UNDERSTANDING PERCEPTIONS AND BELIEFS BIOCHEMISTRY INSTRUCTORS HOLD AND THE INFLUENCE THESE FACTORS HAVE ON THEIR PERSONAL STYLE OF TEACHING

by

Franziska K. Lang

A Dissertation

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Doctor of Philosophy

Department of Chemistry

West Lafayette, Indiana

December 2018

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. George M. Bodner, Chair

Department of Chemistry

Dr. David Eichinger

Department of Biology, Department of Curriculum and Instruction

Dr. Christine A. Hrycyna

Department of Chemistry

Dr. Marcy H. Towns

Department of Chemistry

Approved by:

Dr. Christine A. Hrycyna

Head of the Graduate Program

To my twin boys, Frederick and Theodor, who lit up the fire in me to go all this way

ACKNOWLEDGMENTS

One can only be most productive and successful in a work environment where support and creativity are fostered. I am deeply grateful to have worked with Professor George Bodner, who provided such an environment for me and my fellow graduate students. I appreciated the freedom I had to pursue my research endeavors, but at the same time, his guidance and advice to not get side-tracked by other interesting projects. In addition to having had a wonderful advisor, who created a fun and fruitful research environment, I would also like to thank my doctoral committee. Professor Marcy Towns took me into her research family and provided me a welcoming home to get all that work done. Professor David Eichinger deserves a big thank you for inspiring my research project with thought-provoking questions and for encouraging me to think “outside the box”. With Professor Christine Hrycyna I am very proud to have Purdue Chemistry’s first female department head on my committee and am indebted to her for great advice along my career path and for supporting my research project.

As many before me have recognized, this dissertation is a product of endless support and encouragement by many individuals. Many inspiring and wonderful people have filled different positions so desperately needed to make this all possible. I am hesitant to even begin listing who was all part of this journey as I am sure the list will be incomplete. However, I must mention the names of some people who were an integral part of this journey and enriched my life during my Ph.D. tremendously, from the beginning to the end. I am deeply thankful to work in a department where colleagues become friends, and friends become family. Marybeth Miller, thank you for providing me the platform to grow as an instructor, supervisor and teaching assistant. Through your endless passion for improvement, I was able to launch many projects within my teaching roles and spark my interest for professional development. I also thank Susan Linn, who always had an open ear and open mind. Her positive approach and delightful humor created a home-atmosphere that provided the support and encouragement needed in a time full of sleepless nights and busy days. I am thankful to all staff members in this department, who helped jump over administrative hurdles and fuel each day with energy and motivation. I know how fortunate I am to work in a department with such a big group of chemistry education researchers. I thank each and every one of you, past and present members of the Anderson group, the Bodner group, the Taskernauts, the Towns group, and the Ryu group for fruitful discussions and useful feedback. I experienced a wonderful community to grow professionally in an enriching and safe environment among amazingly intelligent and creative minds. Thank you, Jon-Marc G. Rodriguez, for your rich and valuable feedback on many chapters within this dissertation.

In particular, I also thank those strong women with whom I shared most of my Ph.D. path with, Kamali Sripathi-Garand, Kelly McNear, Reeh Tekane, and Sara L. Johnson. I am filled with deep gratitude to have worked with the four of you. Hurdles seemed less unbearable and challenges more doable through conversations and interactions with you. Thank you for your support along my way and encouragement when it was most needed.

I want to also acknowledge all the support I received from my family back in Germany. Even though they miss us greatly and would rather want to see us close by, they always put my dreams first and encouraged me to reach for the stars. From the bottom of my heart I want to say thank my newly gained American family, who opened their arms for me and my boys. Isobel Miller, my kindred spirit, you have been the pillar I could build on whenever and wherever. Together with your husband David Miller, you have enriched my family‘s life here so deeply that I cannot believe we have not known each other forever. Grammy Bel and Grandad Dusty, the words “thank you” does not live up to what you have done for me and my family here. Rafael, Frederick and Theodor, giving me the strength and courage to live up to my expectations and hopes are invaluable to me – I am looking forward to all of our future adventures that we will tackle together.

Finally, I am indebted to all of my participants. Thank you for your dedication and time. I highly appreciate your patience and your honesty, that made this research possible in the first place and enriched it in so many ways.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Meaning
ACS	American Chemical Society
ASBMB	American Society for Biochemistry and Molecular Biology
ABE	Association of Biochemistry Educators
BCCE*	Biennial Conference on Chemical Education
BER	Biology Education Research
Biochem*	Biochemistry
BCER	Biochemistry Education Research
CER	Chemistry Education Research
COPUS	Classroom Observation Protocol for Undergraduate STEM
DBER	Discipline-Based Educational Research
Ed*	Education
EBIP	Evidence-Based Instructional Practices
FAD*	Flavin Adenine Dinucleotide
ICAP	The Interactive, Constructive, Active, and Passive framework
IRB	Institutional Review Board
NRC	National Research Council
NAD*	Nicotinamide Adenine Dinucleotide
LA*	Learning Assistant
PER	Physics Education Research
PBL	Problem-Based Learning
PD	Professional Development
POGIL	Process Oriented Guided Inquiry Learning
PUI	Primarily Undergraduate Institutions
STEM	Science, Technology, Engineering and Mathematics
TCA Cycle*	Tricarboxylic Acid Cycle

*Primarily used in participants' quotes.

ABSTRACT

Author: Lang, Franziska, K. PhD
Institution: Purdue University
Degree Received: December 2018
Title: Understanding Perceptions and Beliefs Biochemistry Instructors Hold and the Influence these Factors Have on their Personal Style of Teaching
Committee Chair: George M. Bodner

Research investigating faculty and instructors' perception of teaching in discipline-oriented fields such as biology, chemistry and physics suggest that faculty hold diverse conceptions about teaching and learning. This study extended this work to a discipline at the interface between traditional physical science and life science fields, upper-level biochemistry courses. It also compared instructors' perception, beliefs and actions when teaching biochemistry at research institutions with courses taught at primarily undergraduate institutions (PUI's).

In a recently completed review of discipline-based educational research (DBER) in biochemistry, I noted the absence of research regarding the relationship between faculty beliefs and classroom practices in biochemistry and noted that different levels, associated with teaching and learning experiences, have not been studied in the context of the undergraduate chemistry curriculum. As a scientific field, biochemistry bridges chemistry and biology, which each have a consensus regarding the major concepts or ideas that should be taught within their disciplines. However, biochemistry, despite its increased relevance in recent years, has achieved hardly any consensus among those who teach this content material on what should be taught or how instructors should teach it. Biochemistry is also a rapidly growing field with increased relevance that is being taught as a unique discipline in more and more institutions. Another unique feature that distinguishes biochemistry from

other scientific fields is that it is inherently interdisciplinary and taught in different departments, often for a versatile population of various majors and minors. Further research suggests that we overgeneralize conclusions on factors influencing teaching practices within classrooms, which could possible prevent the advancement of teaching methodologies used by instructors. To explore this research interest, classroom observations and semi-structured interviews were used.

Within the scope of this study, I identified two main ways biochemistry instructors thought about their teaching of biochemistry: theory versus practice-oriented. The more theory-driven instructors reflected on their beliefs and perceptions, the more traditional their teaching practices were executed – the contrary held true for instructors with a more practical conception of the teaching of biochemistry. Overall, I was able to portray a multitude of ways in which biochemistry is currently being taught at different institutions, identifying differences and communalities they shared. As well as the unique challenges instructors faced when implementing evidence-based teaching methodologies in their classrooms were identified and categorized. My research should improve the understanding of factors, barriers, and possible opportunities that various scientific disciplines face to inform the development of professional programs that can encourage the use and implementation of evidence-based instructional practices.

CHAPTER 1. INTRODUCTION

1.1 Project Rational

Prior research has investigated instructors' perceptions of teaching in a variety of scientific disciplines such as biology, physics and chemistry (Lund & Stains, 2015). Mack and Towns (2016), for example, investigated faculty perspectives associated with teaching physical chemistry courses. In his work, Mack reported that "… different people have different experiences with the same phenomenon" (Mack, 2015, p. 1), which is consistent with the results suggested by others (Fang, 1996; Mack & Towns, 2016; Stipek, Givvin, Salmon, & MacGyvers, 2001). As Hativa and Goodyear (2001) noted faculty hold diverse conceptions about teaching and learning, which was confirmed by Mack's research.

In a recent review of DBER in biochemistry (Lang & Bodner, manuscript in preparation), I noted an absence of research regarding the relationship between faculty beliefs and classroom practices in biochemistry. Although previous work of this nature was conducted by Brickhouse and Bodner (1992) with respect to K-12 classrooms, there is a gap in this research at the college-level, especially in discipline-specific areas such as biochemistry. While there is a developing interest among DBER researchers about investigating non-traditional teaching methods in both lecture (Aldarmahi, 2016; Jansson, Söderström, Andersson, & Nording, 2015) and laboratory settings (Domin, 1999; Kahveci & Orgill, 2015, pp. 217-233), there is a lack of awareness how biochemistry instructors perceive their teaching. In particular, no one has yet explored how instructors view the use of non-traditional teaching methods in biochemistry classes, although work has been done in fields such as physics, biology, and chemistry (Lund & Stains, 2015). This topic needs to be better understood because research has shown that less-traditional lecturing and more involvement of students lead to greater learning outcomes (Chi & Wylie, 2014).

Biochemistry, despite its increased relevance in recent years (Akerfeldt, 2009; Committee on Professional Training, 2015; Kirch, 2013; McCoy & Darbeau, 2013; Wenzel, McCoy, & Landis, 2015) has had hardly any consensus on what should be taught and how instructors should teach it (Association of Biochemistry Educators (ABE), 2017; Niederhoffer, et al., 2017; Peterson & Carroll, 2015; Yarden, Macaulay, & Akdogan, 2017). Recent high-stake education reports have highlighted the call for raising the awareness of our students to the interdisciplinary nature of science (AAAS, 2011). As a scientific field, biochemistry is inherently interdisciplinary because it exists on the interface between chemistry and biology. Because of the interdisciplinary character of biochemistry, discourse across departments is necessary to agree on the content of the biochemistry curriculum and topics that will be covered. However, it can be difficult to track the content that is being taught in different courses. These challenges demonstrate why it is necessary to investigate the way we teach biochemistry content in a variety of classrooms.

Research has shown that students involved in more interactive classrooms are more successful than students in the traditional passive classroom (Chi & Wylie, 2014; Freeman et al., 2014; Prince, 2004; Wieman & Gilbert, 2015, 2015). Several documents (National Science Research Council, 2012; Wieman, Perkins, & Gilbert, 2010), describing the trends in teaching and research, have been highlighting the need to transform our classrooms into more active learning environments.

Knowing how biochemistry instructors perceive their teaching and how they act in their classrooms is essential to moving towards an evidence-based teaching reform in biochemistry classrooms. Only with that knowledge, can informed direction and changes be initiated, toward more active classroom environments. Understanding the challenges and barriers instructors face when to implement student-centered teaching approaches is essential to inform future professional development (PD) activities, to encourage adopting active learning strategies in Science, Technology, Engineering, and Mathematics (STEM) classrooms. Ultimately, work in this area should enhance the implementation of effective student-centered teaching methodologies and their success being established in everyday teaching.

Reports such as the *President's Council of Advisors on Science and Technology* report (Olson & Riordan, 2012) or the report for *The National Academies - National Research Council Board of Science Education* (Fairweather, 2008) within the field of undergraduate STEM education have highlighted the need for individual faculty, to take on the responsibilities of improving their teaching. Supporting arguments have been made in various research articles (Austin, 2011; Henderson, Beach, & Finkelstein, 2011; Henderson, Dancy, & Niewiadomska-Bugaj, 2012). Many of these resources have stated that it is the responsibility of faculty to become more aware of theories of learning as well as knowledge of student learning experiences. Furthermore, faculty are encouraged to enrich their knowledge in evidence-based instructional practices (EBIP) (Austin, 2011; Fairweather, 2008; Hativa & Goodyear, 2001; Kenny et al., 1999; Olson & Riordan, 2012), which is a significant focus of this dissertation.

There is a rising acknowledgement in the literature of the importance of helping faculty extend their consciousness of educational research. Multiple obstacles have to be considered, such as the content of individual subjects' practices and characteristics that inevitably influence instructors' thoughts, and actions in their classrooms – all of these have to be carefully considered and balanced (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003; Henderson & Dancy, 2011; NRC, 2012). There have been calls for closing the research and teaching gap in chemical education, (de Jong, 2000; Towns, 2013) but no such calls have been made in the field of biochemistry education yet.

The aforementioned reasons highlight the need to investigate the teaching by biochemistry faculty members in terms of their perceptions, beliefs and the actions they take in their classrooms. To achieve this, we need to characterize how faculty view their teaching and different teaching methods so that we can understand why there may be resistance to adopting interactive teaching methods.

With this research, I intended to work towards closing the research and teaching gap in biochemistry. In order to add to the existing knowledge on teaching in discipline-specific education, extending research on faculty perceptions and beliefs on teaching (Richardson, 1996; NRC, 2012) to the field of biochemistry is necessary, extending the body of knowledge on faculty thinking and approaches they take when teaching in subject specific settings will improve the understanding of factors, barriers, and possible opportunities that each scientific discipline faces. Understanding these aspects better will help facilitate conversations, PD opportunities, and institutional and departmental change in regard to teaching quality as well as help faculty obtain research-based instructional strategies for their respective classrooms (Henderson & Dancy, 2007, 2009; Henderson et al., 2012). The current research literature that focuses on students' understanding of conceptions of STEM topics at the upper-division and graduate course-level is relatively limited overall (NRC, 2012) and would significantly benefit from being enlarged through this study, by focusing on the environment instructors' build for student learning in biochemistry.

1.2 Guiding Research Questions

The goals of this qualitative study were to understand biochemistry instructors' perceptions and beliefs about teaching, and the influence these factors have on their actions in the classroom.

My guiding research questions were:

- What are biochemistry instructors' perceptions and beliefs about teaching biochemistry at the college-university level?
- How do biochemistry instructors think they teach biochemistry? What guides the decisions they make on the methods they use to teach biochemistry?
- Do beliefs and styles of teaching biochemistry vary across different types of institutions?

