undergraduate biochemistry course sequence. The study was conducted at a large research-based institution located in the southeastern United States. The faculty participating in this project selected creative exercises as an intervention to implement within the courses as part of a collaborative action research initiative. The faculty chose the exercises to encourage students to draw connections between concepts which is a main objective for the course considering biochemistry is a subdiscipline largely defined by diversity of conceptual underpinnings that give a holistic perceptive on the influences of chemical processes on biological function. This research focuses on the introductory undergraduate biochemistry course, Biochemistry I. The exercises were initially implemented in the fall semester of 2020 and subsequently in the fall of 2021 and the spring of 2022. From these semesters we recruited participants for the creative exercise interviews. Interview recruitment of the IFCB interviews occurred during the fall semester of 2022. For more details on the timeline for this aspect of the project, see chapter 1 project timeline (page 3).

Interview Protocol

Creative exercise interviews

The students were interviewed via semi-structured think-aloud via zoom. These interviews typically lasted 20 minutes in which the students were asked to say out loud their thoughts as they went about engaging with 3 creative exercises. The participants were both audio recorded and video recorded and these recordings were kept confidential from the faculty in order to prevent biased interactions between the participants and the instructors.

Initially, the interviews were conducted virtually due to the pandemic and would remain online for the convenience and safety of the participants. The students were provided with the exercises the day before the interview session. During the interview, the participants were asked to engage with the creative exercises while saying their thoughts out loud. The interviewers minimized their interactions with the students to simply request the participant to continue verbalizing their thoughts should they fall silent. This was done to avoid leading the participants to interact with the exercises in a particular manner (Bowen, 1994). Then the participants were asked to describe their experiences with the creative exercises in the class. For more information on the interview process, see the interview protocol provided in the supplemental materials.

The target for this study was to have the participants engage in two interviews: one at the midpoint of the semester, the other one during the week after final exams. The purpose of the two-interview approach was twofold; to observe the student protocol over time and to observe student engagement with the in-class exercises during the second interview. Given that the first interview was held in the middle of the semester, the first set of exercises were unique to the interview. Literature suggests that having multiple interviews with the participants can lead to an enriched data set (Knox & Burkard, 2009). That said, retaining participation for both interviews was not a simple task and this affected the number of interviews each participant engaged in.

IFCB interviews

The protocol for the IFCB interviews was similar to the one used for the creative exercises. The distinction between these protocols was that we could not send the students the IFCB questions for them to share their screen. Instead, the interviewer, the undergraduate researcher at the time of the interview or I, shared the IFCB questions and the participants via the share screen function on zoom. Also, we did not ask the participants about their experiences with the IFCB in the classroom.

The questions selected for the interview were based on both the faculty reflections described in chapter 4 as well as the psychometric data presented in appendix A. These questions included 1 alpha helix question as a practice question as well as the full question sets for the remaining concepts. The questions were arranged in the order that they appeared in the instrument except for the alpha helix question which was included first.

Participant Selection

Participants were recruited from the introductory Biochemistry I courses during the semesters in which the creative exercises were submitted, the targeted sample size was 6 interview participants per semester of data collection. To solicit ideas from a diverse sample of students, we intended to select participants who varied in performance on a concept inventory given at the beginning of the course However, due to a low response to the interview recruitment, we typically interviewed any student who volunteered to participate. A summary of the participants, their concept inventory score, and their instructor is displayed in table 6. Note that the mode for the number of concepts that the students answered correctly (out of 4) for each sampling semester was 0. Note that the score for student 10 was unavailable as they did not take the pretest.

Table 6: Participant scores on the pretest concept inventory, Mode score for the class was 0 out 4 concepts.

Participant	Instructor	Number of pretest concepts correct out of 4
Student 1	Instructor 2	1
Student 2	Instructor 3	0
Student 3	Instructor 2	0
Student 4	Instructor 3	2
Student 5	Instructor 3	0
Student 6	Instructor 2	0
Student 7	Instructor 2	0
Student 8	Instructor 3	0
Student 9	Instructor 3	0
Student 10	Instructor 3	NA

From the fall semester 2020, 6 potential participants were selected based on their scores and course sections from a sample frame of 8 recruitment respondents. However, only 4 participated in an interview (students 1-4) and only 1 was willing to participate in the second interview (student 4). In the fall of 2021, 6 participants indicated interest in participating via the interview recruitment. From this group, 3 agreed to be interviewed and they were interviewed twice (students 5-7). In the spring semester of 2022, recruitment was carried out only for the post semester interview set. From this recruitment, we had 6 potential participants in which 3 participated in the interview (Students 8-10).

As for the participants selection in the fall 2022 IFCB interviews, 7 students responded to the recruitment. Of the 7 potential participants, 6 agreed to the interview and subsequently participated. The interviews occurred within the first quarter of the semester in order minimize the influence of the course on their responses to the instrument.

Analysis

Transcription

All of the interviews were initially auto transcribed via zoom's built in otter.ai transcription software for cloud recording or directly through otter.ai. The transcripts were subsequently cleaned by me or one of the undergraduate research assistants depending on the interviews in question. The only distinction between the transcription process for the creative exercise and IFCB interviews was that only the student responses to the questions were cleaned for the IFCB interview recordings.

Creative Exercise Interviews

In order to present the student's approaches to the creative exercises in a visual representation, we utilized the digrammic modeling framework. This framework guides the analysis by constructing graphical maps of the participants' protocol for a given task using the language of the subjects as a guide (Bainbridge & Sanderson, 1995). These maps are typically sequential in their design (Trickett & Trafton, 2009), though for my application of this framework I did have one instance of a non-sequential component due to the nature of this feature of the student's approach.

In order to generate the diagrams of the student approaches, I first went about reading the transcripts to get a sense of the data. From there, I went about highlighting features of the transcripts that I felt were key to the student's method of tackling the exercises as well as having a commonality amongst the students. These inductive codes were added to a document along with a description of what I felt they represented. These freshly created codes could then be applied to subsequent transcripts for analysis. Additionally, I kept track of when codes were developed across semesters to understand how the codes changed or entered the code book. Upon the inclusion of an undergraduate assistant as a part of the project team in 2021, I included them in the coding process for the interviews collected during that time. To ensure the quality of the coding, we coded each of the transcripts individually and then discussed the analysis until complete agreement was reached. This data was also shared with the corresponding author in order to gain her input.

IFCB Interviews

For the analysis of the IFCB think-aloud interviews, I relied on the IFCB itself to act as a guiding framework of the analysis. I utilized the IFCB's structure to frame how I coded the interviews and look for inconsistencies between the student responses and the logic of behind the instrument.

To condense the student responses further into more manageable parts, the undergraduate research assistant and I selected statements from the transcripts that best reflected the students' responses and reasonings towards the questions (similar to significant statement selection in the previous chapters). We individually selected statements for three of the interviews and then compared our selections. Since we were considerably similar in our selection of statements, we split the remaining three interviews to code separately.

The statements were then transferred into an excel file in which the student responses were organized based on concept type and the specific questions. Then these responses were coded based on a set of prior codes: right answer, wrong answer consistent, wrong answer inconsistent, correct reasoning, incorrect reasoning, overall consistency. Within coding the student's overall consistency, I also indicated if a particular structural feature of the IFCB was involved in the student responses. The result of this analysis was used to construct Table 7-9 shown later in this chapter.

Results

Creative Exercise Interviews

Fall 2020 online implementation semester student protocols

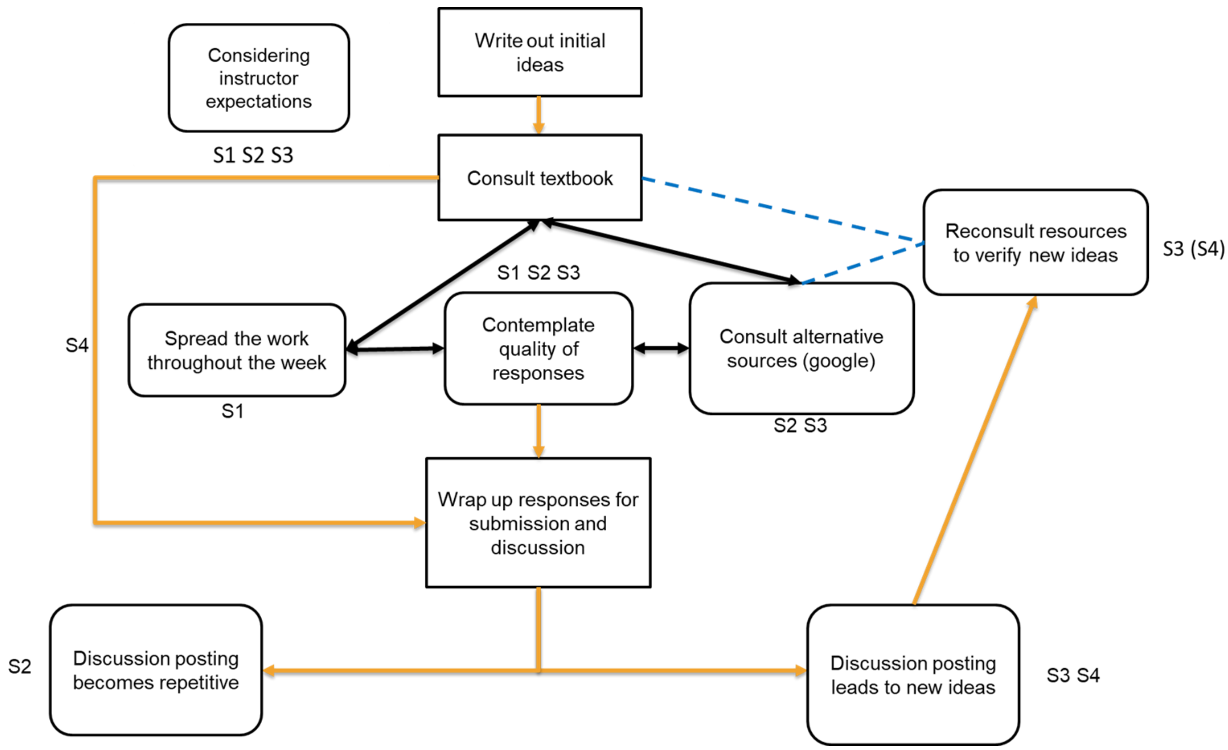

Figure 13: Fall 2020 online class participant creative exercise protocol map, creative exercises implemented online.

The analysis of the fall 2020 interviews led to the protocol model seen in Figure 13 which represents the participants approaches to the creative exercises. The square boxes of this figure represent key features of the students that were consistent across the fall 2020 participants whereas the curved boxes represent features that were specific to one or a set of participants. The orange single headed arrows represent movement from one feature of the process to the next while the double headed black arrows signify movement back and forth between features. The blue dashed lines represent a reconnect to prior features of the approaches without entering back into the sequence.

As indicated in Figure 13, the participants' approaches to the creative exercises did not diverge until after they consulted the textbook for additional responses. At this point, while student 4 would move directly to the next consistent moment of the protocol, the remaining 3 participants reveal alternative routes in the solving process. Two of the participants brought up alternative sources from the course materials as a means by which they could derive additional responses for the exercises. The remaining participant discussed how they spread the exercises across multiple days and indeed engaged with the exercises as such with a certain hesitancy to complete the exercises in one sitting. From these deviations, the three participants' approaches converged on contemplation of the quality of their responses. This feature often led to a back-and-forth movement to previous features of the protocol until the participants felt satisfied with their responses.

"But then I have to, like, start really looking at the textbook and like googling stuff" (Student 2)

"Like, I might sit down for like half an hour and like work on it. And then like, I'll get some stuff down. And then I'll come back like maybe the next day or so and work on it for another half hour or like another hour" (Student 1)

"Like, I'd rather just like read the chapter and then come back and like write something at least like, looks like I tried, like, put a little more effort into it. Not so it looks like I try but like actually put a little more effort into it." (Student 1)

At this point within each of the students' protocol, if they were in the class setting, they would wrap their responses and would submit them to the online discussion setting. One interesting aspect of this wrapping up that some of the students brought up and even did during the interview was counting their responses. Despite not being requested of them during the interview, one of the participants counted their responses and mentioned that they typically strove to have a few more responses than was required of them. After wrapping up, I sought to understand the role of the discussions in the student approaches by having the students retrospectively recall this feature of the activity. Once again, I had some deviation in the sequence with a mixed perspective on the value of the discussions. One student noted that the discussions often became repetitious in that each subsequent post would often repeat the same statements as the previous. In contrast, two of the participants noted that the discussion post led to new ideas about the exercises prompt which could be included in their existing understanding. From this feature of the student engagement with the discussion, student 3 explicitly mentioned that they would then consult resources (both alternative and course materials) while student 4 eluded such actions.

"So, um, but yeah, I mean, I don't mind it, the discussion post isn't bad. And then I don't know if like, in other classes, people are required to like respond. But after a while, it's just everybody's saying the same thing." (Student 2)

"And then we respond to like other classmates, which I think is really helpful because you just take what they think and how they got, like their answers" (Student 4)

"There was something about, um, like, it was something about hydrogen bonding that I'd never heard of. And I looked it up and it was like a thing. And I was like, that's, I'm gonna respond to it on this as the person's comment. I was like, I've never heard of this." (Student 3)

One feature of the student’s engagement present within 3 of the participants engagement that was difficult to place within the sequence was the participants consideration of instructor expectations. This feature of the student engagement with the exercises appeared at various points of the process in which the students expressed concerns as to whether their responses to the exercises aligned with what the faculty expect for the responses.

"Sometimes I look at these like I'm trying to figure out if there's like a pattern they want me to catch on to …" (Student 1)

“But I don't know if that's really what I'm supposed to be doing or which is supposed to be what I think.” (Student 2)

“I didn't, I kind of didn't know what they (instructor pronoun) wanted.” (Student 3)

Fall 2021 & Spring 2022 Student Protocols

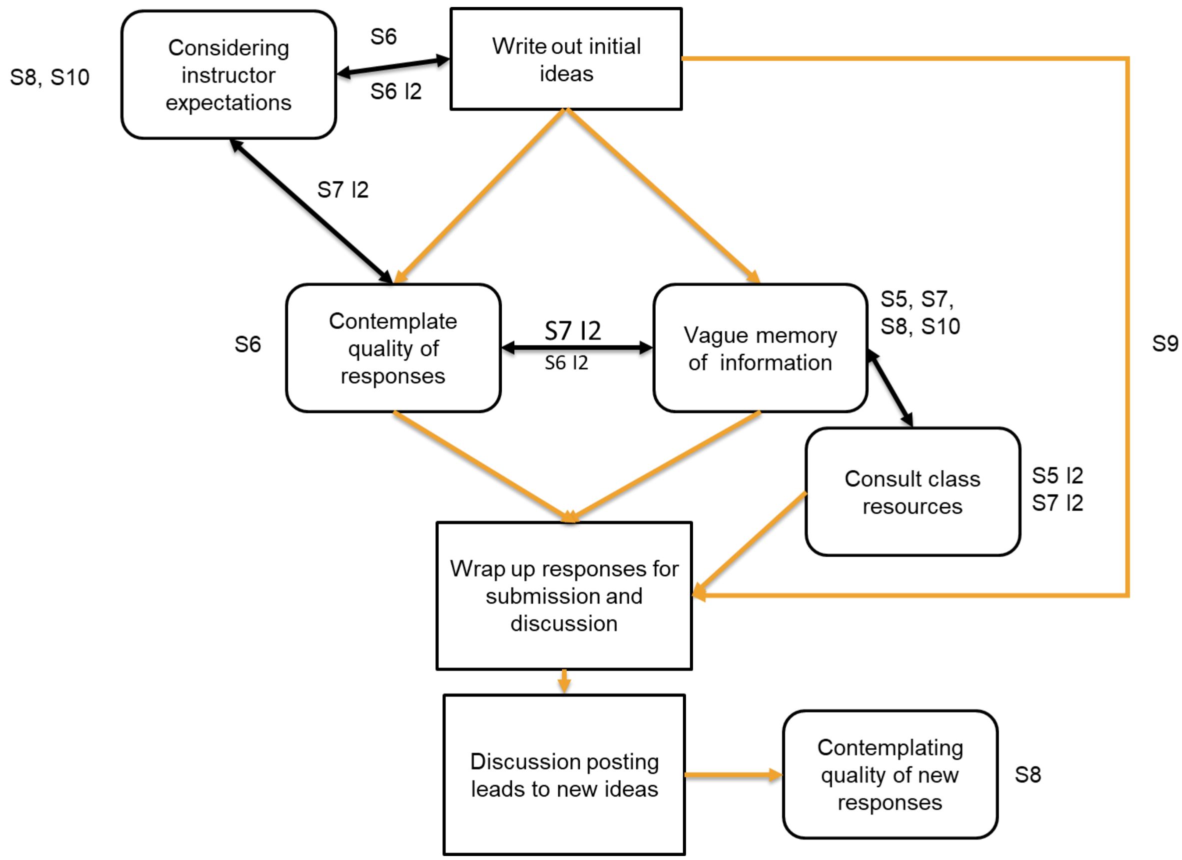

Figure 14: Fall 2021 & Spring 2022 in-person classes participant creative exercise protocol map, creative exercises implemented face to face and online.

As with the previous dataset, Figure 14 displays the digrammic model of the fall 2021 and spring 2022 participants' sequential approaches to the creative exercises. The representational characteristics (boxes, arrows, etc.) are consistent with the previous figure. The student identifiers with the additional I2 indicates the second round of interviews experienced by the fall 2021 participants. It is also important to restate that the students 8, 9 and 10 (S8, S9 and S10 within the figure) represent the three participants from the spring semester of 2022.

The semesters in which the creative exercises had a varying degree of in-person encounters had variations in the student approaches to the creative exercises not seen in the previous semester's dataset. Consultation of resources played a more limited role in the student engagement with the exercises and this feature was no longer consistent across participants. Resource consultation only appeared in the second round of the fall 2021 interviews to address the newly identified feature of vague memory of information relevant to the exercise prompts. Furthermore, the students did not consult alternative sources and they did not mention this as a part of their typical approaches to the exercises.

Another feature of the students approaches that differed from those presented in the online only dataset was the contemplation of faculty expectations. For the fall 2021 participants, this feature of the student approaches was less prominent than that of the previous fall semester. Only 2 interviews (S6, S6 I2 and S7 I2) were coded for this feature and could be isolated to a specific point in the sequences of their approach to the creative exercises. Student 6 only mentioned considering faculty expectations retrospectively rather than a current concern. However, the spring 2022 participants saw a return of concern for faculty expectations as a larger feature of the student engagement with the exercises.

"Definitely felt more comfortable on an individual basis, especially after having a few and knowing what was really expected and what like." Student 6 (interview 2) *"then we like never went over it in class or anything like that so like I didn't know how I did or like what I was missing."* Student 8

Participant key response features

While the focus of the analysis was largely on how the students were approaching the creative exercises, I did encounter a set of particularly interesting responses that were either unexpected or highlight as beneficial features of the exercises in the literature (Gilewski et al., 2019; Lewis et al., 2010; Warfa & Odowa, 2015). These responses included explicit linking of concepts, misconnecting concepts and responses acquired from google.

Linking concepts

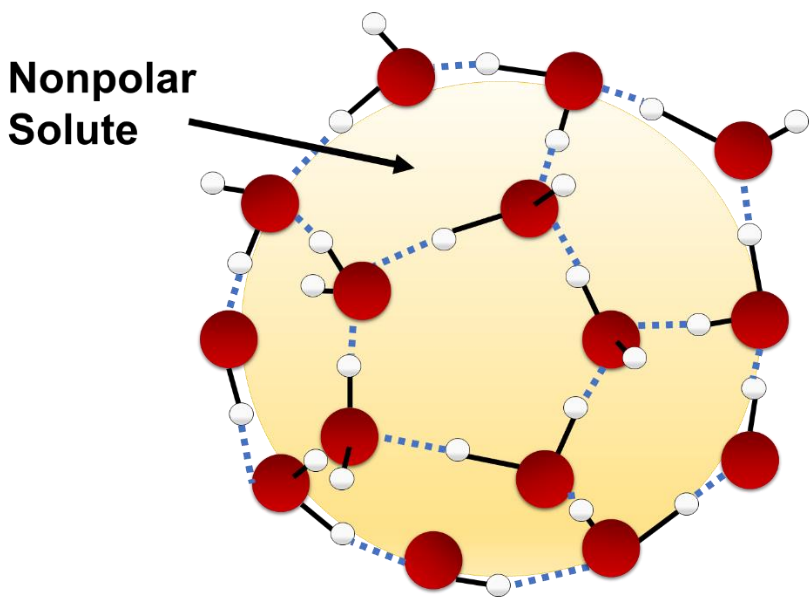

Figure 15: Representation of creative exercise prompt which drew out linking between concepts, original image from Voet et al. (2016).