Individual interviews were used to investigate the first guiding research question. The second research question was investigated through classroom observations. Results from those two research questions were then used to probe the answer to the third research question. A review of the literature revealed significant gaps in the research on teaching and learning biochemistry done so far (Lang & Bodner, manuscript in preparation). There is a developing trend in the biochemistry education community that reflects the increasing interest in the investigation of alternative teaching methods (Bevan, Chan, & Tanner, 2014; Cicuto & Torres, 2016; Cowden & Santiago, 2016; Fernández-Santander, 2008; Loertscher, Villafañe, Lewis, & Minderhout, 2014). This development is consistent with DBER (NRC, 2012). Although biochemists are beginning to document how pedagogical techniques are utilized by biochemistry instructors (Lang & Bodner, manuscript in preparation), there is still a lack of research to capture the "status quo" of the field, such as: What techniques do instructors use to teach biochemistry? Why do they make the choices they are making and how can the literature stimulate their thinking and innovations when teaching an interdisciplinary topic like biochemistry?

CHAPTER 2. LITERATURE REVIEW

2.1 The Need for Improving Biochemistry Education

The National Science Board (2009) has argued that educational research has the potential to improve instruction and should be used to do so. For at least 30 years however, we have been arguing within the field of educational research whether changes should be subtle, rather than overt (Eisner, 1984). In recent years, DBER has been growing steadily, which incorporates areas such as chemistry education research (CER), biology education research (BER), physics education research (PER), and a host of other examples of domain-specific educational research. In addition, there has been recent efforts to expand the context of educational research beyond the traditional focus on the K-12 classroom to address challenges of teaching and learning at the introductory college level (NRC, 2012) and, to extend this work, as well, to advanced-level courses such as upper-level undergraduate biochemistry courses (Bodner & Weaver, 2008). In order for educational research to achieve its potential impact on instructional practices, it is essential to raise awareness of biochemistry education research (BCER) to practicing biochemists who teach these courses.

The call for improving biochemistry education has yet to be heard, compared to other established STEM education research fields such as PER and CER. Biochemists have yet to recognize the role that BCER could play in their field, based on the models of CER, PER and BER. As mentioned earlier, we have not yet agreed on the product – curriculum content – or the process of new approaches to teaching, which should be implemented in biochemistry classrooms at colleges and universities. Several programs attempt to address this issue and implement BER and CER. The American Society for Biochemistry and

Molecular Biology (ASBMB), for example has attempted to raise awareness on improving education and PD (Peterson & Carroll, 2015). The ABE has advocated similar changes within the context of improving the teaching of biochemistry in medical fields (ABE, 2017). Other efforts have been made to bring together researchers and teachers to enhance discourse about change within the field of biochemistry education. The International Union of Biochemistry and Molecular Biology (IUBMB) and the Federation European Biochemical Societies (FEBS) held a conference on “New horizons in biochemistry and molecular biology education” at the end of 2017, to “[…] provide a think-tank setting in which to draw up ideas to improve the current approach to teaching these subjects, and to generate a series of recommendations to be shared with the educational community” (Yarden et al., 2017). Efforts like these stress the importance of improvement in biochemistry education and serve as the foundation for raising awareness and making change happen.

2.2 Possibilities of Learning about Faculty Teaching Approaches through Interviews

2.2.1 Evaluating Teaching Practices

Several approaches have been used in prior work to explore teachers’ thinking. One method that has been particularly fruitful is the use of interviews (Seidman, 2013), which allowed in-depth investigations to explore the ways teachers think about their teaching. This method allows the researcher to achieve a deep exploration of instructors’ beliefs regarding important aspects of teaching biochemistry. Interviews to elicit faculty thinking have been commonly used in many research studies (Brickhouse & Bodner, 1992; Bruck, Towns, & Bretz, 2010; Mack & Towns, 2016; Martin, Prosser, Trigwell, & Benjamin, 2000). By selecting interviews as my method of choice, I was able to be better prepared for unexpected issues that I did not account for when designing the interview protocol. For example, when my interviewees brought up additional personal insight during their interviews, I was able to probe further (see Figure 3.3 for semi-structured interview).

I had expected instructors to bring up possible misconceptions of the implementation of instructional practices (AAAS, 2012), because they were not likely to be familiar with the research literature on evidence-based teaching practices. The flexibility provided by utilizing a semi-structured interview style would have not been possible with more restricted methods, such as online surveys. Interviews enabled me to build an awareness of instructors' beliefs and any perceived barriers (as perceived by the biochemistry instructors themselves) to implement more evidence-based teaching practices (e.g. lectures that facilitative active learning). By using interviews as my major data source, I was able to obtain a deeper understanding about the instructor's beliefs and perceptions.

2.3 Why Do We Teach the Way We Teach?

2.3.1 An Overview on Conceptions on Teaching

Henderson (2002, p. 28) described conceptions to be "instrumental in defining tasks and selecting cognitive tools with which to interpret, plan, and make decisions regarding such tasks." Henderson's definition was informed by prior research by Knowles and Holt-Reynolds (1991), Nespor (1987), and Pajares (1992). Research on instructors' conceptions of teaching has been extensively done using a phenomenographic lens (Åkerlind, 2004; Gonzalez, 2011; Mack & Towns, 2016; Martin et al., 2000; Prosser, Trigwell, & Taylor, 1994), that looks at the limited number of different ways people "experience" a common phenomenon. The goals of most of these studies were to account qualitatively for the existing differences that faculty have in their thinking in the context of teaching, and to gain insight in existing differences among their ways of thinking. Using this approach, two main teaching relationships were identified by Åkerlind (2008): teacher- and student-centered teaching conceptions.

Åkerlind proposed that student- and teacher-centered teaching exist at two ends of a spectrum and instructors may incorporate varying levels of student- or teacher-centered instructional methods such that students are more or less involved in the learning process. At the least interactive level (teacher-centered), faculty focus mainly on presenting material with the goal for students to retain the information, but without any further interactions between lecturer and audience – a rather “top-down” approach. A more interactive way of teaching is the student-centered teaching approach. Using this conception, faculty facilitate student learning, with a heavy focus on students’ knowledge construction. With this approach, the focus lies on both educators and learners to contextualize in a symbiotic teaching and learning environment. Prosser et al. (1994) highlighted different ways of thinking about teaching by twenty-four science faculty at Australian universities, with specialties in chemistry and physics. They found teaching conceptions that fit into both the student- and teacher-centered frameworks: transmitting concepts through teaching, teaching as a tool transmitting the teacher’s knowledge, teaching to help students acquire concepts in the syllabus, teaching to help students acquire teacher knowledge, students develop conceptions through teaching, and teaching as a tool to help students change their own conceptions. The first two of these conceptions truly represent a teacher-centered approach, whereas the remaining conceptions represented a movement from a teacher-centered approach towards a student-centered teaching approach.

Other phenomenographic studies have looked at conceptions in science teaching. Samuelowicz and Bain (1992) and Prosser et al. (1994) analyzed a range of conceptions on teaching in their research. In their study, Samuelowicz and Bain (1992) included thirteen science and social science faculty from two Australian universities. The teaching conceptions they found ranged from teacher-centered conceptions such as "imparting information", "transmitting knowledge" to student-centered conceptions such as "facilitate understanding" and "changing students' conceptions". Prosser et al. (1994) identified teacher-centered conceptions ranging from "transmitting concepts of the syllabus" to "helping students acquire teacher knowledge". Student-centered conceptions they identified ranged from "helping students develop concepts" to "helping students change conceptions". Both studies showed a broad range of use and variability of teacher-centered and student-centered conceptions, indicating that it is an oversimplification to describe instructors' teaching as exclusively student- or teacher-centered.

Kember (1997) reviewed 13 studies that characterized conceptions found on teaching in five conceptual categories that range from "imparting information" to "conceptual change/ intellectual development" (Figure 2.1). His model visualizes a multi-level categorization of the transition stages between an extreme teacher and student-centered oriented way of teaching. The two black bars show the boundaries existing between certain transition stages.

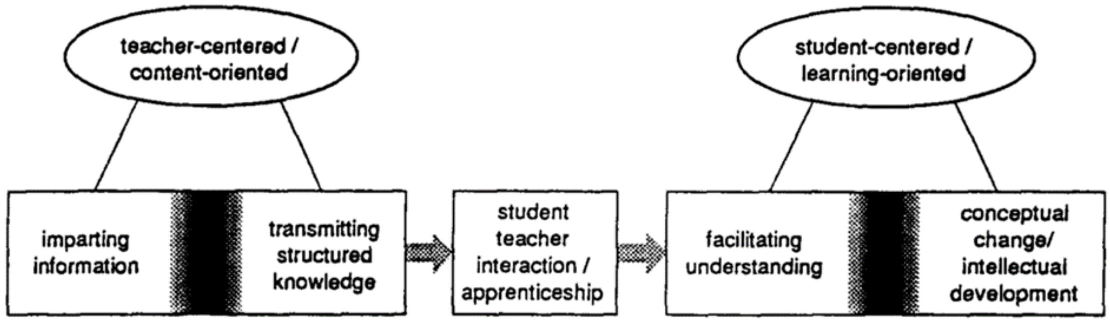

Figure 2.1 Kember's model of conceptions of teaching. Original diagram from Kember (1997, p. 264, Figure 2)

The category “conceptual change/intellectual development” emphasized students’ own development of knowledge. Including intellectual abilities such as engaging in argumentation or highlighting differences, this conception is representative of a more student-centered interest and teaching approach. Interestingly, the study found that faculty tended to believe their course goals and the material they presented fulfilled the interdisciplinary intentions to enhance students’ skills, such as problem solving or critical thinking. On the spectrum from teacher-centered conceptual approaches to more student-centered categories, they also reported on a conception present in the transition phase such as the “student-teacher interaction/apprenticeship”.

Åkerlind’s (2004) interviewed a total of 28 university faculty across different disciplines at an Australian university. In her study, Åkerlind (2004) described her results in terms of a range of conceptions form “teacher transmission focused” to “student learning focused”. Her focus was on faculty’s beliefs on the benefit of their teaching experiences. Faculty grouped within the teacher-centered conceptual approach tended to believe that through their teaching experiences they developed further subject matter knowledge. Faculty that were identified as having more student-centered approaches, however, tended to believe they were able to approach the course material with novel ways of comprehending the content by observing students' ways of thinking about the course material.

In a later research project, Gonzalez (2011) used interviews to investigate faculty's conceptual categories, which ranged from "transmitting basic information of the discipline" to "changing students' understanding/ developing critical thinking". This study was performed at two Australian universities and focused on the interdisciplinary range of faculty who were interviewed and the different ways teachers think about their ability to enhance student engagement in learning. This study noted that teachers with a student-centered approach found it important to motivate students and further engage them in learning, as well as to challenge students' existing conceptions.

Most studies on different ways of thinking about teaching have been limited because they did not compare the interview results to actions taken in classrooms. In my study, it was therefore of special importance to compare instructor beliefs from interviews with their actions in classrooms. This had been done in the study by Martin et al. (2000) that found that instructors toward the teacher-centered side of the continuum ended to make use of a lecture-based style of teaching. When deciding on assessments within their classrooms, the same population tended to prefer challenging exams. Teachers grouped within the student-centered orientation tend to utilize whole-class discussions or student presentations.

A recent study by Mack and Towns (2016) reported on the beliefs of instructors about teaching physical chemistry. They specifically looked at faculty beliefs about the purposes for teaching, with a special focus on undergraduate physical chemistry courses.

Within their phenomenographic, interview-based study they focused on a versatile population of instructors. Faculty interviewees seemed to agree on the main purpose of teaching physical chemistry. They thought that teaching physical chemistry is important to equip students with a good foundational understanding of the material, in particular of the conceptual knowledge of the course subject matter. Within my study, the biochemistry instructor population I interviewed showed a range of conceptions on teaching, such as from "teaching as transmission of information" to "teaching as facilitating conceptual change", as first suggested by Prosser et al. (1994) in the context of physical science university teachers. Since biochemistry is an interdisciplinary field, I expected that proven conceptions might be confirmed, and new conceptions might arise.

2.3.2 Research on How Teachers Think

Research on teacher thinking dates back to the 1970s, when guiding research questions addressed teachers' knowledge about teaching, the organization of that knowledge, and how their actions were informed (e.g. Clark & Yinger, 1987; Calderhead, 1996; Shavelson & Stern, 1981). The main focus of such research was to obtain an understanding of how teaching occurs (Clark & Yinger, 1987). In particular, the guiding interest in teacher-thinking research was to see which teachers' thoughts and judgments guided their decision-making process (Shavelson & Stern, 1981). It is of high importance to look at teachers' ways of thinking about why they use certain methodologies in their classroom or why they do not, to better understand what holds them back from advancing their teaching practices to more EBIP. Shavelson and Stern (1981), in their review, encouraged further research being done in this area, to better understand decision processes teachers experience, especially in discipline-specific contexts. Within the next pages, I am highlighting exemplary resources that explored the literature on teachers' thinking, on how they went about their teaching, to build the ground-work for investigating biochemistry instructors' perceptions and beliefs on their teaching practices. I chose to focus on planning processes in the next sections, to elucidate the ways teachers' think and on which beliefs they ground their choices in instructional practices on, in more depth.

Clark and Yinger (1987) described planning as a "psychological process in which a person visualizes the future, inventories means and ends, and constructs a framework to guide his or her future action" (p.86). Teachers' behavior in the classroom and the choices they make when choosing certain teaching methodologies are influenced through the planning processes educators go through when making choices for their classroom teaching. Those planning processes are suggested to be influenced by their beliefs, their ways of thinking about teaching (Calderhead, 1996). Case studies have identified consistencies among teachers' beliefs about the topics teaching and learning, particularly how teachers' plan their work and execute instruction in their classrooms (Cornett, Yeotis, & Terwilliger, 1990; Wilson & Wineburg, 1991). Within this study, I am focusing on instructors' typical style of teaching and their reasons why they choose to teach the way they do. Teacher's thoughts (Shavelson & Stern, 1981), and planning processes are an integral part in making choices and decisions for teaching purposes, therefore I chose to explore that body of literature further to inform my study.

2.3.2.1 Planning Processes and Decision-Making Actions in the Context of Teaching

Since teaching at universities and colleges is very different compared to K-12 schools, I did choose to not draw extensively on the enormous body of literature that exists on teacher planning processes for K-12 educators (Golland, 1998; Panasuk & Todd, 2005; Peterson, Marx, & Clark, 1978; Strangis, Pringle, & Knopf, 2006; Wischow, 2008). However, relevant studies were included were appropriate, since parallels among educators teaching at different school levels might exist. Within the context of this research, the most appropriate reference was a review on teacher thinking by Calderhead (1996), which I refer back to throughout this chapter. I also cite selected references out of that review, that were most applicable to the context of this dissertation.