"And in water they constantly form and break hydrogen bonds. Yeah, the water molecules just kind of ... form a cage around the nonpolar solutes. Even though this is water, this is kind of how soap works. Like how it helps you get rid of ... any dirt and grime in your hands at forms like bubbles around the, the dirt and you can wash it off. [ah hmm] From what I see it's just a

completely nonpolar solute, but if it was amphipathic, then it would form a little membrane like … Phospholipids. The polar heads with turn towards the water and everything nonpolar would, would bunch up inside away from the water." (Student 7 interview 1)

The quote above is an example of the participants explicitly linking concepts they perceived in the prompt shown in Figure 15 which were covered at various points within an undergraduate chemistry curriculum. The participant was able to recognize the relationship between "water cages", soap and membranes (though without explicit mention of the hydrophobic effect). The participant also acknowledged the distinctions that divide these concepts.

Misconnecting concepts

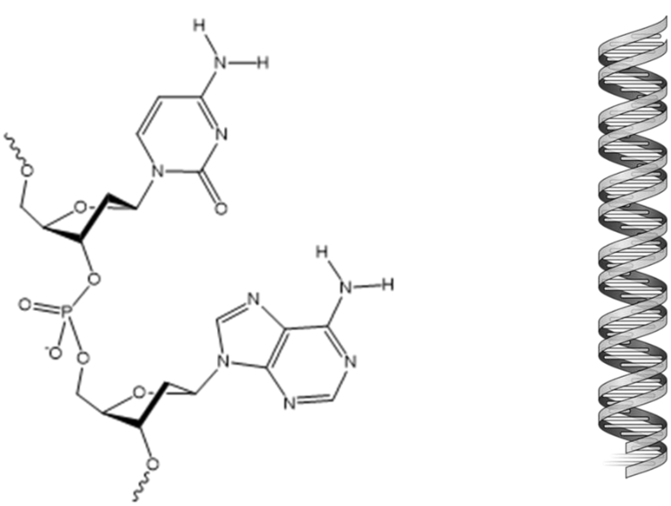

Figure 16: Creative exercise prompt that elicited discussion of misconceptions, DNA helix art is an open source counterpart to original prompt image.

"And then, like that would be equivalent to be b-DNA because b-DNA is right-handed and then … uh, yeah just like an alpha helix is like a secondary structure nucleic acids." (Student 5 interview 1)

"I see a phosphate group … phosphate group on molecule. Oh, I can also say … the double helix is formed by bonds between amino acid residues. For that structure … I'll say the helix is a secondary structure." (Student 6 interview 1)

"The difference, I guess, oh these are amino acids? I believe, or no, because there's too many nitrogen's, I think, I don't know, they just look like big complex molecules to me." (Student 2)

Given that the creative exercises utilized in this study were developed to target concepts that students struggle with, I was keenly interested in what misconceptions would appear in the participants' responses. The quotes provided above show the students misconnecting (or nearly in the case of student 2) protein secondary structures (alpha helices) and DNA double helixes when engaging with the prompt represented in Figure 16. These snapshots of the participant's misconnections between these concepts also provides evidence supporting the hypothesis the faculty had that students struggle to differentiate between the helical structures of amino acids and nucleic acids (see chapter 3 faculty experiences).

Consulting Google

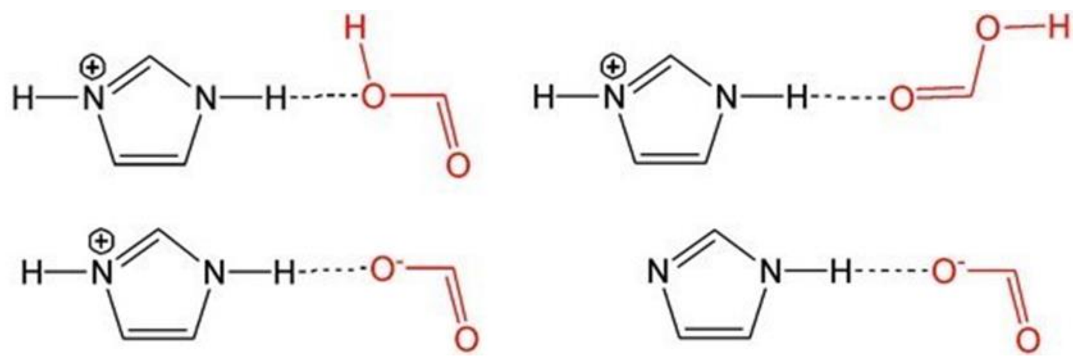

Figure 17: Creative exercise prompt that elicited consultation of an alternative resource, prompt created by the faculty in ChemDraw.

"Okay. So I will probably google like the structure like here's what are saying earlier that CO2 is double. I don't know where the hydrogen is missing. I'm trying to find ... three ... so this is called hydrocarboxyl (unclear dialog) So this is rada, this is radical chemistry, which is probably why I don't know what it is. And then I would do and I probably just get the name for this" (student 3)

As seen in Figure 13, 2 of the participants included consulting alternative sources to generate responses and understand the prompts. The quote from student 3 was a concurrent instance in which the alternative resource consultation was coded. The exercise that the participant referred to in the quote is represented in Figure 17. The participant was attempting to search the name of the formic acid presented in associated prompt in which the omission of a hydrogen led the participant to discuss hydrocarboxyl radicals.

Table 7: ICFB interview analysis results for hydrogen bonding questions

Participant	Key reasoning	Overall consistency	Related item feature
Student a	*"Okay, based on what I said earlier. Hydrogen bonding was **intramolecular**"*	Consistently incorrect	none
Student b	*"The H is bonded to a carbon which has such a close electronegativity to hydrogen like, the difference is less than one. So there's no hydrogen bonding."*	Incorrect partial consistency	none
Student c	*"I'm going to select the ones where it **currently exists** in the drawing, not where it could, or currently existing, not where it could"*	Consistently incorrect	item prompts
Student d	*"So that means that so five and six is between ... carbon, which is not electronegative enough."*	Incorrect partial consistency	none
Student e	*"Just because there's hydrogen and oxygen, and that's basically what it is."*	Consistently incorrect	none
Student f	*"Just because, like I mean hydrogen bonding, I know occurs with the hydrogen, and then fluorine, oxygen, or nitrogen"*	Consistently incorrect	none

Table 8: ICFB interview analysis results for thermodynamics questions

Participant	Key reasoning	Overall consistency	Related item feature
Student a	*"Because if I already know anything, negative Delta G is spontaneous, and the same must be true, for anything that's positive must be not spontaneous."*	Consistently correct	none
Student b	*"So, anyway, so because it said that it's not spontaneous, it can be positive. I don't think I could say B, because it's … the magnitude of the free energy change should not really tell me whether it's, like based on heat or based on entropy."*	Consistently correct	none
Student c	*"If it said that heat will be released, then I say maybe D. I think I would choose. D if it didn't say quickly when it says quickly. I think it implies that the rate of reaction which I don't think we would know."*	Consistently correct incorrect logic	Answer wording item 2
Student d	*"would say no to B just, because not magnitude. The sign of Gibb's free energy determine if it's going to be release or taken heat, which is also related to spontaneity."*	Incorrect partially consistent	Answer wording item 1
Student e	*"When I was reading D at the last minute, I thought, Oh, heat will be released, but heat could also be absorbed if the Delta H is positive."*	Consistently correct	Answer wording item 2
Student f	*"We know the sign of the free energy change would be negative, and that heat would be really as quickly because it's an exergonic, really, exergonic reaction."*	Inconsistently incorrect	Answer wording item 2 & 3

Table 9: ICFB interview analysis results for pKa questions.

Participant	Key reasoning	Overall consistency	Related item feature
Student a	*"Wait, okay. pKa is lower than pH then it loses its proton, but wait no, I know it loses its proton"*	Consistently correct	none
Student b	*"So probably at pH three point five, it's kind of hard to tell which is the predominant charge, because it's, like, in the middle"*	Consistently correct	none
Student c	*"So anything above 8.0 is going to be made deprotonated (NH_2) to be neutral."*	Consistently correct	none
Student d	*"Since pH of 8 falls between 3 and 10, so I would go with the positive and negative."*	Consistently correct	none
Student e	*"Since the pKa value is three point five. That means at a pH of three point five. This group would become negative and lose that hydrogen."*	Incorrect Partial consistency	none
Student f	*"Just because I remember if pH is greater than pKa, like, it's a negative charge. So five is the only one that's greater than three point five"*	Consistently correct	none

The results of the IFCB interview analysis are shown in Tables 7, 8, and 9 in which each table corresponds to one of the concepts tested in the interviews. The tables included the key reasonings which reflect either the consistent logic applied to answering the questions consistently or the reasoning associated with an inconsistent response. Reasoning involving features of the IFCB were favored for inclusion within the tables. The tables also include indications if a question and feature of said question had any influence on how the participant answered the question. For example, on Table 7, Student c reasoning was tied to the question prompts for the hydrogen bonding question containing the word existing.