Planning is involved in every profession that involves creativity and autonomy, so it is of relevance to investigate further decision-making processes instructors follow that guide their actions in classrooms. For teachers, planning becomes an essential daily task to convey knowledge in a sequential manner. Therefore, explicit training is included in the preparation of future teachers to help them understand the importance of "lesson planning." An early study on teacher planning (Tyler, 1950) showed a linear sequence of steps that teachers take when designing their courses, including: specification of objectives, selecting learning activities, organizing learning activities, specifying evaluation procedures.

This summary of pedagogical steps when planning an instructional session represents what might seem to be a simple process; in practice, however, this process becomes complex because it involves thinking about the topic, the level of student involvement, and many other factors. Not only is the planning and decision-making process complex while thinking about how a day's lesson will be implemented, on-the-spot decisions made during teaching can also be complex. Teachers are required to come up with solutions to intricate, unique problems that arise during the process of teaching and learning (Schön, 1995). Calderhead (1996) compiled a review of teacher thinking and highlighted several key points of the planning process crucial to teachers. Topics from his work that I will explore in the following sections include: teachers' utilization of different kinds of planning, planning's reliance on prior knowledge and experiences, the need for flexibility in planning, design and teaching**,** and the context of planning within a philosophical and pragmatic cycle.

2.3.2.1.1 Utilizing Different Planning Processes

Teachers utilize different planning processes (Clark & Yinger, 1987). These planning processes vary, depending on whether they have to make a teaching plan for the day, the week, or more long-term periods. Henderson (2002) pointed out that teachers may focus on the big picture, such as selecting topics, when planning for the overall course. When planning on a smaller level, however, teachers focus more on timing issues and the organization of activities.

2.3.2.1.2 Planning Based on Prior Knowledge and Experiences

While taking into account that planning draws from prior knowledge and experiences, Clark and Yinger (1987) and others (Shavelson & Stern, 1981) have pointed out that teachers draw on multiple resources when making decisions on planning their teaching, such as incorporating student prior experiences, taking into account student content knowledge on the subject, as well as utilizing any instructional strategies they use or are aware of.

2.3.2.1.3 Planning as a Flexible Task

The extent to which teachers are flexible with regard to their teaching depends on their experience within their profession. Henderson (2002), for example, determined that teachers who have not taught for long are more likely to follow their original plans, which experienced teachers realize is not always beneficial. Calderhead (1996) pointed out that experienced teachers build off of a skillset and practical knowledge that they have accumulated over the years, which equips them to deal with unforeseeable situations that may arise within the course of teaching.

2.3.2.1.4 Teaching and its Component of Design

Teaching requires actively designing new tasks and measures to address a number of versatile problems that vary in complexity (Clark & Yinger, 1987). Problems like these cannot be solved by following a rulebook or contrived procedures; they often require a unique solution (Schön, 1984, 1995). Identifying the unique solution is a challenge encountered by every practitioner who find themselves in the process of reflection. This process is most beneficial if it is routed in a cycle, where the cycle should consist of action taken to account for the problem, an appreciation to phase the problem, and a platform to provide steps towards the problem faced. The more cycles a practitioner goes through, the more refined the solution becomes (Schön, 1984).

2.3.2.1.5 The Philosophical and Pragmatic Cycle of Planning - Exemplary Studies

Many factors influence the philosophical and pragmatic cycle of instructional planning, such as materialistic considerations of the availability of resources, or which books or equipment can be used. The setting (e.g. the philosophy of the school and the expectations of institutions) in which the teacher works also plays a significant role in the planning process, as well as teacher’s personal views, beliefs, and perceptions of teaching (Henderson, 2002). In the context of my study, I also looked at what factors instructors considered when or when not choosing a teaching strategy within their specific teaching environment. This choice making process is tightly linked to planning processes in teaching settings. I wanted to therefore elicit more on exemplary literature discussing the research on lesson planning processes, because some of the same problems may also occur with faculty who teach biochemistry.

The literature reveals that research on how educators plan has been predominantly focused on primary-school educators (Calderhead, 1996). However, studies have also concentrated on the planning and decision-making processes instructors are involved in at the secondary, college, and university-level (Andresen, Barrett, Powell, & Wieneke, 1984; Taylor, 1970). The studies that have been done so far seem to show similar experiences in teaching, even though instructors at higher-level schools have to face different context-dependent challenges based on their unique and varying teaching settings. Taylor (1970) focused on the planning strategies of secondary teachers by using focus-group interviews, analysis of accompanying course documents, and questionnaires. His results describe four main factors that surrounded instructional and curricular planning by teachers: 1) materials and resources, 2) students' interests, 3) aims and purposes of teaching, and 4) evaluation considerations. These results are in contrast with the sequential model (Tyler, 1950) I described above, which focused primarily on the purposes of teaching and its objectives, rather than interacting factors within a classroom. Taylor found that the group of teachers incorporated contextual factors as well as characteristics from the student population more than paying attention to objectives, indicating the complexity of instructional planning.

Andresen et al. (1984) studied college teachers' involvement in planning by conducting weekly interviews with college teachers from various disciplines. Their data showed that teachers seemed to have adopted an ongoing routine of planning throughout their teaching, primarily focusing on subject-matter knowledge, and, in particular, on how to select, organize, and communicate content. For faculty, organizing teaching material of any sort helps them transfer their knowledge and skills to their students. Even Tyler (1950) described promising implications for planning, it was likely to break down when spontaneous and situational decisions within the classroom needed to be made.

When looking closer at planning strategies in the primary-school setting, Yinger (1980) designed a cyclical three-stage model that could describe ways teachers plan which entailed: finding the problem, designing the cycle, and planning implementation and evaluation. At the stage of finding the problem, many factors such as the teachers' goals and the utilized planning materials can interact to cause a problem. Yinger found that instructors became deeply involved in their investigations while solving problems. Through the acquisition of knowledge and practical problem-solving experience, teachers gain expertise that might be of use in future planning processes. This reflection allows them to learn from and evaluate implementations, informing future changes instructors can make. Yinger's model replaces the sequential model proposed by Tyler (1950), which focused on the purposes and objectives involved in teaching. The cyclical nature of using prior knowledge and experience to inform future planning and implementation aligns well with today's understanding of instructor performance in unforeseeable teaching situations (Schön, 1984, 1995).

While the existing literature mostly describes teacher planning processes and actions taken when making decisions and focuses primarily on elementary and secondary teachers, these references are applicable to this study because the biochemistry professors that are the subject of my study may have similar experiences while planning for lecture.

Instructors at all levels take part in the cycle of theoretical planning, taking action, and reflecting on their teaching. As stated earlier, the contextual setting in which teaching will be investigated needs to be considered, since this is a variable that changes significantly among institutions and levels of educational practices. By looking at instructors' intentions for teaching, problem-solving, and facing educational challenges, I intended to gain further insight into their knowledge and beliefs, informing my understanding of the actions they take when teaching biochemistry. These complex relationships led me to utilize qualitative research methods to deeply study the perceptions and beliefs biochemistry instructors hold and how they relate to their teaching actions in classrooms.

2.3.3 Looking at Ways to Teach

2.3.3.1 Reporting on the Relationship of Beliefs and Actions in a Hermeneutic Fashion

Research on the practice of teaching has been described for decades in research articles (Fang, 1996; Shavelson & Stern, 1981; Stipek et al., 2001) and books (Carlgren, Handal, & Vaage, 1994; Cochran-Smith & Lytle, 1993; Zeichner, 1994) and will continue to be of interest in a world experiencing continuous change in teaching reforms. The section highlighting conceptions on teaching provided an excerpt from the literature to build a foundation to investigate the actions of teachers in classroom settings and their corresponding individual beliefs. Studies situated within a hermeneutical framework, in particular, propose a versatile relationship between actions taken by teachers in classrooms and their associated perceptions and beliefs (Richardson, 1996). Beliefs and actions mutually influence each other, in that beliefs can drive actions and teaching experiences can lead to changes in beliefs. Since beliefs and practices about teaching can be both individual- and context-dependent, a closer look at various populations in different teaching contexts could provide a better understanding of how beliefs and actions relate to each other, acknowledging that their relationship is considered dynamic and interactive (Richardson, 1996). This is one reason why recruiting a versatile group of instructors from varying institutions will add to the enrichment of my results.

Exploratory groundwork on teachers' beliefs within a hermeneutic lens was conducted by Bussis, Chittenden, and Amarel (1976). Their study focused on investigating teachers' personal constructs with respect to the curriculum and the students. The researchers concluded that personal constructs emerge from individualistic interpretations of everyone's world. Furthermore, in order for teachers to change, they need to be continuously involved in a cycle of self-exploration, continuous reflection, and experimentation.

About ten years after the work by Bussis et al. (1976), Clandinin (1986) concluded that each teacher's experiences result in the construction of images that are an integral part of their personal practical knowledge. In his interpretation of the formation of teachers' beliefs, the author stated that each teacher's images, about their experiences, were reflected in in-class practices and routines. Cochran-Smith and Lytle (1990, p. 7) went a step further and called teachers' theories "sets of interrelated conceptual frameworks grounded in practice". This definition differs from simply stating that teachers' beliefs result in images that define their ways of teaching by describing their beliefs as influencing their instructor whole approach to teaching.

The studies mentioned above were conducted in the hermeneutic tradition and emphasized attempts to include the interactive nature of beliefs and actions. This approach can also be seen in the work of Schubert (1991, p. 214) who looked at the relationship between beliefs and actions in praxis and defined the symbiotic link of both as “a union of theory and practice in reflective action”.

With these benefits and viewpoints in mind, I conducted my study in the hermeneutic tradition to obtain in-depth insight into teacher’s beliefs and to situate the results of my research within their historical context. This theoretical framework put the results of my interviews into a contextual framework that guided my way of thinking. It was a framework that helped me frame my focus of this study and provided guidance when interpreting the results.

2.3.3.2 Actions Taken in Scientific Classrooms

Bodner, Metz and Tobin (1997) addressed the relationships between the levels of interactions within a classroom setting. Figure 2.2 indicates there are different levels of student-teacher interactions between the extreme teaching approaches described as teacher-centered or student-centered, and that these different levels occur in everyday classroom settings. As noted previously, teacher-centered approaches have non-interactive teaching and whole-group interactions in common, whereas student-centered teaching approaches is characterized by interactive approaches to teaching and small-group engagement.

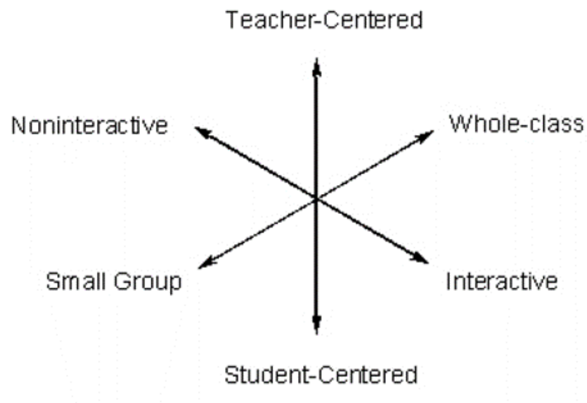

Figure 2.2 The relationships between styles of teaching within a classroom setting. Original diagram from Bodner et al. (1997, p. 2, Figure 1)

Bodner et al. (1997) observed that math and science classes have traditionally involved the whole group of students being exposed to a teaching environment where non-interactive lecturing is the primary teaching method. This is unfortunate because previous work has shown that the level of student engagement is critical and is directly correlated with student success (Trigwell & Prosser, 1991). Furthermore, active learning approaches have been repeatedly recommended to improve student engagement, which ultimately results in deeper learning (Anderson, 2007; Klymowsky & Cooper, 2012). There are many resources that instructors can utilize to provide ideas regarding active teaching methods (McKeachie & Svinicki, 2014). However, there are many factors that influence faculty's teaching behavior and might influence their resistance or reluctance to use active learning pedagogies.

As mentioned previously, it is necessary to understand how instructors think about teaching so we can understand why they teach the way they do. By exploring biochemistry instructors' perceptions about teaching, I was able to reveal barriers experienced by these faculty that prevent the use of active learning and student-centered teaching methods. Once we, as a community, better understand these barriers, we might be able to address them and thereby work toward improving instruction.

2.3.3.3 Examples of Barriers to Adopt Evidence-Based Practices

Changes in teaching through the translation of research into practice does not come easily. One reason for this is that teaching behavior is largely impacted by factors such as situational context, just like human behavior in general (Bronfenbrenner, 1979). Wieman et al. (2010) proposed possible barriers for adopting evidence-based teaching practices in upper-level science classrooms. They called for a fundamental change in “how science is taught at major research universities” (p. 14) and described how this remains a challenging but important goal to be achieved. Wieman et al. (2010) stated that educational transformation should happen on three levels: i) the departmental, ii) the faculty, and iii) the course.

Henderson and Dancy (2007) developed the Toy model shown in Figure 2.3 on the basis of interviews with instructors of introductory college-level physics. Their model illustrates the relationship between characteristics (situational, individual) influencing instructors’ adaptation to change of their teaching practices with respect to their different ways of teaching (alternative, semi-alternative, mixed, semi-traditional, or traditional instruction).

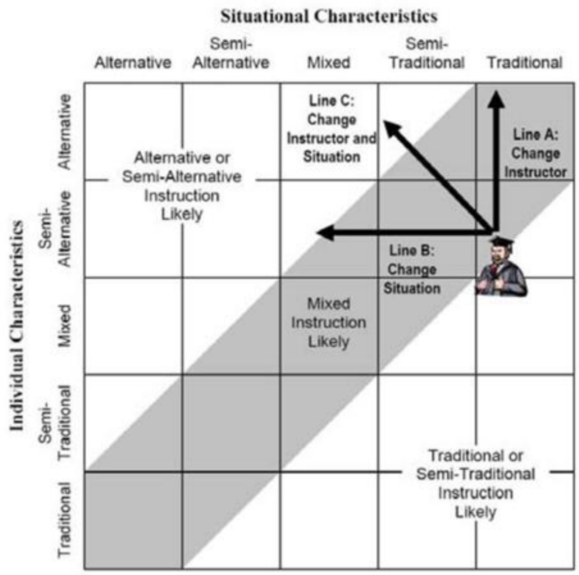

Figure 2.3 Toy model - the prediction of behavior related to individual and situational characteristics. Original diagram from Henderson and Dancy (2007, p. 11, Fig. 2)

Individual characteristics consist of beliefs, values, and instructor knowledge. Situational characteristics include, for example availability of teaching resources and acknowledgement of efforts for change in teaching practices within the department. According to their model, instructors will become more varied in their teaching practices if situational characteristics are less supportive of traditional teaching instructions. Other studies that looked at college science faculty as well as non-science faculty in the context of this model have agreed that situational factors significantly influence instructional choices (Murray & Macdonald, 1997; Norton, Richardson, Hartley, Newstead, & Mayes, 2005; Prosser & Trigwell, 1999; Sunal et al., 2001). It has been suggested that the situational characteristics of individual instructors are crucial for making changes in instructional choices (Henderson & Dancy, 2007).

More recent studies have increased our understanding of barriers to making changes in teaching practices and introducing research into classrooms Austin (2011) and Fairweather (2008), for example, identified “local” barriers such as departmental peers, instructional leadership, personal beliefs and values as well as the reward systems they do or do not experience. Several researchers have analyzed these factors in greater detail (Eckel & Kezar, 2003; Fairweather, 2005; Fisher, Fairweather, & Amey, 2001; Kezar, 2008; Komives, 2010; Schuster & Finkelstein, 2006). Even though institutions can be organized very differently, they face common challenges and obstacles (Eckel & Kezar, 2003). One major difference various levels of institutions face are their emphasis on scholarly acknowledging the advancement in teaching of academics (Fairweather, 2005). Doctoral granting institutions, in particular, may not yet value the quality of teaching their faculty deliver in a monetary way (Fairweather, 2005) or include it with responsible means into their academic advancement on the reach to tenure (Stains et al., 2018). However, it is needed to advance the methods we use in teaching, to promote the implication of learner-centered environments as stated by Fisher et al. (2001) for instance. The pace in which change academic institutions underwent in the past and are still facing (Schuster & Finkelstein, 2006) needs to be further addressed (e.g. Kezar, 2008; Komives, 2010).

The recent book *Transforming Institutions* by Weaver, Burgess, Childress, and Slakey (2015) emphasized that faculty deal with multiple influences throughout their teaching, including human relationships, departmental restrictions, and institutional goals. Weaver et al. (2015) called for a change in instruction while also addressing faculty development and considering spatial and technology constraints. This call was supported by the Teagle Working Group for ASBMB (Wolfson, 2010), who emphasized not to “…

underestimate the barriers to changing the culture in ways that promote effective teaching" (p. 22).

The references described in this section demonstrate the need to investigate instructor beliefs and perceptions. Instructor beliefs are an important factor within the characteristics that hinder faculty making changes in their teaching practices. By understanding these beliefs, we might be able to influence changes in the way biochemistry is taught toward the use of evidence-based practices.

2.3.3.4 Teaching Practices in Biochemistry

The ASBMB has been involved in broadening educational goals for biochemistry and molecular biology majors (Wolfson, 2010). This is consistent with the National Science Foundation and the National Academy of Sciences efforts to raise awareness to improve science education (Fairweather, 2008). The overarching goal is to bring active learning techniques into the biochemistry classrooms (Palocaren, Pillai, & Celine, 2016) at a rate best described as "one step at a time" (Loertscher, 2009).

What still remains to be determined, however, is which methods are currently used in biochemistry classrooms, since only a few studies have done that leave the overall impression that biochemistry is still be taught mostly by lecture and seldom makes use of active learning techniques (Alamoudi, Hassanien, Al Shawwa, Bima, Gad, & Tekian, 2018; Wolfson, 2010). These results are consistent with teaching practices we see enacted in other STEM disciplines (Stains et al., 2018).

Several recent studies have appeared on the teaching styles used in science classrooms. The recent study by Lund and Stains (2015) focused on the importance of context in influencing chemistry, biology and physics faculty towards student-centered teaching methods. That study looked at the influence of departmental factors that might contribute to why faculty teach the way they do. Observational and survey data obtained at one research-intensive university in the United States indicated that existing disciplinary differences are among the most important barriers to implementing EBIPs (Lund & Stains, 2015). Physics instructors dominated the group that verbalized the most positive views on student-centered teaching. In addition, physics faculty tended to experience no departmental holdbacks to adopting EBIPs. In contrast, the chemistry faculty revealed more teacher-centered views and also experienced contextual factors that hindered them from successfully adopting student-centered practices. In the case of biology faculty, they seemed to fall between the viewpoints and experiences reported by the physics and chemistry faculty. With their study, the Lund and Stains showed that departmental influences correlate with the level of adoption of EBIPs used by instructors. This study also revealed a need to further investigate what influences vary among departments and the status quo regarding the level of adoption of EBIPs in different departments. This is a particularly important point to consider in my research, since biochemistry is taught across multiple institutions and departments and the biochemistry community has yet to document the degree of variation of teaching beliefs and actions in biochemistry classrooms.

An analysis of the BCER literature (Lang & Bodner, manuscript in preparation) reveals, among other trends, a focus on improvements and suggestions on classroom and laboratory practices for teaching biochemistry. This analysis also revealed that the published studies are predominantly situated within the lecture setting, with a focus on identifying learning difficulties and suggestions for improved teaching. Criteria for the papers selected for this review were: a clearly defined topic of investigation, an explicitly stated methodology, and clearly presented results. Within the scope of this dissertation, I will incorporate only a few exemplary papers to give an insight into the state of BCER today.

When looking at classroom and laboratory practices for teaching biochemistry, specifically with regard to lecture practices, I noticed an increasing body of literature focusing on the use of technology within biochemistry classroom settings. The U.S. Department of Education (2017) begins a discussion of the use of technology in teaching and learning by noting:

> Technology ushers in fundamental structural changes that can be integral to achieving significant improvements in productivity. Used to support both teaching and learning, technology infuses classrooms with digital learning tools, such as computers and hand held devices; expands course offerings, experiences, and learning materials; supports learning 24 hours a day, 7 days a week; builds 21st century skills; increases student engagement and motivation; and accelerates learning. Technology also has the power to transform teaching by ushering in a new model of connected teaching … [that] … links teachers to their students and to professional content, resources, and systems to help them improve their own instruction and personalize learning.

There are clear patterns in the BCER literature. One historically established interest is the use of visual images in teaching biochemistry. As noted by Bodner, a collection of handouts using visual images was handed down to him by previous instructors when he first taught biochemistry in 1975. Articles that discuss the incorporation of visualization into biochemistry courses have used a variety of different forms of technology (Allred, Zahilyn, Tai, Bretz, & Page, 2017; Dash, Kamath, Rao, Prakash, & Mishra, 2015; Gunersel & Fleming, 2014; Terrell & Listenberger, 2017; Richardson et al., 2005). However, there has not been a significant amount of research that examines the effect this technology has on student learning, attitude, retention of content knowledge, or transferability to other courses of content learned through the use of this technology. There has been relatively little BCER that differentiates between the strengths and weaknesses of various approaches. Studies that have been carried out often focus on the training of medical professionals (Dash et al., 2015; Prakash, Muthuraman, & Anand, 2017; Shaw & Molnar, 2011), which can be fundamentally different from the sample population in a typical undergraduate biochemistry lecture and/or laboratory course. As a result, there exists a gap in the CER literature that suggests the need for research to examine the effects of technology on student learning, attitude, retention, and/or transfer of knowledge resulting from incorporation of new forms of technology into the biochemistry lecture and/or laboratory classroom.

Without commenting on the strengths and weaknesses of various approaches to integrating technology into the biochemistry classroom, I noted studies involving the use of videos, clickers, and games in both classroom-based and online settings only within the context of the biochemistry lecture. In general, by summarizing exemplary papers that provide a brief overview on this developing field, research on the use of technology in biochemistry courses suggests:

- Using a video in class can improve working memory capacity and cognitive processing (Dash et al., 2015).
- When lectures were videotaped and provided to students online, student test scores improved significantly, with a more significant benefit for non-native English speakers (Shaw & Molnar, 2011).
- Within the context of multimedia instruction, logical thinking was the only factor related to learning outcomes (Schoenfeld-Tacher, Jones, & Persichitte, 2001).

- The use of clickers in distant and non-distant learning is enjoyable and beneficial to students and, from the students' perspective, could be used more in classes or online (Miles & Soares da Costa, 2016).
- The use of reaction animations can lead to improved student performance (Gunersel & Fleming, 2014).

Learner-centered approaches to teaching in biochemistry are being investigated in the BCER literature. Anderson (2007, p. 465) began a useful stream of papers on the issue of bridging the gap between the results of educational research and teaching practice by noting:

> There is a large body of educational research results available in the science education literature that could be usefully applied for the improvement of teaching practice in biochemistry and molecular biology. Unfortunately, for a great variety of reasons, such applications are relatively limited in our discipline. In this first paper in the series, *Bridging the Gap*, I describe some of the barriers that are hampering the bridging of this gap and suggest some possible strategies that colleagues might wish to try in order to promote the wider use of this excellent educational resource.

Research into learner-centered techniques for teaching in chemistry is a well-established field. It has been over 30 years since Bodner (1986) presented to the CER community an approach addressing ways of thinking about teaching and learning based on the constructivist theory of knowledge. He advocated new approaches to teaching through rising awareness in our courses that we need to investigate how we teach, not only changing what we teach (Bodner, 1992).

A series of papers have appeared in the last 10 years on new approaches to teaching the content associated with biochemistry courses (e.g. Bevan et al., 2014; Conway, 2014; Minderhout & Loertscher, 2007). There has been a particular emphasis on the use and effectiveness of interactive teaching approaches as well as an emphasis on introductory courses, with special attention to the general topic of structure and function. Bevan et al. (2014), for example, compared an interactive teaching approach versus a didactic, lecture-based approach in terms of both surface-level and deep learning in different classroom settings. They concluded the traditional lecture setup encourages students to adopt a surface-learning approach, whereas biochemistry taught in a more engaging way utilizing different forms of assessment resulted in deeper levels of student learning. The benefit of interactive environments was also studied by Conway (2014) who compared students' performance on exam grades and final course grades taught by lecture, lecture/guided inquiry, and guided inquiry course formats. She concluded that student performance after guided inquiry instruction [using Process Oriented Guided Inquiry Learning (POGIL) materials or even partially guided inquiry approaches] was significantly better than performance after traditional lecture techniques.

Loertscher, a firm believer in POGIL, sought to answer the call for more student engagement and active learning methodologies in biochemistry classroom settings (Bailey, Minderhout, & Loertscher, 2012). Within this active teaching methodology, one would apply in a classroom the following format to engage more student-centered teaching: (i) a pre-class assignment, (ii) an in-class assignment and (iii) a post-class assignment (Minderhout & Loertscher, 2007). In general, the research literature reveals a strong benefit for students and teachers when using any sort of inquiry-based approaches, such as community-approaches (Goeden, Kurtz, Quitadamo, & Thomas, 2015) or group-work approaches (Fernández-Santander, 2008).

Problem-based learning (PBL) techniques are also widely studied in BCER. Anderson, Mitchell, and Osgood (2005) investigated a learning environment that involved cooperative learning, PBL, and inquiry-based learning. They noted improvements in student performance in terms of specific content knowledge and problem-solving skills as well as students' opinions of the course when these techniques were implemented in an introductory biochemistry class. Cowden and Santiago (2016) also studied the effect of implementing a PBL approach.

The BCER community has started to look at verbal and physical models to help students gain better access towards learning biochemistry. Orgill, Bussey, and Bodner (2015) have reported extensive research on the use of analogies in biochemistry classrooms. Physical models have been shown by Forbes-Lorman et al. (2016) to improve students' understanding of three-dimensional mental models of the structure of biomolecules and their ability to logically predict structure-function relationships.

These studies reflect a growing number of attempts to investigate the benefits of alternative teaching resources that biochemistry educators could use at college/university-level institutions.

More than 30 years ago, Bodner (1986) noted that "teaching and learning are not synonymous; we can teach, and teach well, without having the students learn." It is therefore encouraging to note that recent research has focused on finding effective ways of not only teaching biochemistry, but having students learn biochemistry. Studies have probed the positive effects of these new approaches on student performance, attitude, retention, and transfer. Many of these new approaches to teaching are based on creating an interactive learning environment that often involves cooperative or collaborative environments or techniques such as problem-based learning. Others involve incorporating inquiry-based or authentic research approaches into the laboratory.

Much of this work presumes that we expect more from our students, including skills such as critical thinking or research-based thinking, that might not have been made an integral component of traditional biochemistry classes. While the groundwork has been laid in many different areas, more work must be done to better understand how we can improve biochemistry teaching. Fortunately, the work done so far suggests that more engaging learning environments can give rise to better-motivated students, who have a more positive attitude toward learning the material we value most.

At one point in their evolution, chemistry, mathematics, and PER each separated themselves from "science education" by recognizing the importance of disciplinary expertise in shaping the guiding research questions that not only could, but should, be asked. It is this sentiment that narrows the focus of this study to a discipline-specific instructor population, the discipline of biochemistry. No matter how broad or interdisciplinary they might be, BCER and engineering education research have had the advantage that they can focus primarily (if not exclusively) on college/university level courses. They are ideal topics, therefore, for DBER, which the NRC report entitled *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (NRC, 2012) described as having the following goals:

- Understand how people learn the concepts, practices, and ways of thinking of science and engineering.
- Understand the nature and development of expertise in a discipline.
- Help identify and measure appropriate learning objectives and instructional approaches that advance students toward those objectives.

- Contribute to the knowledge base in a way that can guide the translation of DBER findings to classroom practice.
- Identify approaches to make science and engineering education broad and inclusive (p. 9).

These goals for DBER make an important point: It is obvious that biochemistry education researchers need to communicate with each other to move this field of scholarship forward, but they also need to communicate with practitioners, to guide the translation of research results into classroom practice. The most recent DBER report by the NRC (2012) also recommend that "research is needed in a wider variety of undergraduate course settings" as well as enhancing the contributions on "interdisciplinary studies of cross-cutting concepts and cognitive processes".

If we do not begin investigating discourse among educators who carry out biochemistry education in classrooms and researchers, we will not know what stops the teaching of biochemistry from advancing toward evidence-based educational practice. We need to know why educational innovation is not being done and what holds instructors at university and college level from making use of more innovative teaching techniques to foster student learning.