Discussion

Creative Exercise Interviews

This study provided an exploration into how students approach creative exercises in the context of biochemistry. One common feature of the student approaches to the exercises that was of particular interest was the student's considering faculty expectations. These considerations were typically out of concern that the participants might not understand the expectations of the faculty. Such concerns could very well be a cognitive barrier in the student's the approaches to the exercises as described by Bandura's social learning theory (Bahn, 2001; Bandura & Walters, 1977). Hence, when I first observed these concerns for the fall 2020 participants, I informed the faculty and worked with them to dismantle these concerns about expectations. Furthermore, I was also interested in seeing if the in-person experiences of subsequent semesters would influence this feature. As seen in the fall 2021/spring 2022 data, the consideration of faculty expectations was less prevalent than during the fall 2020 semester. These considerations amongst later participants could be positioned within the sequence of approaches and in some cases were retrospective rather than a current concern.

Another particularly interesting protocol feature identified within the think-aloud interviews was the use of resources. Most of the participants utilized a resource in order to engage with creative exercises, though with notable variation. The greatest contrast in resource consultation existed between fall 2020 participants and the subsequent participants. In the fall semester of 2020, the participants consulted the textbook to generate responses after brainstorming what they knew about the prompt. In contrast, participants from later semesters would only consult resources if they had trouble remembering a term or concept. Thus, despite a limited sample set, I observed notable differences in resource use between methods of creative exercise implementation within the course. This finding can be of particular value to prior studies that voiced uncertainty as to how students generated responses to creative exercises (Ngai & Sevian, 2018; Warfa & Odowa, 2015). This finding also provides space for further contemplation on the benefits of resource access depending on the method of implementation.

Another intriguing facet for the use of resources in the participant approaches to the creative exercises was the consultation of alternative sources. Although I only had one student concurrently utilize a search engine (google) as they approached the exercises, the outcome of the participant's search led to a fascinating misdirection from the chemical of interest. Of course, such results are undesirable for the development of students conceptual understanding. However, to catch a glimpse at this approach does shed light as to how students can generate a response that is highly unexpected given the subject of the prompt.

As for the participants' impressions of the creative exercises, they predominately had a positive outlook on the creative exercises as a class activity. The participants not only gave a retrospective account of how the class discussions played a role in the understanding exercises, but they also noted how they typically enjoyed the process. That said, one participant noted that the discussions were repetitive after so many entries in the discussions when conducted online.

Thus, I recommended to the faculty that they keep the discussion posts limited to smaller groups rather than large groups or whole classes to limit potential repetitiveness. I did see in later semesters that the subject of repetitive discussions was not mentioned by students even if they primarily had online discussions.

IFCB Interviews

For the hydrogen bonding questions on the IFCB, there were 2 peculiar response types that I noticed in the interviews. The first of these interesting responses I would like to discuss were the inconsistent answer choices made by students b and d indicated on Table 7. Both students were answering consistently with hydrogen bonding misconception 1 except for 1 question, neither question being the same for both students. Yet both of the students used the correct logic as seen in Table 7 to correctly answer these questions. As for the second unexpected response, student c was fixed on the word exists within the question prompts and shaped their answer around this word. As seen in their logic presented in Table 7, the student consistently selected the covalent bond with hydrogen stating that because it was shown in the figure, it must be the existing bond referred to in the questions. While I do not believe the student would have answered correctly in the absence of this term, the student may have responded differently if the implicit hydrogen bonds were made explicit (something expressed by instructor 3 in the results of the previous chapter).

For the pKa concept questions, only one of the participants, Student e as indicated in Table 9. answered inconsistently for one of the questions in which they otherwise answered the questions correctly. For this question, Student e selected the pKa of the carboxylic acid as the point in which the predominant charge of the functional group would be negative. However, their reasoning across the questions was not entirely inconsistent with the responses given for the subsequent questions. The student reasoned that at the pKa a functional group would be deprotonated, thus they were still able to answer the remaining questions correctly with this logic. Yet I cannot state that the structure of these questions would result in a false positive score as the student would still be coded as incorrect.

The thermodynamics questions, however, resulted in several of the participants responding inconsistently to the questions as shown in Table 8. These inconsistencies were tied to one of the answer choices for the second thermodynamics question presented to the participants. The answer choice states that for the spontaneous process, the sign of the free energy change will be known and the process releases heat quickly. The answer choice itself was not always the direct cause for the inconsistency, but this answer was related to the inconsistencies in each case. Student c noted that they would have chosen this response if it had not included the word quickly. The student was classified as consistently correct despite this incorrect reasoning that spontaneous processes release heat as seen in Table 8. Student e also experienced difficulty with this item and nearly selected it before changing their mind shortly after, realizing that enthalpy could not be determined with the given information. Students d and f selected this answer choice which was not consistent with previous responses. Student d noted that the reason they did not chose related answer in item 1 to the answer in item 2 was due to the mention of magnitude of free energy. Student f answered the first thermodynamics question in terms of heat, the second due to their idea that spontaneity resulted in a vigorous reaction. For their third question they did not respond to the answer choice consistent with the one from item 2 because it stressed the term quickly more than they were comfortable with. This confusion surrounding the answer choices, particularly for items 1 and 2, is consistent with the psychometric data presented in appendix A (Table 31 and Table 32). Therefore, I believe that these findings suggest a serious threat exists within the thermodynamic questions towards the construct validity of the IFCB.

While these findings do suggest that alterations are necessary for further application of the IFCB, this issue with the structure of a concept inventory is not an isolated case. One example of a popular concept inventory which had its validity put into question was the chemical concept inventory (Barbera, 2013; Krause et al., 2004). The instrument was widely used without much question of its reliability until subsequent work revealed that the instrument identified two overarching concepts rather than its intended set (Arjoon et al., 2013; Barbera, 2013).

Another example of a well-known concept inventory that has had inconsistency with validity and reliability is the physics force concept inventory (Hestenes et al., 1992). The instrument was not validated upon its initial release and subsequent investigations have had mixed results regarding the psychometric data (Antti & Philip, 2002; Nieminen et al., 2010; Traxler et al., 2018; Yasuda & Taniguchi, 2013). More recent exploration into the force concept inventory's structural validity unveiled that the instrument did not perform as intended with a female population (Traxler et al., 2018).

The examples from the literature further reinforce the value of the data presented in this study as a general necessity for concept inventories to continually undergo scrutiny by researchers. The data from these interviews represents an additional angle to explore the construct validity of the IFCB similar to the research conducted on force concept inventory (Traxler et al., 2018; Yasuda & Taniguchi, 2013). That said, by no means do I suggest that the original instrument development was insufficient to meet the needs of their desired population, rather that the instrument may need to be adjusted for different population sets.

Chapter 5 Concluding Remarks

As part of this chapter, I sought to explore how students approach biochemistry creative exercises via semi-structure think-aloud interviews. Using the diagrammic modeling framework, I constructed representations of the participants approaches for two distinct periods of these exercises' implementation within a beginning undergraduate biochemistry course. Though the 10 participants began the exercises in a similar fashion, the participants displayed variations in the remainder of their engagement with the exercises as documented within the presented models. Furthermore, certain key features of the approaches were distinct towards a particular period of implementation such as consulting alternative sources (Fall 2020, online only exercises) and recalling vague memories of information (Fall 2021 and spring 2022, in-person exercise opportunities). One key feature that appeared to varying degrees for both periods of implementation that caused concern was the student contemplation of faculty expectations. This feature was concerning as the participants tended to express discomfort in not understanding what they believed was expected of them. Another key feature of a more positive note was a common retrospective appreciation of the discussion aspects of the creative exercises and the new ideas they would generate.

As for the IFCB interviews, I utilized think-aloud interviews to understand how students are responding to the questions. Through the analysis of the data, I found that while participants did not typically respond to the pKa questions in a manner that was unpredicted by the IFCB, the same could not be said for the thermodynamics questions and hydrogen bonding to a lesser extent. For the thermodynamics questions, the participants were particularly drawn to an answer found for one of the questions which was inconsistent with previous responses. One participant was consistently correct despite incorrect logic when discussing to the wording of this particular answer choice. Therefore, I would recommend that these questions should undergo further refinement before further implementation of the IFCB.

Limitations

One aspect of this study that limited our exploration of the student approaches to the creative exercises was the sample size. As much as I would have liked to sample more students each semester in order to increase the saturation of our data, I was limited by the degree of interest and willingness of our sample frame. This smaller recruitment of students also limited our use of the concept inventory to sample our participants. That said, since few students had scored concepts correctly on the inventory, the instrument could only provide a small degree of diversity in conceptual understanding. Furthermore, the fall 2020 participation in only one interview round did limit our ability to observe how the students' approaches might have changed over the semester.

Another limitation to the study was the ability of the interviews to capture the genuine process that the participants used to engage with the creative exercises. While I made efforts to ensure that the environment was as familiar and comfortable, these interviews may still not able capture all the nuances of their approaches. Furthermore, the presence of the interview, despite strict avoidance from directing the participants during the activity, could still influence how the students engage with the creative exercises. These limitations are limitations of the methodology and are beyond the control of this study.

CHAPTER 6: OVERALL IMPLICATIONS

Concluding Remarks

This dissertation documents the efforts and experiences of a group of faculty members who were engaged in a collaborative action research effort to reform the curriculum of a beginning undergraduate biochemistry course. Furthermore, within this dissertation I also explored the participants engagement with the intervention (creative exercises) chosen by the faculty as well as the influence that this intervention had on the concepts targeted by the faculty. This research effort included both quantitative and qualitative explorations of the curricular development undertaken by the faculty.

In terms of the quantitative analysis of the faculty's chosen concept inventory, the IFCB, I uncovered a large portion of the students did not know the concepts before and after the course. This lack of knowledge on the given topics as identified by the instrument was the most apparent for the concept of hydrogen bonding. I also identified common misconceptions amongst the student population for the concepts of hydrogen bonding and alpha helices. Application of the creative exercises to the first biochemistry course led to a small increase in learning for the concept of pKa. However, the remaining concepts appeared relatively unaffected by the presence of the creative exercises. The misconceptions present within the intervention semester also did not differ much from the baseline semester. One caveat to the IFCB itself was the question of how well the participants understood the question-and-answer choices presented in the concept inventory. Within clinical student interviews for the IFCB, I discovered that the students were confused by the presentation of one of the consistent distractors for the thermodynamics questions. This confusion could very well be present within the larger population of the participants and therefore limits our interpretations of the related quantitative data.