CHAPTER 3. METHODS

3.1 Guiding Research Questions

Within this study I investigated biochemistry instructors' perceptions and beliefs about teaching, and factors influencing their ways of instruction. The following three research questions guided this work:

- What are biochemistry instructors' perceptions and beliefs about teaching biochemistry at the college-university level?
- How do biochemistry instructors think they teach biochemistry? What guides the decisions they make on the methods they use to teach biochemistry?
- Do beliefs and styles of teaching biochemistry vary across different types of institutions?

3.1.1 Clarifying My Research Questions

3.1.1.1 How do I Define Biochemistry?

As a working definition for biochemistry for this study, I operationalize the one proposed by the American Chemical Society (ACS) that biochemistry is

> the study of the structure, composition, and chemical reactions of substances in living systems. Biochemistry emerged as a separate discipline when scientists combined biology with organic, inorganic, and physical chemistry and began to study how living things obtain energy from food, the chemical basis of heredity, what fundamental changes occur in disease, and related issues. Biochemistry includes the sciences of molecular biology, immunochemistry, and neurochemistry, as well as bioinorganic, bioorganic, and biophysical chemistry. (ACS, 2016)

3.1.1.2 What do I Mean by the Term “Teaching”

According to (AAAS, 2012), the term ‘teaching’ describes activities performed by people fulfilling a role whose intention is to bring about student learning. When investigating the manner in which teaching is executed, one looks at the way knowledge and beliefs affect how instructors go about a desired outcome within their classrooms, and the steps they take to communicate their own knowledge to their audience. Each instructor approaches teaching through mental frameworks that are considered “instrumental in defining tasks and selecting cognitive tools with which to interpret, plan, and make decisions regarding such tasks” (Henderson, 2002, p. 28). This definition made it necessary for me to further articulate my working definitions of beliefs and perceptions, and describe their interplay within the context of this study.

3.1.1.3 What do I Mean by the Term “Beliefs”?

Pajares (1992) offered a description of the concept of a ‘belief’ that reflects how I interpret it within the context of this study. He contrasted belief and knowledge: “Belief is based on evaluation and judgment; knowledge is based on objective fact” (p. 313). This definition highlights the strong subjective component inherent in beliefs. Within the scope of this study, I was interested in elucidating the instructors’ personal beliefs on the teaching of biochemistry and what actions they take in the classrooms as a result of these beliefs. Several studies have shown that beliefs among individuals vary (Fang, 1996; Mack & Towns, 2016; Stipek et al., 2001). Since I assumed the same to be true for the instructor population I was investigating, I choose to use the working definition illustrated above.

3.1.1.4 What do I Mean by the Term “Perceptions”?

Munhall (2008) described perception in *The SAGE Encyclopedia of Qualitative Research Methods* as follows:

> Perception is a mode of apprehending reality and experience through the senses, thus enabling discernment of figure, form, language, behavior, and action. Individual perception influences opinion, judgment, understanding of a situation or person, meaning of an experience, and how one responds to a situation. A common way of defining perception is “how we see things.” However, perception is a process involving not only the senses but also complex underlying mechanisms. Perception, which is mediated through the interconnectedness of mind and body, is an individual's access to experience and interpretation in the world. Perception of varying objects depends on the context in which they are experienced for interpretation and meaning. Perception is like a set of lenses through which an individual views reality. These lenses evolve from perspectives of location, subjectivity, particularity, history, embodiment, contradiction, and the web of teachings imparted to the individual.

Munhall emphasized that individuals express their perceptions through behavior and reactions towards one’s environment. Realities are constructed based on perceptions and can be understood as interpretations, which often become the individual’s “truth.” This definition and description reflect the interconnectivity between perceptions and actions that I needed clarify for this research study.

Overall, through each instructor’s own beliefs and perceptions, each inevitably establishes a working attitude under which one operates. This working attitude can influence the way an individual teaches – whether or not they are aware of it. By investigating and understanding an instructor’s perceptions, beliefs, and actions I aim to elucidate the ‘status quo’ of teaching biochemistry to further initiate change to enrich the field. By understanding instructors’ beliefs and perceptions about teaching, and how those relate to and reflect on their actions in the classrooms, we can better understand what challenges and barriers they face when choosing to enact or not enact evidence-based teaching approaches. Knowledge of such challenges and barriers are crucial, e.g., for expanding the body of literature on creating better PD opportunities for instructors at colleges and universities to more successfully implement effective teaching methods in their classrooms.

3.2 Theoretical Framework

3.2.1 Hermeneutics

It is considered best practice to state the theoretical framework that will be used for a particular study. While not all qualitative researchers verbalize their viewpoints clearly, it is assumed that all research has a theoretical perspective (Bodgan & Biklen, 1998; Merriam, 2009). Whether stated in the work or not, researchers can only benefit from a theoretical framework if they are intentional in communicating their interpretation as well as application of theory in respect to their work (Bodner, 2004).

For this work, I used a broad viewpoint on the role of theory in qualitative research (Anfara & Mertz, 2015).

The theoretical framework I chose for this study was hermeneutics, which functioned as both the theoretical foundation upon which the study was based (Denzin & Lincoln, 2011) as well as a lens to view and analyze my data.

Hermeneutics is considered the "art of understanding" (Shane, 2007, p. 108): "… the researcher acts as the voice of the participants by establishing the context of their actions and by communicating both overt and tacit findings in a clear, fair, and comprehensive manner" (Gadamer, 2000; Patton, 2002). Although hermeneutics has its origins in the interpretation of sacred texts, it is now commonly used in qualitative research as a means for interpreting any kind of text, either written or spoken, and is useful to understand the way in which individuals and groups construct meaning within a given context (Patton, 2002). Hermeneutics bases its execution on four key assumptions (Gadamer, 1976, 1996, 2000; Patton, 2002).

- A specific, historical context is important for understanding to occur.
- A fine interplay between the individual doing the interpretation and the object/ phenomenon being interpreted is key, where understanding must be formed during a mediated or dialogic event.
- Language aids formulation of understanding; this can occur in written or oral context.
- Throughout the entire research process, it is crucial for the researcher to document their own personal biases, perceptions, and metamorphosis of understanding.

Patton (2002, p. 497) describes how hermeneutics can be used to generate meaning from qualitative data: “Hermeneutics focuses on interpreting something of interest, traditionally a text or a work of art, but in the larger context of qualitative inquiry, it has also come to include interpreting interviews and observed actions”. Its use is rather generalizable, either when using spoken or written language. Other researchers such as Bodner and MacIssac (1995) and Geelan and Taylor (2001) have helped establish hermeneutics as a useful choice for qualitative research.

In order to use hermeneutics as a theoretical framework, the researcher must recognize the complexity and context-sensitivity required in educational environments. The choice of hermeneutics as my theoretical framework guided my approach to collecting and interpreting data from participants with varying backgrounds and narratives to share. Implementing hermeneutics as my guiding framework through data analysis and interpretation, enriched my research design and gave my study the necessary theoretical structure upon which I could build this project.

Discussions of hermeneutics as a theoretical framework emphasize the importance of the hermeneutic cycle or spiral "… to facilitate understanding and to generate holistic meaning from specific components embedded within qualitative data" (Shane, 2007). Within this process, I, as the researcher, cycled through the data, related research, and my earlier interpretations to gain a better understanding of the phenomenon under study. The hermeneutic cycle closes when "… the specific parts of the data can be interpreted within a greater whole" (Shane, 2007).

With this theoretical framework, I intended to build on a foundation of understanding how to interpret various data sources and how to communicate the message in my dataset in a fair and comprehensive manner. By successfully closing the hermeneutic cycle, I achieved the task of giving my participants a "voice" in an environment in which they might not otherwise have been able to express themselves.

3.2.2 A Critical View on the Framework Used

Hermeneutics has limitations that needed to be considered for this study. A broad criticism that is also leveraged against qualitative research in general is the lack of guidance in data analysis. The main problem is that there is no "… standard or universal analysis procedure" (Bodner & Orgill, 2007, p. 116). The circle, then, is not formal in nature. It is neither subjective nor objective, but describes understanding as "the interplay of the movement of tradition and the movement of the interpreter" (Gadamer, 2000, p. 293). In order to overcome this limitation for reliability purposes, I used additional data analysis tools such as the general inductive approach (Thomas, 2006), to condense my results during the hermeneutic cycle. Furthermore, I performed investigator triangulation (Patton, 2002) by carrying out peer-review: I asked other graduate students with similar educational or research background to review results that evolved during the analysis process. As an additional method of data triangulation, I shared my interpretation of the interview transcripts and additional artifacts with my faculty interview participants.

3.2.3 Research Design

The goal of this study was to understand and describe instructors' perceptions and beliefs about teaching biochemistry in lecture settings. In particular, I was interested in the factors that biochemistry instructors perceive to be crucial for determining the way they teach their courses and the actions they take in their classrooms that are based on these beliefs and perceptions.

While the main focus of this project was on undergraduate-level biochemistry courses, observation of graduate-level courses was incorporated to reveal broader understanding among different levels of biochemistry courses. The degree of comparison between the levels (beginning to advanced) were determined by the variety of participants I was able to recruit. This approach helped to gather information about the presumable "patterned knowledge" (Patton, 2015, p. 250) present in biochemistry courses, which is a key assumption in this research. I used a "one-point-in-time" data collection methodology for this study (Patton, 2015, p. 255, Tbl, 5.4). This allowed me to cover a broader range of beliefs and perceptions with a one-time observation followed by an interview investigation. Since the goal of this study was to cover a broad range of beliefs and perceptions, a large sample size of seventeen instructors was needed. I achieved the necessary sample size by capturing similarities and differences in the teaching of biochemistry across multiple institutions as well as a broad range of biochemistry instructors.

"Interviews create a constructive opportunity for a researcher to interact with an individual and… explore everything from teaching activities and beliefs to motivations and perceptions, and can be used to identify common barriers to, or misconceptions about, STEM teaching and other complex or poorly understood topics" (AAAS, 2012, p. 19). I used interviews in order to identify, describe, and understand individual instructors' beliefs and perceptions (Richardson, 1996). Interviews provided environments where participants could explore ways of thinking about teaching that were unique to each individual instructor.

As noted previously, biochemistry is taught within a variety of departments at different universities. At Purdue University, biochemistry is taught across campus, including in chemistry, biochemistry, the basic medical sciences, pharmacy, and agriculture. Despite its ubiquity among programs, there have been no studies that pursue an in-depth understanding of biochemistry instructors' views on teaching and learning. Within this study, I intended to learn about instructors' ways of perceiving and executing teaching in biochemistry based on their own experiences. As an education researcher, I needed to become aware of my own experiences and beliefs as well as my own biases about teaching in order to keep them separate from my participants' views on teaching and their personal experiences. However, while I took measures to ensure that my own philosophies did not influence the answers of my participants, I believe that my experience in teaching and science helped to build a rapport with biochemistry faculty. My perspective helped me facilitate a discourse to guarantee rich interviews with faculty participants (see 3.2.8).

3.2.4 Participants and Setting

In carrying out this study, I chose to collect data from participants who would offer a broad range of biochemistry instructors' teaching beliefs and perceptions (Åkerlind, 2004; Kuzel, 1992). As a result, I recruited participants from various tertiary institutions that offer biochemistry as a lecture course. To capture communalities and differences in biochemistry instruction, I intended to collect data from participants who would offer a broad range of evidence and views (Åkerlind, 2004; Kuzel, 1992). I therefore looked at a range of courses across multiple institutions with a range of biochemistry instructors to provide diversity in my participant pool. The population involved in this study is further outlined in Table 3.1. Ten participants were recruited from doctoral granting universities, of which seven were universities with highest research activity, two universities with higher research activity and one university with moderate research activity, according to the Carnegie classification. Furthermore, four participants were recruited from master-granting colleges/universities, and two participants from baccalaureate-granting colleges. Two of my participants held lecturer positions, all others either held an assistant, associate or full professor position. Two of my participants held a faculty position, with teaching as their main focus (clinical assistant professor, associate professor of practice). Class sizes and teaching experience varied across institutions. Typically, junior- and senior-level courses were investigated. This diverse sample of participants allowed an insightful investigation on teaching practices in biochemistry classrooms.

Table 3.1 Participants' demographic information

Participants (pseudonyms)	Gender[b]	Experience[b]	Carnegie Classification[c] Basic	Population (majority)	Department taught in[b]	Current average class size	Estimate of teaching experience with course observed
Dr. Derrick[a]	male	Associate Professor	Doctoral Universities: Highest Research Activity	Non-Biochemistry graduate students; Biochemistry majors, junior/senior	Biochemistry	~50	Over half a decade
Dr. Devora[a]	female	Clinical Assistant Professor	Doctoral Universities: Highest Research Activity	Non-Chemistry, Biochemistry majors; others	Biochemistry	In person: ~200 Online: ~80	Half a decade
Dr. Duna[a]	female	Professor	Doctoral Universities: Highest Research Activity	Biology majors, pre-medical; junior/senior others	Chemistry	~200	Less than half a decade
Dr. Dixie[a]	female	Assistant Professor	Doctoral Universities: Highest Research Activity	Chemistry graduate students	Chemistry	~12	Less than half a decade
Dr. Donald	male	Professor	Doctoral Universities: Highest Research Activity	Biology majors, pre-medical	Biological Sciences	~170	Multiple decades
Dr. Danner[a]	male	Associate Professor of Practice	Doctoral Universities: Highest Research Activity	Non-Chemistry, Biochemistry majors; others	Chemistry	~125	Less than half a decade
Dr. Dana[a]	female	Assistant Professor	Doctoral Universities: Highest Research Activity	Exploratory/undecided majors	Biochemistry	~50	Half a decade
Dr. Dalton	male	Professor	Doctoral Universities: Higher Research Activity	Chemistry, Biology majors, junior/senior; physiology masters, graduate students	Chemistry	~40	Multiple decades

Table 3.1 Continued

Dr. Dolly	female	Senior lecturer	Doctoral Universities: Higher Research Activity	Chemistry, Biochemistry majors, others	Chemistry and Biochemistry	~75 per section, 2 sections total	Over half a decade
Dr. Donna	female	Assistant Professor	Doctoral University: moderate research activity	Chemistry, Biology majors, others	Chemistry and Biochemistry	~55	Less than half a decade
Dr. Magnus[a]	male	Professor	Master's Colleges & Universities: Larger Programs	Biochemistry majors and other majors, others	Chemistry	~40	Multiple decades
Dr. Manju	male	Instructor	Master's Colleges & Universities: Larger Programs	Various non-majors	Physical Sciences	~20	Less than half a decade
Dr. Maggie[a]	female	Professor	Master's Colleges & Universities: Larger Programs	Different pre-physical therapy major; pre-physician assistant major	Chemistry	~80	Over one decade
Dr. Mickey	male	Assistant Professor	Master's Colleges & Universities: Small Programs	Chemistry major	Natural and Applied Sciences	~10	Over one decade
Dr. Brigid	female	Professor	Baccalaureate Colleges: Arts & Sciences Focus	BCHM majors; junior/senior	Chemistry	~20	Over one decade
Dr. Berry	female	Associate Professor	Baccalaureate Colleges: Arts & Sciences Focus	Chemistry, Biochemistry majors and minors, Biology majors, pre-medical	Chemistry	~30	Multiple decades
Dr. Bobbie	female	Associate Professor	Baccalaureate Colleges: Diverse Fields	Natural science majors	Chemistry	~30	Multiple decades

[a] Participants from same institution; [b] Information collected through official departmental websites; [c] https://www.wikidata.org/wiki/Q2475371, Basic Carnegie classification; http://carnegieclassifications.iu.edu/classification_descriptions/basic.php for R classification, M classification.

All participants were given pseudonyms that reflected their gender and the highest degree which their institution offered. Dr. Mickey, for example, is male and teaches in a department that offers master's degrees. Dr. Dana was given an appropriate name for a female who teaches at a doctoral granting institution.

3.2.5 Participant Recruitment and Sampling Strategies

I recruited participants from colleges and universities that teach biochemistry to undergraduates and/or graduate students, as summarized in Table 3.1. Within these institutions, participants had different levels of involvement in education research and/or teaching, which added diversity to my pool of participants. Participants held the title of instructor, lecturer or professor. I found participants by contacting instructors who had been recommended to me. Recruitment of participants then continued through snowball sampling (Creswell, 2013), where existing participants recruited future participants from their circle of acquaintances. Recruitment began by contacting instructors on campus by visiting them before or after their class periods. Instructors further away or not easily reachable were contacted through email. Convenience sampling (Creswell, 2013) was performed in the beginning of the study to recruit instructors from nearby institutions. All contact information was obtained through publicly available websites at the instructors' institution. I also recruited potential participants during conferences (e.g. ASBMB in Chicago, April 2017).

All participants had teaching experience in biochemistry at the undergraduate and/or graduate level as well as a willingness to participating in a chemical education research study. Purposeful recruitment continued until I had a sample population of instructors and classes that reflected a diversity in the following areas, to enlarge the applicability of my study results to a broader population:

- Institution-type PUI and Research Universities (RU).
- Level of course (upper-level course, with a focus on undergraduate and graduate student population).
- Career stage.
  - I focused on instructors who had taught at least one semester of introductory or advanced biochemistry, depending on the level at which each instructor was teaching.
- Gender.
  - I tried to increase the variety of perceptions, beliefs and actions in teaching biochemistry through recruiting participants with different gender.

The diversity in participants proved useful in order to represent a broad range of evidence and views (Åkerlind, 2004; Kuzel, 1992).

3.2.6 Data Collection

While collecting observations and interviews, I wrote memos (Corbin & Strauss, 2008) throughout the entire data collection process. This way of self-reflection is considered an essential part of the hermeneutics theoretical framework, so that one's own biases are acknowledged and embraced for data collection and interpretation: "Prejudices are not necessarily unjustified and erroneous so that they inevitably distort the truth. In fact, the historicity of our existence entails that prejudices, in the literal sense of the word, constitute the initial directedness of our whole ability to experience" (Gadamer, 1976, p. 9).

3.2.6.1 Observations

For data collection during classroom observations, I relied on three established sources to create a classroom observation protocol to use throughout all observations within this study. The choice of using observations and interviews to investigate instructors' beliefs was a methodological approach considered to be effective when trying probing instructors' beliefs and actions (Richardson, 1996). When constructing my observation protocol, I used the following three main resources:

- Patton's *Ten Strengths of High-Quality Observations* (Patton, 2015, p. 334, exhibit 6.2).
- Patton's *Guidelines for Fieldwork* (Patton, 2015, p. 416, exhibit 6.13).
- Classroom Observation Protocol for Undergraduate STEM (COPUS) protocol (Smith, Jones, Gilbert, & Wieman, 2013).

In this section, I will describe my final observation protocol. I will then highlight each source and how it contributed to the observation protocol I used for my classroom observations. My observational protocol (see Figure 3.1) consisted of three parts:

- Class background information: e.g., topic of class, and if the topic was new or already introduced.
- Style of teaching observed during lecture: e.g. methods, technology, level of student involvement, with the intent to refer to topics discussed during the interview.
- Personal experiences or influences discussed during the observation.

Observation Protocol

Class Background Information:

- Pseudonym for instructor observed
- Topic taught in class period observed
    - First, second, third, … lecture on that topic? (e.g. activities continued from lecture prior)
- Duration of session

Style of Teaching Observed During Lecture:

- Description of overall structure of lecture/room lecture was held in
- Observers perception of instructor's style of teaching during the lecture observed
    - Nature, extend and purpose of teaching methods/activities (e.g. type of teaching practice, length)
    - Overall perception of teaching methodologies used in class (e.g. student-centered, teacher-centered)
- Instructor's beliefs, perception shared with class related to teaching methodologies used
    - Reasons verbalized in class why a certain task was chosen, or teaching style was used
- Other notable observations
    - E.g. challenges encountered during lecture held

Personal Experiences During Observation:

- My experiences during observation
- How did my observation influence the observed?
- How did my observation influence myself?

Figure 3.1: Observation protocol created

Initially, I utilized Patton's suggestions on what high-quality observations should entail. His suggestions have ten strengths that enabled me to enrich the observations I made in classrooms (Patton, 2015, p. 334, exhibit 6.2):

1. “Rich description”: Readers are taken into the setting more easily, providing an experience, a deepened understanding.
2. “Contextual sensitivity”: Observing participants in action shows choices they make, which I used to reflect on interview design as well as what was said in the interview.
3. “Being open to what emerges”: Without any presumptions, observation can give an introduction to the chosen research topic and illuminate the “real world”.
4. “Seeing the unseen”: interviews alone do not reveal all behind-the-scenes and obvious features in classrooms.
5. “Testing old assumptions and generating new insights”: Particular factors can be observed that are usually not investigated.
6. “Opening up new areas of inquiry”: New information from observations can help shape the interview protocol and help the interviewer prompt participants with more in-depth questions.
7. “Delving into sensitive issues”: Deeper understanding can be gained during an observation that participants might not necessarily share, or would be reluctant to bring up, during an interview.
8. “Getting beyond selective perceptions of others”: What is said in an interview can be compared to actions taken in the classroom.
9. “Getting beyond one’s own selective perceptions”: It was helpful for me to remember to move beyond my own selective perceptions, to get a more

comprehensive understanding about the situation or circumstance that is observed.

10. "Experiencing empathy": This means that during observations, participants can be observed under the conditions they are working, and the researcher is part of their experienced reality. Observations provide the possibility to come to understand the participant's situation in a way distinct from interviews.

Research has shown that observing teaching is context-dependent (Martin et al., 2000). With this in mind, I noted the biochemical content taught during observations to put my participants' individual teaching into perspective. This was the motivation behind the first section of my observation protocol, so I could record the topic of the session, as well as if the topic was recently introduced or discussed previously in class. This was done through additional memoing during class period observations. For further insight on note-taking during the observations, I drew from Patton's *Guidelines for Fieldwork* (outlined in Table 3.2) to establish a clear mindset on obtaining rigorous notes during observations and therefore answering the questions that guided my observations (Figure 3.1). For example, when collecting the observations, I deliberately did not participate in class and chose to sit somewhere in the classroom, where I was not among the students or too close to the instructor (first item on the list of Table 3.2). Secondly, I continuously evaluated if my presence influenced the observed and the classroom dynamic, by attempting to notice if either the students or the instructor appeared distracted by me, e.g., if either looked over to me several times during class (last item on the list of Table 3.2).

I specifically drew from Patton's suggestions on for high-quality observations for the last part in my observation protocol, while observing the teaching styles present in the classrooms. Observations contributed enriched my set of data by providing insight into how my participants acted in their teaching environment (Patton's 1st through 3rd and 5th points). They also enhanced my understanding of each participant's individual story (Patton's 9th and 10th points) allowing me to connect their stories to real-life settings where my participants practiced their beliefs and perceptions (Patton's 2nd and 4th through 8th points). Observations such as these enhanced and supplemented my primary source of data (the semi-structured interviews).

Table 3.2 Patton's guidelines for fieldwork. Table modified based on Patton (2015, p. 451, exhibit 6.13)

Patton's Guidelines for Fieldwork	My implementation
"Design the fieldwork to anticipate, be clear about, and deal with classic tensions and trade-offs"	• I kept myself as invisible and unobtrusive as possible in the classroom • I did not participate when class period was in session • I used discretion when recording and observing
"Take detailed, descriptive field notes"	• To ensure I captured everything, I recorded class periods in parallel • Notes on site entailed instructor-student engagement for example
"Stay open and observant"	• Research questions were the main focus of the observations; however, if new impressions arose I made a note of them
"Capture, use, and report direct quotations"	• I consulted video recordings for direct quotations and noted summaries of what was said during the observations
"Select key informants and key knowledgeables wisely, and use them carefully"	• My protocol helped to keep focus on pursuing my research questions, see below
"Be aware of and strategic about the different stages of fieldwork"	• My structured observational protocol kept me on task and alert during all phases of observation
"Be reflective and reflexive"	• I included in my observational notes my own experiences and perspective during the time of observation
"Document reactivity"	• I included a description of how my observation may have affected what was observed and how I was affected during observations
"Engage ethically"	• I stayed alert and evaluated several times during the observation process if observations could be continued

The questions I incorporated in my own observation protocol were from a validated research tool, the COPUS protocol, which was created by Smith and colleagues in 2013 and updated in 2015. The COPUS protocol is a classroom observation protocol that any instructor can use to investigate and characterize their classroom practices either by themselves or using an observer. The COPUS protocol allows characterization of what happens in the classroom from both the perspective of the instructor and the students. The protocol itself consists of two parts, one qualitative/introductory part and a quantitative/measurement part (see Figure 3.2). I felt the qualitative questions of the COPUS protocol were particularly relevant to the context of my intent for this study, especially section two ("classroom and background") and section three ("narrative description of class (also known as field notes)"). For example, COPUS section three, allowed me to focus on the overall classroom structure, how the material was presented, and the amount and nature of activities used in class.

Since the intent of my study was to investigate biochemistry instructors' beliefs and perceptions on actions taken in their classrooms, I also chose to incorporate sections in my observational protocol that allowed me to elaborate on any beliefs that were shared during the lecture by the instructors themselves (e.g. why a certain teaching strategy was used). In addition, I incorporated a self-reflection section to note down anything that might have influence the observed or the observer during the observation itself. Using this section, I was able to collect data that the video recording device could have missed (e.g. perception of teaching environment, atmosphere during different portions of the class period observed, as also stated by Corbin & Strauss, 2008).

Overall, through incorporating ideas from the qualitative section of the COPUS protocol, I was able to approach each observation as a holistic experience. These ideas allowed me to acknowledge my own interpretation as the researcher and as the primary data-collection instrument, while still providing me with enough freedom and guidance to capture actions in the classroom when teaching biochemistry.

Classroom Observation Protocol for Undergraduate STEM – COPUS

Smith MK, Jones FHM, Gilbert SL, and Wieman CE. 2013. The Classroom Observation Protocol for Undergraduate STEM (COPUS): a New Instrument to Characterize University STEM Classroom Practices. CBE-Life Sciences Education

Date and time of Observation: ____

1) **Background Information**
   a) **Observer Name:** ________________________
   b) **Class No./name/section:** ____
   c) **Observer's location in the class:** ____

2) **Classroom and background**
   a) Room location and layout (e.g., type of student seating, instructor on podium, etc.).
   b) Note if there is anything unusual about this particular class/lecture (e.g., quiz day, first day of semester, etc) (try to avoid observing classes that are particularly anomalous)
   c) **(Optional, if known)** What goes on out of class? ☐Homework? ☐Pre-readings? ☐Labs? ☐Projects? ☐Other? Explain briefly.
   d) **(Optional, if know)** How varied are classes for this course? Circle one each, to show balance of ***Active Students / Instructor Delivery*** ...
      i) for the **Whole Course,** balance approximates: 0%/100% 20/80 40/60 50/50 60/40 80/20 100%/0%
      ii) in **Today's Class Only,** balance approximates: 0%/100% 20/80 40/60 50/50 60/40 80/20 100%/0%

3) **Narrative Description of Class (also known as field notes)** **(optional)**

Information could include ...

- The structure of the lesson (e.g., how the instructor sequenced material, the narrative arc of the class)
- The range and nature of activities that occurred.
- Dialog/behaviors that illustrate codes you gave, especially for teaching techniques and student engagement.
- Instructor's actions that appear to have affected students' engagement.
- Evidence of variability among students (e.g., if small groups, to what extent did groups behave and engage similarly?)