As for the creative exercises, I also explored how the students were approaching the exercises via verbal protocol analysis of think-aloud interviews in which the students engaged with the exercises. Within these interviews I observed the students expressing concerns over the expectations of the faculty, though the students held a generally positive outlook and appreciation for the discussion aspect of the assignment. This concern for the faculty expectations might act as a cognitive barrier towards their engagement to the exercises. Participants who had more in class experiences with the exercises tended to have less concern about these expectations. I also observed that the participants' reliance on textbook materials also shifted depending on the degree of in class experiences with the exercises.

The principal interest in this dissertation was that of the faculty experiences during the course of the collaborative action research process. I collected their experiences via a set of interviews after each phase of the project via interviews conducted by my advisor. When reflecting on their experiences teaching biochemistry, the faculty emphasized early teaching experiences as a major contributor to their teaching practices. Furthermore, after reflecting on the baseline data, the faculty expressed a motivation to adjust the curriculum, but also the faculty noted a need for guidance on how to approach these changes. After their first intervention phase, the faculty appreciated the creative exercises as medium for facilitating discussion in the classroom and its student-centered structure. However, the faculty were concerned about the minimal influence of the creative exercises on the student IFCB performance. Despite these concerns, the faculty remained keen to explore additional changes to their curriculum.

Additionally, the faculty greatly valued the opportunity that the project presented to constructively engage with each other and the research team to tackle the curricular reform and integrate new understanding of research-based teaching practices.

Overall Implications

Chapter 3 is an example of how stakeholders, who are invested in widespread adoption of evidence-based practices, can prioritize the experiences and conceptions of practitioners throughout the implementation process to better understand the shared and individual qualities that influence change on a curricular level. While our findings from this study provide insights into one faculty group's experiences as they prepare to engage in curricular redesign, more work is needed to identify the transferable aspects of successful faculty team engagement in curricular change. Although this has been explored in other studies, these studies still recommend further exploration of such aspects on a broader scale (Pelletreau et al., 2018). It also highlights the importance and the need for professional development in earlier points in faculty members' careers, such a graduate teaching.

In terms of chapter 4, the statistical analysis of the IFCB data suggested that the creative exercises had only a small impact of the student learning of pKa. This lack of impact on the student performance adds a concerning tone towards the effectiveness of the creative exercises to the existing body of literature (Gilewski et al., 2019; Lewis et al., 2011; Mai et al., 2021). That said, this does study does not ultimately indicate that the exercises were ineffective as an educational practice, rather, this study does allow future research to consider what implementation strategies could be employed to enhance the impact of the exercises.

Adding to the exploration of the faculty experiences, chapter 4 unveiled the faculties reflections on the intervention phase of the project. The faculty, though concerned about the results of the IFCB pre/post-test analysis, remained committed to exploring additional curricular changes, albeit cautiously. The faculty also stated that the collaboration with the researchers and their interactions with the other faculty both encouraged them to engage in the project and aided in their understanding of research-based practices. This expression by the faculty adds weight to my argument that collaborative action research may be a valuable tool to bridging the gap between researchers and practitioners of chemistry education and beyond.

In addition to the previous two chapters, chapter 5 provided insights as to how the participants approach the creative exercises as well as how students respond to the IFCB. The findings on for the creative exercise interviews provided insights into the sequences of student approaches which had yet to be explored in the literature (Ngai & Sevian, 2018; Warfa & Odowa, 2015). I was also able to observe differences in the student approaches if they had exposure to the exercises in class rather than only online, both in terms of their focus on faculty expectations and the manner to which they used resources. As for the IFCB interview analysis, I found a concerning degree of misrepresentation of the thermodynamics answer selection and the participants reasonings for their answer selection.

Suggestions For Future Research

One critical remaining question relates to faculty buy-in, specifically, what experiences lead faculty towards embracing education research as a tool for improving instruction. While studies have investigated how faculty networks have influenced adoption of evidence-based practices (Dancy et al., 2019; Lane et al., 2019; Pelletreau et al., 2018), there still remains more to be explored as to why some faculty adopt evidence-based practices and others do not. These lived experiences of faculty involved in curricular decision-making demand more attention to understand this gap. Similarly, while authors have explored faculty persistence and motivation for curricular change (Corrales et al., 2020; Dancy et al., 2019; McCourt et al., 2017), more investigation of the motivations that initiate and sustain chemistry faculty participation in curricular change is needed.

While this study provides insights into how the students approach creative exercises for figural prompts, creative exercise prompts are not simply limited to figures. Prior studies have also employed text based prompts for creative exercises as well (Lewis et al., 2010). Future endeavors could be made to better understand how students approach non-figural creative exercises.

Another possible area of students approaches to creative exercises that could be further explored by the community could be a longitudinal exploration of the student approaches. This would be particularly valuable to the community should these exercises be applied across chemistry curriculums. While I was already able to see a degree of variation in the students approaches to the creative exercises, it remains to be seen how these approaches might develop over an extended period.

Furthermore, while the students gave a retrospective account of how they engaged with the creative exercises during the discussion aspect of the assignment, the details of these discussions remain to be explored. Given that these exercises have already been applied as discussion activities both with this study and the literature, it would be of great value to the community to understand how the students are discussing their responses to the creative exercises (Gilewski et al., 2019). Also, it would be helpful for the community to understand how these discussions influence what responses the students provide at the end of the discussion.

As for the IFCB, given the discrepancies observed during the interviews, the field would benefit from additional refinement of the instrument. These efforts would protect future studies from and encourage wider scrutiny of the concept inventory. Such refinement will most likely require participant interviews moving forward to better understand the student perspective of the instrument.

APPENDIX A: IFCB SUPPORTING MATERIALS

IFCB Misconception Figures

Hydrogen bonding	**1. Hydrogens bonded to carbons can participate in hydrogen bonding** **2. Any bonding between hydrogen and another atom is a hydrogen bond** **3. Covalent bonds between hydrogen and other atoms are hydrogen bonds**
Alpha helices	**1. The interior of the helix is composed of side chain groups (R groups)** **2. The interior of the alpha helix is empty and the structure is not rigid** **3. Molecules such as water fill the interior of the alpha helix**
Thermodynamics	**1. A spontaneous process will always release heat** **2. A spontaneous process will proceed quickly** **3. The sign of the Gibb's energy describes whether or not the process releases heat**
pKa	**1. When the pKa of a Carboxyl group is greater than the pH, the charge is negative** **2. When the pKa of the amine group is less than the pH, the charge is positive** **3. The charge of substituents is not effected by the pH of the solution**

Figure 18: Misconceptions embedded in the distractor answer choices on the IFCB concept inventory.

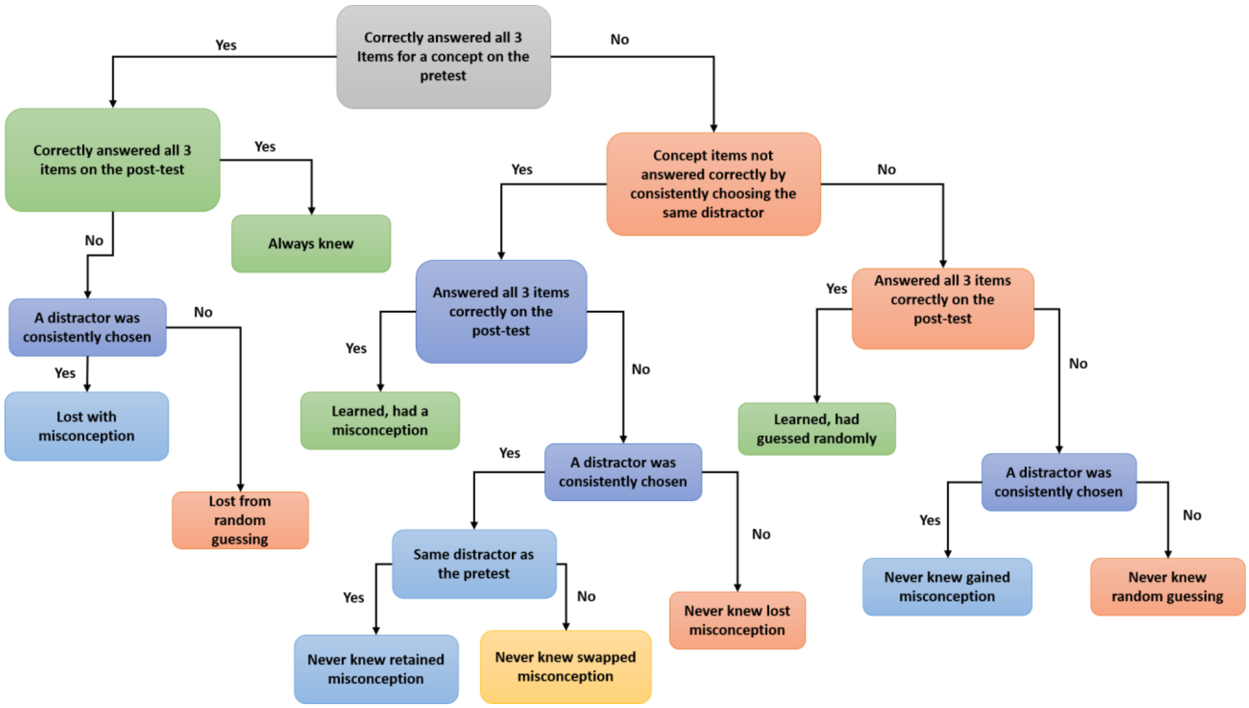

Figure 19: IFCB learning levels expanded to show changes of misconceptions from pre- to post-tests

Baseline Misconception Distributions

Table 10: Fall 2019 hydrogen bonding large section student misconception categorizations (n = 143, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	1	0	0
Never knew learned misconception	42	12	1
Never knew retained misconception	2	4	1
Never knew lost misconception	1	5	14
Never knew swapped misconception	4	0	0
	9	3	0
Learned from misconception	0	2	0
Never knew random guessing	30		
Lost with random guessing	1		
Learned from random guessing	11		

Table 11: Fall 2019 hydrogen bonding honors student misconception categorizations (n = 13, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	1	0	0
Never knew learned misconception	6	1	0
Never knew retained misconception	1	0	0
Learned from misconception	1	0	0
Never knew random guessing	2		
Lost with random guessing	1		
Learned from random guessing	0		

Table 12: Fall 2019 alpha helix large section student misconception categorizations (n = 295, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	11	0	6
Never knew learned misconception	29	0	9
Never knew retained misconception	21	0	1
Never knew lost misconception	28	1	7
Never knew swapped misconception	0 0	0 0	4 0
Learned from misconception	4	0	1
Never knew random guessing	73		
Lost with random guessing	15		
Learned from random guessing	23		

Table 13: Fall 2019 alpha helix honors student misconception categorizations (n = 12, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	0	0	0
Never knew learned misconception	2	0	0
Never knew retained misconception	3	0	0
Learned from misconception	2	0	1
Never knew random guessing	0		
Lost with random guessing	0		
Learned from random guessing	4		

Table 14: Thermodynamics large section student misconception categorizations (n = 271, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	0	0	1
Never knew learned misconception	1	0	15
Never knew retained misconception	0	0	0
Never knew lost misconception	2	0	10
Never knew swapped misconception	0 0	0 0	0 0
Learned from misconception	0	0	2
Never knew random guessing	141		
Lost with random guessing	13		
Learned from random guessing	84		

Table 15: Thermodynamics honors student misconception categorizations (n = 8, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	0	0	0
Never knew learned misconception	0	0	0
Never knew retained misconception	0	0	0
Learned from misconception	0	0	0
Never knew random guessing	3		
Lost with random guessing	2		
Learned from random guessing	3		

Table 16: Fall 2019 pK_a large section student misconception categorizations (n = 295, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	0	0	0
Never knew learned misconception	4	3	0
Never knew retained misconception	1	1	0
Never knew lost misconception	12	4	5
Never knew swapped misconception	0 0	0 0	0 0
Learned from misconception	1	5	2
Never knew random guessing	137		
Lost with random guessing	6		
Learned from random guessing	112		

Table 17: Fall 2019 pK_a honors student misconception categorizations (n = 7, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	0	0	0
Never knew learned misconception	0	0	0
Never knew retained misconception	0	0	0
Learned from misconception	0	0	0
Never knew random guessing	4		
Lost with random guessing	0		
Learned from random guessing	3		

Table 18: Contingency table for alpha helix post-test misconception data

	No Misconception	Misconception 1	Misconception 3
Instructor 1			
Count	57	12	5
Expected count	55	15.8	3.2*
Standardized residual	0.3	-1.0	1.0
Instructor 2			
Count	65	23	2
Expected count	67	19.2	3.8*
Standardized residual	-0.2	0.9	-0.9

Intervention Phase Misconception Distributions

Table 19: Fall 2021 large section student hydrogen bonding misconception categorization (n = 169, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	3	1	0
Never knew learned misconception	24	5	4
Never knew retained misconception	21	6	6
Never knew lost misconception	9	2	5
Never knew swapped	10	4	1
misconception	9	4	1
Learned from misconception	6	1	0
Never knew random guessing	36		
Lost with random guessing	3		
Learned from random guessing	8		

Table 20: Fall 2021 large section student alpha helix misconception categorization (n = 151, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	4	0	3
Never knew learned misconception	18	0	6
Never knew retained misconception	8	0	0
Never knew lost misconception	12	0	4
Never knew swapped misconception	0	0	0
	1	0	0
Learned from misconception	5	0	2
Never knew random guessing	52		
Lost with random guessing	8		
Learned from random guessing	28		

Table 21: Fall 2021 large section student thermodynamics misconception categorization (n = 152, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	0	0	0
Never knew learned misconception	1	0	6
Never knew retained misconception	0	0	1
Never knew lost misconception	0	1	3
Never knew swapped misconception	0	0	0
	0	0	0
Learned from misconception	0	0	1
Never knew random guessing	89		
Lost with random guessing	12		
Learned from random guessing	39		

Table 22: Fall 2021 large section student pKa misconception categorization (n = 161, always knew not included)

Categories	Misconception 1	Misconception 2	Misconception 3
Lost with misconception	0	0	0
Never knew learned misconception	1	2	0
Never knew retained misconception	0	0	0
Never knew lost misconception	2	2	1
Never knew swapped misconception	0	0	0
	1	0	0
Learned from misconception	1	1	1
Never knew random guessing	76		
Lost with random guessing	8		
Learned from random guessing	65		

Learning Level vs Semester Contingency Tables

Table 23: Random sample hydrogen bonding learning level vs semester contingency table, starred expected count does not meet assumed minimum of 5.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	2	102	5	10
	Expected	4.0*	101.1	3.5*	10.5
	Standardized Residual	-1.0	0.1	0.8	-0.1
Intervention	Data	6	101	2	11
	Expected	4.0*	101.9	3.5*	10.5
	Standardized Residual	1.0	-0.1	-0.8	0.1

Table 24: Total sample hydrogen bonding learning level vs semester contingency table, starred expected count does not meet assumed minimum of 5.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	2	128	7	13
	Expected	4.2*	128.5	4.2*	13.1
	Standardized Residual	-1.1	0.0	1.4	0.0
Intervention	Data	7	147	2	15
	Expected	4.8*	146.5	4.8*	14.9
	Standardized Residual	1.0	0.0	-1.3	0.0

Table 25: Random sample alpha helix learning level vs semester contingency table.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	33	175	15	26
	Expected	30.2	165.6	19.3	34.0
	Standardized Residual	0.5	0.7	-1.0	-1.4
Intervention	Data	14	83	15	27
	Expected	16.8	92.4	10.7	19.0
	Standardized Residual	-0.7	-1.0	1.3	1.8

Table 26: Total sample alpha helix learning level vs semester contingency table.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	44	216	22	34
	Expected	38.3	205.7	27.3	44.8
	Standardized Residual	0.9	0.7	-1.0	-1.6
Intervention	Data	15	101	20	35
	Expected	20.7	111.3	14.7	24.2
	Standardized Residual	-1.3	-1.0	1.4	2.2

Table 27: Random sample thermodynamics learning level vs semester contingency table.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	11	132	36	70
	Expected	12.8	138.0	33.4	64.8
	Standardized Residual	-0.5	-0.5	0.5	0.6
Intervention	Data	9	83	16	31
	Expected	7.2	77.0	18.6	36.2
	Standardized Residual	0.7	0.7	-0.6	-0.9

Table 28: Total sample thermodynamics learning level vs semester contingency table.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	14	169	47	86
	Expected	16.9	174.5	42.8	81.8
	Standardized Residual	-0.7	-0.4	0.6	0.5
Intervention	Data	12	100	19	40
	Expected	9.1	94.5	23.2	44.2
	Standardized Residual	1.0	0.6	-0.9	-0.6

Table 29: Random sample pK_α learning level vs semester contingency table.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	21	160	17	51
	Expected	16.1	147.6	16.0	68.7
	Standardized Residual	1.1	1.0	0.2	-2.1
Intervention	Data	5	70	8	56
	Expected	9.3	82.4	9.0	38.3
	Standardized Residual	-1.4	-1.4	-0.3	2.9

Table 30: Random sample pK_α learning level vs semester contingency table.

Semester	Count type	Lost	Never Knew	Always Knew	Learned
Baseline	Data	26	198	23	69
	Expected	22.1	183.6	21.4	88.9
	Standardized Residual	0.8	1.1	0.3	-2.1
Intervention	Data	8	85	10	68
	Expected	11.9	99.4	11.6	48.1
	Standardized Residual	-1.1	-1.4	-0.5	2.9

<u>Baseline IFCB Psychometric Analysis</u>

Table 31: Confirmatory factor analysis factor loadings (std. all) for each concept on the IFCB pre and posttest. Starred values indicate different p value and does not meet minimum threshold.

Concept	Pretest std.all ($p < 0.001$) *($p = 0.003$)			Posttest std.all ($p < 0.001$)		
Hydrogen Bonding	1.020	0.923	0.870	0.965	1.000	0.957
Alpha Helix	0.882	0.944	0.754	0.948	0.869	0.897
Thermodynamics	0.534	0.551	0.985	0.587	0.665	1.056
pKa	0.992	0.272*	0.740	0.910	0.747	0.921

Table 32: IFCB pre and posttest concept Cronbach's alpha for internal consistency. Starred values do not meet standard threshold.

Concept	Pretest Cronbach's α	Posttest Cronbach's α
Hydrogen Bonding	0.835	0.902
Alpha Helix	0.763	0.806
Thermodynamics	0.560*	0.651*
pKa	0.522*	0.768

Table 33: IFCB pretest pKa inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.166	0.514
Item 2	0.166	1.000	0.122
Item 3	0.514	0.122	1.000

Table 34: IFCB pretest thermodynamics inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.190	0.347
Item 2	0.166	1.000	0.360
Item 3	0.347	0.360	1.000

Table 35: IFCB pretest alpha helix inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.624	0.441
Item 2	0.624	1.000	0.483
Item 3	0.441	0.483	1.000

Table 36: IFCB pretest hydrogen bonding inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.736	0.632
Item 2	0.736	1.000	0.516
Item 3	0.632	0.516	1.000

Table 37: IFCB posttest pKa inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.471	0.627
Item 2	0.471	1.000	0.476
Item 3	0.627	0.476	1.000

Table 38: IFCB posttest thermodynamics inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.736	0.632
Item 2	0.736	1.000	0.516
Item 3	0.632	0.516	1.000

Table 39: IFCB posttest alpha helix inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.611	0.596
Item 2	0.611	1.000	0.535
Item 3	0.596	0.535	1.000

Table 40: IFCB prosttest hydrogen bonding inter-item correlation matrix

Questions	Item 1	Item 2	Item 3
Item 1	1.000	0.779	0.697
Item 2	0.779	1.000	0.792
Item 3	0.697	0.792	1.000

APPENDIX B: INTERVIEW PROTOCOLS

Spring 2020 Faculty Interview Protocol

Starter:

The interview will be initiated with the following statement:

So, tell me about your experiences teaching biochemistry.

Questions

What experiences have shaped the way you design your class?