Figure 3.2 Classroom observation protocol for undergraduate STEM – COPUS. Original from Smith, Jones, Gilbert, and Wieman, (2013, supplemental material, p. 2-5)

Figure 3.2 Continued

Observation codes

1. Students are Doing	
L	Listening to instructor/taking notes, etc.
Ind	Individual thinking/problem solving. Only mark when an instructor explicitly asks students to think about a clicker question or another question/problem on their own.
CG	Discuss clicker question in groups of 2 or more students
WG	Working in groups on worksheet activity
OG	Other assigned group activity, such as responding to instructor question
AnQ	Student answering a question posed by the instructor with rest of class listening
SQ	Student asks question
WC	Engaged in whole class discussion by offering explanations, opinion, judgment, etc. to whole class, often facilitated by instructor
Prd	Making a prediction about the outcome of demo or experiment
SP	Presentation by student(s)
TQ	Test or quiz
W	Waiting (instructor late, working on fixing AV problems, instructor otherwise occupied, etc.)
O	Other – explain in comments
2. Instructor is Doing	
Lec	Lecturing (presenting content, deriving mathematical results, presenting a problem solution, etc.)
RtW	Real-time writing on board, doc. projector, etc. (often checked off along with Lec)
FUp	Follow-up/feedback on clicker question or activity to entire class
PQ	Posing non-clicker question to students (non-rhetorical)
CQ	Asking a clicker question (mark the entire time the instructor is using a clicker question, not just when first asked)
AnQ	Listening to and answering student questions with entire class listening
MG	Moving through class guiding ongoing student work during active learning task
1o1	One-on-one extended discussion with one or a few individuals, not paying attention to the rest of the class (can be along with MG or AnQ)
D/V	Showing or conducting a demo, experiment, simulation, video, or animation
Adm	Administration (assign homework, return tests, etc.)
W	Waiting when there is an opportunity for an instructor to be interacting with or observing/listening to student or group activities and the instructor is not doing so
O	Other – explain in comments

3. Student Engagement (optional)	*Student engagement alternatives:*
L Small fraction (10-20%) obviously engaged.	*(1) Just mark when engagement is obviously high or obviously low.*
M Substantial fractions both clearly engaged and clearly not engaged.	*(2) Count "N" students near you (~10) and assess how many appear engaged at every 2 minute interval. Enter value for all engaged instead of L/M/H. NOTE what your value of N was.*
H Large fraction of students (80+%) clearly engaged in class activity or listening to instructor.	

Suggestions regarding codes and comments:

- Clarify code choices with comments.
- Consider indicating your confidence regarding coding, especially when you aren't sure about choice of codes.

HOW TO USE OBSERVATION MATRIX: Put a check under all codes that happen anytime in each 2 minute time period (check multiple codes where appropriate). If no codes fit, choose "O" (other) and explain in comments. Put in comments when you feel something extra should be noted or explained.

Figure 3.2 Continued

Date:________________ **Class:** ________ **Instructor:** ___________________________**No. students** _______ **Arranged how?** ___________________________________

1. **L**-Listening; **Ind**-Individual thinking; **CG**-Clicker Q discussion; **WG**-Worksheet group work; **OG**-Other group work; **AnQ**-Answer Q; **SQ**-Student Q; **WC**-Whole class discuss; **Prd**-Predicting; **SP**-Student present; **TQ**-Test/quiz; **W**-Waiting; **O**-Other

2. **Lec**-Lecturing; **RtW**-Writing; **FUp**-Follow-up; **PQ**-Pose Q; **CQ**-Clicker Q; **AnQ**-Answer Q; **MG**-Moving/Guiding; **1o1**-One-on-one; **D/V**-Demo+; **Adm**-Admin; **W**-Waiting; **O**-Other

For each 2 minute interval, check columns to show what's happening in each category (or draw vertical line to indicate continuation of activity). OK to check multiple columns.

COPUS																													
	1. Students doing													2. Instructor doing												3. Engagement			**Comments:** EG: explain difficult coding choices, flag key points for feedback for the instructor, identify good analogies, etc.
min	L	Ind	CG	WG	OG	AnQ	SQ	WC	Prd	SP	T/Q	W	O	Lec	RtW	Fup	PQ	CQ	AnQ	MG	1o1	D/V	Adm	W	O	L	M	H	
0 - 2																													
2																													
4																													
6																													
8 - 10																													
	L	Ind	CG	WG	OG	AnQ	SQ	WC	Prd	SP	T/Q	W	O	Lec	RtW	Fup	PQ	CQ	AnQ	MG	1o1	D/V	Adm	W	O	L	M	H	
10 - 12																													
12																													
14																													
16																													
18 - 20																													
	L	Ind	CG	WG	OG	AnQ	SQ	WC	Prd	SP	T/Q	W	O	Lec	RtW	Fup	PQ	CQ	AnQ	MG	1o1	D/V	Adm	W	O	L	M	H	
20 - 22																													
22																													
24																													
26																													
28 - 30																													

Smith MK, Jones FHM, Gilbert SL, and Wieman CE. 2013. The Classroom Observation Protocol for Undergraduate STEM (COPUS): a New Instrument to Characterize University STEM Classroom Practices. CBE-Life Sciences Education

Figure 3.2 Continued

1. **L**-Listening; **Ind**-Individual thinking; **CG**-Clicker Q discussion; **WG**-Worksheet group work; **OG**-Other group work; **AnQ**-Answer Q; **SQ**-Student Q; **WC**-Whole class discuss; **Prd**-Predicting; **SP**-Student present; **TQ**-Test/quiz; **W**-Waiting; **O**-Other
2. **Lec**-Lecturing; **RtW**-Writing; **FUp**-Follow-up; **PQ**-Pose Q; **CQ**-Clicker Q; **AnQ**-Answer Q; **MG**-Moving/Guiding; **1o1**-One-on-one; **D/V**-Demo+; **Adm**-Admin; **W**-Waiting; **O**-Other

For each 2 minute interval, check columns to show what's happening in each category (or draw vertical line to indicate continuation of activity). OK to check multiple columns.

page 2																													
	1. Students doing													2. Instructor doing												3. Engagement			**Comments:** EG: explain difficult coding choices, flag key points for feedback for the instructor, identify good analogies, etc.
min	L	Ind	CG	WG	OG	AnQ	SQ	WC	Prd	SP	T/Q	W	O	Lec	RtW	Fup	PQ	CQ	AnQ	MG	1o1	D/V	Adm	W	O	L	M	H	
30 - 32																													
32																													
34																													
36																													
38 - 40																													
	L	Ind	CG	WG	OG	AnQ	SQ	WC	Prd	SP	T/Q	W	O	Lec	RtW	Fup	PQ	CQ	AnQ	MG	1o1	D/V	Adm	W	O	L	M	H	
40 - 42																													
42																													
44																													
46																													
48 - 50																													

<u>Further comments</u>:

If you would like to have a protocol sheet that extends beyond 50 minutes, please check the following website: www.cwsei.ubc.ca/resources/COPUS.htm or contact the corresponding author (michelle.k.smith@maine.edu) for a modifiable spreadsheet.

In this study, I did not intend to quantitatively capture the distribution of teaching methods used during a class period (as the COPUS protocol was designed to do) because this was not the focus of this study. Instead, I observed the actions of instructors during a "typical" session to see if the beliefs and perceptions they expressed in the interview aligned with the actions taken during a class period. My intentions were also not to focus on the students and their involvement, but rather at student-centered teaching methodologies used by the instructor. Therefore, I did not incorporate quantitative measures of the COPUS into my observation protocol. However, when taking notes during the observations and filling out my observational protocol, I consulted the instructor section of the COPUS observation codes table (as outlined in Figure 3.2), to inform myself about possible classroom interactions that I could encounter. I treated the observations as a secondary data source, whereas the interviews were my primary data source.

During each class period, videos were recorded using a Drift Ghost-S Professional HD Action Camera, which was mounted on a stationary stand and placed in the lecture hall facing the lecturer. This setup allowed me to capture his or her actions in class. All faces were blurred for de-identification purposes. Video recordings were only used for analysis purposes. Data was reviewed using QuickTime Player after each class period. In-class observational notes using the observation protocol (as shown in Figure 3.1) were taken during each class period observed. By video-taping all classroom lectures, I was able to summarize the class periods. I supplemented my notes taken during observations by re-watching the lessons. Through this process, I ensured I was comprehensively applying my observation protocol and not relying solely on memory.

As outlined in Table 3.3, remote and in-person recordings were collected, depending on where the institution of interest was located and if lectures could be attended. If it was not possible for me to be present during the class period, I arranged for the videos to be recorded with the help of the instructors themselves. Although remote recordings were not ideal, as mentioned above observations were only used to enrich my in-depth interview dataset and were not my primary data source. Table 3.3 highlights the further details on who was observed in person and who was observed remotely (last column on the right). I was able to observe about half of my participants in person. Most study participants were only observed once. Three instructors were observed twice, because they provided me with two different styles of lectures to best reflect their teaching style. All other instructors believed one lecture was sufficient to provide an accurate representation of their typical lecture style.

Table 3.3 Details on observational data

Participants (pseudonyms)	Gender	Experience	Carnegie Classification Basic	Number of observations taken and included in analysis[a]	Remote or in person recordings
Dr. Derrick[b]	male	Associate Professor	Doctoral Universities: Highest Research Activity	1	In person
Dr. Devora[b]	female	Clinical Assistant Professor	Doctoral Universities: Highest Research Activity	2	In person
Dr. Duna[b]	female	Professor	Doctoral Universities: Highest Research Activity	1	In person
Dr. Dixie[b]	female	Assistant Professor	Doctoral Universities: Highest Research Activity	1	In person
Dr. Donald	male	Professor	Doctoral Universities: Highest Research Activity	1	Remote
Dr. Danner[b]	male	Associate Professor of Practice	Doctoral Universities: Highest Research Activity	1	In person
Dr. Dana[b]	female	Assistant Professor	Doctoral Universities: Highest Research Activity	1	In person
Dr. Dalton	male	Professor	Doctoral Universities: Higher Research Activity	1	In person
Dr. Dolly	female	Senior lecturer	Doctoral Universities: Higher Research Activity	1	Remote
Dr. Donna	female	Assistant Professor	Doctoral university: moderate research activity	2	Remote
Dr. Magnus[b]	male	Professor	Master's Colleges & Universities: Larger Programs	1	Remote
Dr.Manju	male	Instructor	Master's Colleges & Universities: Larger Programs	1	Remote
Dr. Maggie[b]	female	Professor	Master's Colleges & Universities: Larger Programs	1	Remote
Dr. Mickey	male	Assistant Professor	Master's Colleges & Universities: Small Programs	2	Remote

Table 3.3 Continued

Dr. Brigid	female	Professor	Baccalaureate Colleges: Arts & Sciences Focus	1	Remote
Dr. Berry	female	Associate Professor	Baccalaureate Colleges: Arts & Sciences Focus	1	In person
Dr. Bobbie	female	Associate Professor	Baccalaureate Colleges: Diverse Fields	1	In person

[a] The number of observations varied if instructors felt that their typical style of teaching was not represented adequately in one lecture but was spread out more over multiple lectures. If that was the case, multiple observations were taken if possible. Within this dissertation, all participants agreed that the number of observations taken and the lectures videotaped represented their typical style of teaching.
[b] Participants are from same institution

This observation strategy enabled me to collect data from more instructors and institutions. The maximum number of observations I collected for each participant was two int total, similar to the methodology of Lund and Stains (2015). The intent of observations as a data source within this dissertation, however, was to observe the preferred teaching methods used during a typical class. Since I confirmed with each instructor about their perception of generalizability of the session observed, it was reasonable to assume that I obtained an accurate picture of their general teaching style.

Observations were conducted before interviews occurred to provide a basis for interview prompts, and to gain a better understanding on how instructors talked about their ways of teaching in comparison to teaching methods I had observed. Before I attended their class, I emphasized to the participants that they should approach teaching during my observation using the teaching style they felt was appropriate and reflecting their “typical” style of teaching.

3.2.6.2 Interviews

Observations alone would have not provided me sufficient insight into each participant’s point of view about teaching. According to Patton (2015):

> Observing something doesn’t necessarily mean we can interpret it. In particular, we can’t know what it means to those involved in an event, interaction, or activity without talking to them or hearing from them in some way. […] Every interview is also an observation. Interviewing adds to observation of the perceptions and sense making of the people being studied (p. 417)

Combined with the theoretical framework of hermeneutics, this reasoning led me to use both interviews and observations. I chose a semi-structured (Creswell, 2009), conversational interview style (Figure 3.3) for this study, which consists of three major phases. The first phase of the interview (“introduction/description of research” and “getting-to-know the participant/course background/general inquiries”) was used to establish a positive interview environment. I asked background questions that I intended my participants to have no difficulty answering and I showed interest in the participant as an individual and their career. Such information was obtained prior to the interview, through email exchange (recruitment emails) and searching on official departmental websites associated with my participants.

The second phase of my interview (“Beliefs, perceptions, …” and “student learning”) started with a general question about each instructor’s approach to teaching biochemistry. This opened the discussion to beliefs, perceptions, and practices. My intent was to allow each instructor to state their thoughts without prompting. During this section, I drew from both information that they provided to me, and that I gained through observations and artifacts. This enabled me to ask specific follow-up questions during the interviews on behaviors I had observed in their classrooms, and how these linked to each participant’s interview answers and to what their overall “ideal teaching-world” would be (e.g. each individual’s teaching philosophy).

The third part of my interview ("improvements to teaching") involved concluding the interview by focusing on the instructor's interest in changing the way he/she teaches and addressing any challenges associated with change that were discussed during the second interview phase. This elucidated each instructor's career goals, and how each viewed the development and future of biochemistry teaching.

<u>Introduction/ Description of Research.</u>

INTRODUCING MYSELF AND THE STUDY

- Introduction of myself
- Physical copy of information sheet handed out (prior also sent via email)
    - Study description, content, procedure, and risks as well as rights of participation
    - Clarification of questions they might have
- Thank you very much for agreeing to be interviewed about your experiences teaching biochemistry. I am interested in learning about the ways you think (your beliefs and perception) about the teaching of biochemistry and what actions you choose to take in classrooms to implement your perceptions/beliefs.
    - The study looks at biochemistry instructors at different institutions on…
        - Perceptions: How you experience your classroom, students, your teaching. How you "see" things with your eyes, how you perceive them with your senses.
        - Beliefs: Your personal beliefs on the teaching of biochemistry and what actions you take in the classrooms to reflect these beliefs. In other words, your beliefs in teaching, your opinion and attitude about teaching and learning and the actions you take in the classroom that reflect those.
- Reminder:
    - (Interview is not meant to judge teaching practices or your views on them, your beliefs). It is meant to capture your beliefs and perception and in the bigger scope report on the current state of teaching and the understanding of teaching biochemistry.
    - Some questions might appear redundant – this is part of the interview design, to give me a better understanding of your beliefs and your perception, in a different light, with different examples.
    - If we start to get off-topic, I might kindly ask you to come back to the question
- Do you have questions?
- Let's start with some background information about your courses and yourself

Figure 3.3 Semi-structured interview protocol

Figure 3.3 Continued

<u>Getting to-Know the Participant/ Course Background/ general Inquiries.</u>

Fill in information from previous email, to use as a starter for the interview

- Courses taught already, experience in teaching

Information from Round 1 and 3, see emails When did you start teaching and where?

- How did you get to teach these biochemistry courses?
  - Own choice?
  - Created your own course?
  - Took someone's course over?