What do you think biochemistry students struggle with the most?

Out of the four concepts we are assessing, which do you think the students are best at? Which are they the worst at?

Show data

After the initial interaction, prior to the interview, the participants will be presented with data depicting the performance of their students over the course of the semester.

Post-data questions

After seeing the data from the fall semester (2019), how does it compare with what you were expecting?

How does this information compare to your understanding of student performance in biochemistry?

What changes to the curriculum would you suggest based on the data?

What topics do you feel you would like to focus on the next time you teach the class?

Follow-up questions

What influenced your conception of students' performance?

How do you feel those changes to the curriculum will affect student performance?

Summer 2022 Faculty Interview Protocol

Time/location

Zoom interview/ in-person possibly (participants may be in their offices or their homes)

~40 min interview length

Starter

So, tell me about how your fall semester went

Before data question

How did you feel about the in-person creative exercises?

- Regarding the biochemistry class

- What was the ease of use of incorporating them into your course?

How do you feel the student learning compared to before the project began?

- Do you expect this to be reflected in the assessment data?

- What were specific areas where you think the change occurred?

How do you feel about our team meetings for this curricular intervention?

Show data (show Fall 2021 data)

After data Questions

Having seen the data, how do you feel about the student performance from last semester compared to the baseline?

-Was it what you expected?

-How does this data compare with what you observed with your other class assessments? (Do you think there are things that were not captured with this assessment?)

How do you want to move forward after seeing the data on student performance?

What do you hope to achieve with this project?

- Do you feel that you have made progress in your personal goals for teaching?

Follow up Questions

What are the reasons you felt that the in-person exercises were better than the online?

What are some of the ways you feel that your goals for this project could be achieved?

What aspects of the project do you feel have helped to achieve your goals?

What are the critical components of this collaborative effort that you feel would translate to other faculty groups?

Creative Exercise Interview Protocol

Participants/Timeslots: Interviews will be conducted on an individual basis and will last approximately 1 hour.

Changes to interview setting in the event of campus closure due to COVID: The participants will be given 1 hour interviews individually via a secured Zoom link.

Materials for the participants: The participants will be provided with a live-scribe pen in order to audio record the participants verbal responses. Other materials include textbooks (one from each subject associated with the prompts), scratch paper and the lecture materials provided in the biochemistry course that pertains to the subject.

Changes to Materials in the event of campus closure due to COVID: The participants will use paint or write on responses on paper based on their preference. The interview will be recorded via zoom and transferred to a secure flash drive. The participants will also be able to use their textbooks, should they be available. The participants will be informed of any materials they may need for the interview in the scheduling email.

Number of Prompts: 3 prompts

Introductory Questions: These questions will be used to set the tone of the interview as open and not an assessment of knowledge.

“So, how was your biochemistry course?”

“Have you been enjoying the course so far?”

Statement of Reassurance: This statement is made to ensure that the participant is made aware that they are not being evaluated on their knowledge base rather their thought processes are the subject of interest.

“For this study, we are interested in seeing how you and other participants think about the exercises that will be given to you in order to see if they will be beneficial to the learning environment.”

Discuss the details of the Interview: The participant will be informed that they will be given two exercises regarding chemical concepts they have learned as they pertain to biochemistry. The subject will be asked to discuss their think processes out loud and that the live scribe pen will record what they say. The participant will also be informed that they can rescind their consent at any time during and their data will not be used in the research. The subjects will also be made aware of the materials that are available and that a practice exercise will be given to allow them to practice.

Provide the consent from to the Participant: A consent form will be provided to the subjects which covers the details of the research as well as the significance the interview has in said research. The form will once again inform the participant that their consent can be revoked at any time without consequence to themselves.

Participant is given the 3 Exercises: The participants will be given the exercises for the interview session and reminded to say out loud what they are thinking as they approach the exercises.

Questions to ask should the participants fall silent: Should the participant cease to discuss their thoughts for a long period of time then the following questions can be used as guidelines. However, improvised questions should be modeled on the purpose of such phrasing in order to avoid guided thought for the participant.

- “What are your thoughts about the problem?”

- “So, what's on your mind?”

Should the student inform you that they are stuck then they will be informed that they can work on the other exercise if they like.

Post Exercise Questions

How do you feel about the exercises?

What was your experience with exercises implemented in the course?

What are your suggestions for future implementation of the exercises?

Follow up questions:

If the student mentions an interesting term or a term that was not understood by the interviewer:

You mentioned the term _____, what does this term mean to you?

Other follow up questions:

How did you feel about the discussion?

How frequently do you think the exercises should be implemented.

End of the Interview: When the participant has finished the exercises and answered the interview questions, or the session has ended, then the participant will be thanked for their time and informed that their interview has provided invaluable information for the research.

Identification protection: The names of the participants will be recorded in a password protected and encrypted spreadsheet along with the associated participant codes, transcriptions will be stored in OneDrive using participant codes. Participant identifiers will be disposed of after data collection and analysis.

Student handout: The participants will be provided with a handout with the creative exercises to be examined in the interview.

IFCB Interview Protocol

Participants/Timeslots: Interviews will be conducted on an individual basis and will last approximately 1 hour. The participants will be given 1-hour interviews individually via a secured Zoom link.

Materials for Interview: The participants will be able to write down their answers via the annotation function in zoom. The interview will be recorded via zoom and transferred to a secure flash drive. The participants will not be able to use information materials given the set of questions they will be asked to work with.

Number of Prompts: 6 prompts

Introductory Questions: These questions will be used to set the tone of the interview as open and not an assessment of knowledge.

"So, how was your biochemistry course?"

Statement of Reassurance: This statement is made to ensure that the participant is made aware that they are not being evaluated on their knowledge base rather their thought processes are the subject of interest.

“For this study, we are interested in seeing how you and other participants think about the following problems that will be given to you in order to see if the questions are working as intended.”

Discuss the details of the Interview: The participant will be informed that they will be shown a set of biochemistry problems for them to solve. The subject will be asked to discuss their think processes out loud. The participant will also be informed that they can rescind their consent at any time during and their data will not be used in the research.

Provide the consent from to the Participant: A consent form will be provided to the subjects which covers the details of the research as well as the significance the interview has in said research. The form will once again inform the participant that their consent can be revoked at any time without consequence to themselves.

Participant is given the practice problem followed by remaining questions: A practice problem will be provided to the students which evokes similar thought processes to allow the participant to get comfortable thinking out loud. Then the students will be shown the remaining questions.

Questions to ask should the participants fall silent: Should the participant cease to discuss their thoughts for a long period of time then the following questions can be used as guidelines. However, improvised questions should be modeled on the purpose of such phrasing in order to avoid guided thought for the participant.

- "What are your thoughts about the problem?"

- "So, what's on your mind?"

Should the student inform you that they are stuck then they will be informed that they can work on the other exercise if they like.

Follow up questions:

If the student mentions an interesting term or a term that was not understood by the interviewer

You mentioned the term _____, what does this term mean to you?

End of the Interview: When the participant has finished the questions, or the session has ended, then the participant will be thanked for their time and informed that their interview has provided invaluable information for the research. (Should compensation be necessary then such equity will be provided at this time)

Identification protection: The names of the participants will be recorded in a password protected and encrypted spreadsheet along with the associated participant codes, transcriptions will be stored in OneDrive using participant codes. Participant identifiers will be disposed of after data collection and analysis.

Student handout: The participants will be shown the set of questions that they will be working through. Should the students like to move on to the next question, the interviewer will move the slides to the next question.

APPENDIX C:
REFLECIVITY JOURNALS AND Key FACULTY FEEDBACK

Spring 2020 Faculty Interviews

Reflectivity Journal

Familiarity with the subjects

Having taken the biochemistry course sequence at the same institution where the faculty members are employed, I have had a fair bit of insight into the way the instructors have arranged their curriculum. The exception is one faculty member who the university hired after I had received my bachelor's degree and proceeded to graduate school.

Why did I choose Colaizzi's seven-step method?

I chose this method for two main reasons: this method was the first one introduced to me for phenomenological research, and the idea of a systematic analysis appealed to me. I am a novice when it comes to just about any research method, and thus a more straightforward analysis plan seemed ideal for a first project. While theoretical frameworks can be convenient for the appropriate methodology, it can be rather difficult to find the right one. Such frameworks are considered inappropriate for phenomenology (because the purpose of this method is to let the data speak for itself).

Software tools/post-transcription processing

For this analysis, I had the undergraduate research assistant move the transcripts from a word document to an Excel file. The transcripts were broken up into different spreadsheets based on the major questions asked in the interview. Thus, the related transcriptions for each participant were present on the same spreadsheet for ease of viewing. I also had the associated dialog (sometimes in reduced form) included in the spreadsheet in case it was needed to understand the context of the participant dialog. The participant dialog was bolded to distinguish it from the interviewer's dialog (which was italicized).

Colaizzi's method: Step 1

For this part of the analysis framework, I read through the transcripts a few times to try and obtain a sense of the transcripts (as they say in the framework). Additionally, I had the undergraduate working on this project read the transcripts and do some free coding as well as take notes on what he found to be interesting within the data. I also went through his coding and included more notes on the data, which I highlighted in dark blue.

Colaizzi's method: Step 2

To accomplish this section of the analysis framework, I went about reading the transcripts and extracting statements I felt were significant into a new column of the spreadsheet. I gauged the significance of the statements based on how they related to the direct question from the interviewer as well as the clarity by which the statement represented their experience. The initial coding was also useful for this process because I already had an idea of which statements were significant.

That said, I was worried that my personal experiences and biases would influence the statements. Therefore, I had the undergraduate research assistant and principal investigator determine the significant statements as well. Afterwards, we came together and compared our statements to develop an agreed set of statements. With this course of action, I hoped that having not one but three researchers decide on which statements were significant would limit (but never truly remove) the influences of personal bias on the data analysis.

Furthermore, as a group, we discussed why we chose certain statements as significant based on what we were looking for in the data. The undergraduate research assistant noted that a key feature he was looking for from a significant statement was its relevance to the preceding question. The principal investigator chose statements based on what she felt captured the big picture of the faculty experiences. We decided which statements were genuinely significant based on whether they were answering our research questions or just our own inquisitiveness.

Colaizzi's method: Step 3

From the significant statement selection, I went about defining the meanings for each statement. For this process, I would read the statement and then look at the passage to get its context. Then, I would write what I found the statement to mean while rereading the statement and passage to make sure that the meaning statement made sense.

Colaizzi's method: Step 4

For this step, I had the undergraduate research assistant look at the meaning statements and then highlight them in different colors depending on how similar they were to one another. From there, I placed the colored statements in a new spreadsheet based on matching colors for each column. Next, I wrote descriptive headers for each column, which would be the themes identified from the data. These themes were arranged within another spreadsheet, in which the themes were clustered into overarching emergent themes. These major themes contained two to three subthemes that the undergraduate research assistant identified. During the last stage, I noticed that some of the statements fit other themes more than the current theme. Therefore, I moved these statements into the appropriate columns without changing their colors so that the original assignment could be seen.

Colaizzi's method: Step 5

To create an exhaustive description of what was seen in the data thus far, I transcribed the analysis as a narrative of the experiences/perspectives shared in the data. This was of course at the advice of the guide for Colaizzi's method that I was originally introduced to almost a year before conducting the current study. I initially felt that this step was a few steps backwards in terms of processing the data. However, as I went about writing the description, I started to see a few elements present in the data that I had not considered in the prior analysis steps. Furthermore, as the guide for this method suggested, the format of the narrative would be more familiar to the participants for the member checking step.

Colaizzi's method: Step 6

The exhaustive description data were returned to the faculty. The faculty members were prompted to answer two questions to reflect on the accuracy and holistic nature of this description of their experiences (Colaizzi, 1978). Two of the faculty members stated that the description was an accurate account of their experiences and perspectives. However, instructor 3 noted that the exhaustive description did not accurately depict their perspective of students' understanding of background knowledge. The instructor noted that they believed the students indeed possessed the necessary background knowledge for the course, but the issue lay in students' uncertainty about how to use such knowledge. I was ecstatic to receive this feedback because I felt that we did not receive much input from faculty members on this topic. However, I did not go back and change the description directly; instead, I felt it would be more appropriate to address this in the core structure of the experiences.

Colaizzi's method: Step 7

I racked my brain for ideas on how to condense the description of the data into a publishable format. The description was relatively short because of the number of participants, so it was difficult to decide how to condense the exhaustive description. Because the core structure involved reincorporating segments of the transcripts to let the participants' voices be heard, I decided to remove a few segments from the description that I felt were clearly addressed in the quotes from the interviews. Furthermore, one statement from the description associated with instructor 2 was slightly expanded because I felt that their earlier experience working with instructor 1 was a bit too brief. The corresponding author and I also added statements at the beginning of each narrative shift to better reflect its relationship with the emergent themes. We felt that this would help the readers see the relationship among the different parts of the analysis. The faculty also had an opportunity to view the core structure. Instructor 2 asked whether they could make minor edits to their interview quotes so that they would be easier to understand for the readers. We allowed the instructor to make these grammatical changes because we were sharing their experiences, and the meaning behind the experiences did not change with these edits. We gave the other faculty members the opportunity to edit their quotes as well, though declined as they felt that their quotes were fine as written.

Instructor 3's Return To The Participant Statements

How do the descriptive results compare with your experiences and perspectives?

There is much discussion about prior knowledge, and it is not clear to me that we are able to tell the difference between lack of prior knowledge and inability to understand when the prior knowledge should be applied. My class (and I think my colleagues' classes) began with an overview of gen chem and organic chemistry principles, including thermodynamics and pK_a. We do not need an entire semester to cover these topics, but rather do it in two to three weeks. I think that is clearly a sign that students have prior knowledge, but it needs refreshing prior to diving into new topics where there is context. I think most of the problem is that students have difficulty understanding the contexts to apply these concepts because in prior courses they learn pK_a and thermodynamics for the sake of learning them but do not apply them to complex systems. Meanwhile, there is huge context in biochemistry not only at the molecular level but at the far-reaching physiological level, a topic that many of our students find fascinating. For some students, biochemistry may be the first course that links chemistry with students' intrinsic motivations (e.g., pre-med, health students). It is also an early course that requires understanding the interplay of several chemical concepts, such as thermodynamic vs. kinetics. In many ways, biochemistry is one of the first opportunities where students apply their prior knowledge of chemistry concepts to more complex contexts and I am not sure what we are observing when we say the students "lack prior/background knowledge."

What aspects of your experiences and or perspectives have I omitted?

I am afraid I do not remember what I actually said. The interview was quite a long time ago.

Summer 2022 Faculty Interview Reflexivity Journal

Familiarity with the subjects

At this point, I have worked with these faculty for a number of years, though not continuously. Furthermore, I have had 2 of the faculty as instructors for courses in both my undergraduate and graduate studies. As such I have most assuredly biased by my encounters with the faculty. That is why I was particularly careful this round of interviews to have multiple stages of peer analysis to avoid my bias blinding me to potentially key experiences and perspectives that the faculty wish to express. With these multiple points of accountability, I hope that I can minimize the influence of my personal feelings while understanding how these feelings effect my choices in this analysis.

Why did I choose Colaizzi's seven step method?

The primary reason I utilized this method to analyze the data was that I had already done so with previous data. That said, I also appreciate the systematic nature of this framework as it reduces my anxiety when approaching qualitative analysis. I also feel that I understand how to use this framework more thoroughly than previous efforts due to those experiences.

Software tools/ post transcription processing

For the early stages of this qualitative analysis, we utilized the integrated transcription software to transcribe the interview recordings. One of the interviews used zoom to record the meeting, but the interview was in-person, so audio had inconsistency in quality, which made it difficult to clean this particular transcript. After the transcripts were cleaned, we moved on to the first step of the framework.

Colaizzi's method step 1

To fulfill this step of the process, my undergraduate assistant and I read through the transcripts independently. This was carried out at least twice for each manuscript, and it was particularly difficult not to jump to the next step. Rather, it was important for us to simply read the manuscripts to get a sense of what the participants were sharing with the interviewer.

Colaizzi's method step 2

In this step, my undergraduate assistant and I independently selected significant statements for each of the transcripts. This was the first peer analysis checking that I wished to do in order to avoid my preconceptions from entirely directing the direction of the analysis. Furthermore, I have a hard time describing what exactly those preconceptions might be beyond what my emotion was upon reading a given statement. Statements of disappointment on the progress were particularly difficult to read given my own involvement in the project. I selected statements from the transcripts based on their relation to the questions being asked in the interview as well as how they described their own experiences. After we finished selecting significant statements, we proceeded to discuss each transcript until agreement was reached on which statements, we felt were significant. We kept track of our original statements and agreed statements through the creation of new documents.

Colaizzi's method step 3

My undergraduate assistant and I moved the significant statements that we agreed on to an excel file in order to organize them for the next two steps of the framework. We separated the statements in different spreadsheets based on the instructor. The statements were placed in one column and we each created mean statements for the significant statements, though in this case we split the statements between each other. After we generated the meaning statements, we then read through the other's meaning statements to make sure we understood the new statements. We would also highlight statements that we felt unsure about for our discussion in a subsequent meeting. Once the meaning statements were completed, we prepared to do the next step.

Colaizzi's method step 4

To tackle this next step in the analysis, I created two copies of the spreadsheet from the previous step. Then my undergraduate research assistant and I separately categorized the meaning statements into themes. After we finished categorizing the statements into themes, we met to discuss our themes and come to a complete agreement on what themes to keep. We also discussed the placement of specific meaning statements that we had trouble categorizing. There were a few statements that we did not place within a theme as they were unique to the individual instructor (particularly discussing important topics within biochemistry that were not discussed by the others). We subsequently highlighted statements placed within a theme that we were unsure about the placement.

After we made these adjustments, we moved all the themes into a new spreadsheet and changed the text colors of the statements to reflect which instructor the statements were collected from. To further aid in keeping the meaning statements organized, I also kept the statements within a theme from the same instructor together. This new spreadsheet helped my undergraduate research assistant and I to further refine the themes along with my advisor. We then placed only the theme descriptions in yet another spreadsheet so that the themes could be clustered into major and emerging themes. We had one final sit-down with my advisor to confirm the clustered themes and to decide in what order the theme clusters would be used to construct the subsequent steps of this method.

Colaizzi's method step 5-7

The remaining steps of the analysis were particularly challenging for me. There was a considerable number of themes that I needed to weave into the narrative. The task of reconstructing the faculty narrative was also daunting in that the themes were considerably more intertwined than in the previous set of interviews. I often found myself skipping meaning statements early in the narrative as they would appear later in other themes. I also found myself questioning whether I should condense the description of the data further as is standard within this method. I chose not to, not because I think this step is unnecessary all together, but rather it did not feel conducive to sharing the experiences of only three instructors. If this study had 10 or 15 faculty members interviewed, then I would certainly understand condensing the experiences further than I have for this analysis. The description of the faculty experiences was returned to the faculty to which I did not receive any feedback regarding inconsistencies or omissions.

APPENDIX D: IRB APPROVAL LETTER

UCF

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

EXEMPTION DETERMINATION

April 4, 2022

Dear Christopher Nix:

On 4/4/2022, the IRB determined the following submission to be human subjects research that is exempt from regulation:

Type of Review:	Modification / Update
Title:	Biochemistry Curricular Interventions to increase Student Knowledge Retention and Transfer
Investigator:	Christopher Nix
IRB ID:	MOD00002532
Funding:	Name: UCF/College of Sciences
Grant ID:	None
Documents Reviewed:	• Faculty advisor form, Category: Faculty Research Approval; • biochem II consent, Category: Consent Form; • biochem II interview protocol , Category: Interview / Focus Questions; • biochem II recruitment, Category: Recruitment Materials; • consent student class, Category: Consent Form; • consent_student interview, Category: Consent Form; • Protocol , Category: IRB Protocol

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made, and there are questions about whether these changes affect the exempt status of the human research, please submit a modification request to the IRB. Guidance on submitting Modifications and Administrative Check-in are detailed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Katie Kilgore

Katie Kilgore
Designated Reviewer

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