GENERAL: Beliefs on teaching in general, biochemistry

- What are your beliefs about teaching in the field of biochemistry, at the college-university level?
  - What does teaching look like for you?
  - How should it be done in your opinion?
  - What should be the instructor's mindset?
  - Where are you originally from?
  - Do you think your cultural background shapes your beliefs on teaching?
    - Why?
- What factors such as experiences, interactions influenced the development of your teaching beliefs?
  - How so?

Figure 3.3 Continued

  - Where they interactions with teachers, peers, students, first teaching experiences?
  - The courses you have taught?
    - How does your cultural background influence your teaching beliefs, teaching practices?
- Did your beliefs/ideas about teaching change over the course of your career?
  - How so?
  - Why?
- What are teaching goals that you want to achieve when teaching, in general?

GENERAL: Enacted Teaching Practices, Beliefs/ Perceptions

- What experiences/ inspiring interactions have you collected along your career path that influenced your current teaching practices of biochemistry?
  - Maybe first teaching experiences that had an impact?
  - Own teaching experiences when you taught?
  - Experiences you collected when watching others teach, e.g. your time as a student?
  - Other examples you can think of? (volunteer work)
  - How did they differ/ what did you get out of each and why?
- How, if at all, have your teaching practices changed since your first teaching experience?
  - Why?
  - What changes have you noticed?
- Does your style of teaching vary amongst different classes/ class types?
  - Why?
- What role does teaching play for you in your profession?
  - Do you have teaching obligations outside of your job, that you pursue? Informal teaching, volunteer teaching? (Importance of teaching)
- How would you rate the importance of teaching to you?
- In what way do you prepare for teaching?
  - Why?
  - What changes did you experience over the course of your career?
  - Why?
- Which professional development, if at all, have you received during your career?
  - Why/ why not?
  - Do you plan on attending any professional teaching workshops now?
  - In the future?
  - Have you ever had to write a teaching philosophy or a teaching statement?
- What resources were to be helpful for you to make use of? (instructional helper at the department to help improve the course?/ educator in your department that would do mainly help faculty to improve teaching)
- Which professional development resources on teaching on campus are you aware of?
- How do you perceive the teaching of biochemistry being executed at the college-university level (teaching practices)?

Figure 3.3 Continued

- How do other instructors perceive your beliefs?
  - In what ways, if so, do you share them?

<u>Beliefs, Perceptions Held about Teaching Biochemistry/ Actions Taken in Biochemistry Classrooms to Communicate Beliefs and Perceptions</u>
<u>Teaching Methods.</u>

THIS IS ABOUT TEACHING PHILOSOPHIE AND ACTIONS IN CLASS,
as example the one I have observed

Style of teaching, creativity, openness to change, needs that are not fulfilled yet

Specific Teaching Goals/ Beliefs

- What are your beliefs about teaching _________?
- Let's look closer at the course that I observed as a whole:
  - Tell me more about your goals for the course?
    - Any examples that come to mind?
    - In what ways do you achieve that goal/ these goals?
    - This course is taught in a _____________ department, correct?
- How successful do you feel are you in achieving your goals?
  - Why?
  - How so?
  - What would help you to improve these?
- How do you think learning occurs?

Add information from previous observation(s), to use as context and comparison

Add notes on observations, style of teaching, methods, ….

Teaching Techniques- Current State

- What would you describe is your typical style of teaching?
  - Why?

Figure 3.3 Continued

    - What makes you use these techniques?
- How have your practices changed in that course?
- Can you tell me about other techniques that you use?
        - Why do you use these techniques?
- The way you execute teaching, do you think your cultural background influences your actions you take in the classroom?
- Why do you switch between teaching techniques, at different times of the semester or for different topics, if you do?
    - Which would those be?
    - Why?
- Are there any teaching techniques you would like to try?
    - Why do you hesitate?
    - Would you want to have more information on these techniques?
    - How?
- Are there any techniques you don't use/ avoid?
    - Is that topic dependent?
    - Why?

Teaching Techniques- Being Creative

- Have you made any changes to the course while teaching it, specifically?
    - Any time?
    - Why?
    - This time around?
    - Why?
    - In the future?
- Looking back on the years of experience you have…
    - What are you proud of in your course?
    - What do you perceive as challenges when teaching biochemistry?
    - If so, how would you like to change this course?
        - Why?
    - Regarding those changes, what impact in your opinion would changes like these have on student learning?
        - Do you have evidence to support this?
- What are your perceptions on being creative with your teaching, in terms of techniques used within your classroom?
    - Can you be creative?
    - In what ways would you like to be creative, if at all?
    - In the course I have observed.
    - Does anything limit your creativity, if so?
- How do you define active learning?
    - What is active about your classroom?
- In your department, how would you describe the beliefs about innovative teaching, trying new techniques in the classroom?
    - How, if at all, do you feel supported?

Figure 3.3 Continued

- How do you feel supported when and if you implement changes you wanted to?
- In general, if any, what improvements/changes would you want to see happen in regards to your teaching?
  - To receive better support
  - Any structures you would change

Student Learning
ACTIONS RELATED TO BELIEFS HELD ON TEACHING

Role and responsibilities instructor/ students, student-teacher relationship, facilitating student learning

Perception on Teaching Practices/ Impact on Student Learning

- How do you think your students perceive your main teaching methods you are using?
- Do you think your students would want to be exposed to different teaching techniques?
- If you had changed the way you teach, has it an effect on how you access student learning?
- What do you think is motivating your students?

Perception on Roles/ Responsibilities to facilitate student learning

- Can you describe to me how you see your role and responsibilities as a teacher?
  - Has that view changed over the course of your career?
  - Outside of class
  - In class
  - Why?
- What do you think is the role and responsibilities of students as learners?
  - Outside if class
  - In class
- How do you perceive students' interest to learn?
  - Does that change during the course?
  - What influences that? Population, … .
  - Do you think you can influence their success?
- How much, as an instructor, do you believe you have to guide them, help them to learn?
  - Why?
  - In what ways do you establish what knowledge your students bring into your classroom?
  - Are there ways in which you probe for students' ways of understanding during class time?
    - If so, how?
    - And why?

Figure 3.3 Continued

- How do you believe those assessments help your students?
- How do you think your students perceive these assessments?
- Are there certain populations of students you are more likely to try out new things with?
  - How would that student population look like? How would it have to behave?
- What motivates you to have so many different assessment strategies in your classroom?
- Why do you change your assessments in terms of student learning?

Improvements to Teaching.

IMPACT OF TEACHING

Teaching of Biochemistry in 10 years from now

- 10 years from now, where do you see the teaching of biochemistry?
  - Where do you see teaching methods going (lectures)?
  - Where do you see student learning going?
  - Where do you see yourself as a biochemistry instructor?
  - Are there any changes you see that need to happen in the next 10 years?
- What are your hopes and wishes for the outcomes of your course?
  - Now and in the future

Is there anything you feel is important that I haven't touched on this interview?
Would you want to add anything to any topics we have talked about in the past hour?

Thank you very much for all your time.

The conversational aspect of the interview protocol encouraged participants to freely share their experiences and limit any bias from the interviewer (Hagenauer & Volet, 2014). I intended to delve into salient features related to participants' conceptions of teaching. I initiated a conversation using prompting questions, which I intentionally merged periodically. Through this process, I aimed to build rapport, and show respect for and an understanding of their dedication to both their teaching and any challenges they face (Page, 2014). This approach enabled me to uncover a mutual passion for biochemistry education, and the emphasis instructors placed on selecting appropriate material in their respective classes.

3.2.6.2.1 Creating Prompts for Interviews

I shaped my interviews in a hermeneutic fashion, in which the focus was on maintaining a conversation about the human life world, in particular the perceptions and beliefs of biochemistry instructors influencing the decisions in their classrooms (Kvale, 1996). This manifested in the outlined structure of the interview (the three phases), where I first drew on participants' teaching background, when they started and in what context, and then probed their perceptions further on why they teach the way they do, how these perceptions relate to their beliefs effective ways of teaching students and how students learn. I prepared a basic semi-structured interview protocol for each interview. Prompts were modified or added based on the observational notes taken prior to conducting each interview. In addition, each interview protocol was further individualized depending on the information each participant provided, which included teaching background, syllabus, teaching style, teaching philosophy, etc. Questions were tailored towards each participant if a participant employed an evidence-based teaching method in class during observations or mentioned, for example, evidence-based pedagogy in an email about typical or past teaching activities. For example, I added additional follow-up questions to the interview protocol to more efficiently address underlying themes.

To generate prompts and conduct interviews, I followed Patton's recommendations on The Interview Principles and Skills (Patton, 2015). I also relied on helpful suggestions provided by Seidman (2013), who described helpful information about asking questions, such as practicing active listening during interviews (encouraging my participants to elaborate on their thinking processes) and generating follow-up questions in parallel to investigate topics of interest. Because of the semi-structured interview style, I intentionally avoided dichotomous questions that could narrow and/or potentially influence the direction of the responses. My protocol topics were inspired by an interview protocol designed to reveal instructors' views on teaching physical chemistry (Mack, 2015) and biochemistry using analogies (Orgill, 2003). Additionally, I was also inspired by categories describing possible ways and methods of instruction from the COPUS protocol (Smith, Jones, Gilbert, & Wieman, 2013).

In order to establish a rigorous interview protocol, I had several experts in biochemistry education, chemistry education and physical chemistry education provide feedback on its appropriateness for my proposed research questions. I had one full professor in chemistry education, one physical chemistry Ph.D., two biochemistry education graduate students, and one chemistry education graduate student review my interview protocol with me. To test its usability in an interview, I used my interview protocol with both a full professor and an associate professor in physics.

This process of feedback and review provided me with perspective on which questions were repetitive, too narrow or too restrictive in phrasing, and ideas for additional prompts to assess the key themes in which I was interested. Final prompts were compared to guidelines in the teaching philosophy guide by Goodyear and Allchin (1998) as well as resources described earlier in this section.

3.2.6.2.2 Conducting Interviews

Interviews were conducted on- or off-site, depending on whichever method was more convenient for my participants, as well as what was possible for me in terms of distance. I offered in-person interviews, remote interviews using Skype or equivalent software that was convenient for my participants. Software for each participant is highlighted in the right column in Table 3.4. This method of interviewing allowed me to see and hear my participants at the same time, using computer-based audio/video technology (Hanna, 2012). By using both senses, I aimed to stimulate a richer conversation. If in-person or remotely-conducted interviews were not feasible for the participant, I also offered phone interviews as an option. Sometimes, due to technical issues, a combination of different approaches needed to be used. For example, in Dr. Mickey's interview, I started out with Google Hangouts but ended up using Skype, due to technical difficulties with Google Hangouts audio (as shown in the right column of Table 3.4).

Table 3.4 Details on interviews conducted

Participants (pseudonyms)	Gender	Experience	Carnegie Classification Basic	Interviews conducted remotely or in person
Dr. Derrick[a]	male	Associate Professor	Doctoral Universities: Highest Research Activity	In person
Dr. Devora[a]	female	Clinical Assistant Professor	Doctoral Universities: Highest Research Activity	In person
Dr. Duna[a]	female	Professor	Doctoral Universities: Highest Research Activity	In person
Dr. Dixie[a]	female	Assistant Professor	Doctoral Universities: Highest Research Activity	In person
Dr. Donald	male	Professor	Doctoral Universities: Highest Research Activity	Phone
Dr. Danner[a]	male	Associate Professor of Practice	Doctoral Universities: Highest Research Activity	In person
Dr. Dana[a]	female	Assistant Professor	Doctoral Universities: Highest Research Activity	In person
Dr. Dalton	male	Professor	Doctoral Universities: Higher Research Activity	Phone
Dr. Dolly	female	Senior lecturer	Doctoral Universities: Higher Research Activity	Google hangouts/Skype
Dr. Donna	female	Assistant Professor	Doctoral university: moderate research activity	Google hangouts/Skype
Dr. Magnus[a]	male	Professor	Master's Colleges & Universities: Larger Programs	Google hangouts/Skype
Dr.Manju	male	Instructor	Master's Colleges & Universities: Larger Programs	Phone
Dr. Maggie[a]	female	Professor	Master's Colleges & Universities: Larger Programs	Google hangouts/Skype
Dr. Mickey	male	Assistant Professor	Master's Colleges & Universities: Small Programs	Google hangouts/Skype
Dr. Brigid	female	Professor	Baccalaureate Colleges: Arts & Sciences Focus	Google hangouts/Skype

Table 3.4 Continued

Dr. Berry	female	Associate Professor	Baccalaureate Colleges: Arts & Sciences Focus	Phone/Skype
Dr. Bobbie	female	Associate Professor	Baccalaureate Colleges: Diverse Fields	Google hangouts/Skype

[a]Participants are from same institution

As with the data collection for the observations, each interview was audio-recorded using a Drift Ghost-S Professional HD Action Camera, as well as with a hand-held Olympus digital voice recorder DS-40. Two devices were used, in case one would fail. Interviews were later transcribed for data analysis purposes. In contrast to the data collection process for observations, the video option of the camera was switched off and only audio recordings were taken.

Each interview was approximately one and a half hour in length. Since follow-up interviews often enrich analysis, I considered additional rounds of interviews if I needed to clarify questions from previous interview sessions. Each participant was interviewed at least twice, with the second interview being a follow-up visit involving member-checking. This visit was consequently performed once interviewing was completed for each individual participant (Birt, Scott, Cavers, Campbell, & Walter, 2016; Carlson, 2010). Depending on the location of the institution and the availability, follow-up interviews were performed via email, phone or in person.

Interviews were conducted in a timely manner after the observation had taken place at a time that was convenient for the participant. I mainly referred to the overall teaching methods they used in the class period observed.

3.2.6.3 Other Data Sources

Observations and interviews were accompanied by artifacts presented and used during observed class periods (e.g. PowerPoint presentations, handouts, lecture notes, white board notes). I collected all available data sources and asked instructors to share them with me when observational data was collected. This was useful if, for example, the instructor chose to highlight a teaching task using slides or on the board, while verbalizing it during class. In this scenario, it was beneficial to have the documents used in class in order to reconstruct the scenario as accurately as possible. Ultimately, only additional data that aided in answering my guiding research questions was analyzed.

During interviews, I kept any notes or drawings participants chose to generate and agreed to share with me, as well as any representations or teaching material they wanted me to add to the interview protocol to support the points they discussed. These additional data sources provided further insight into their perceptions, beliefs and actions to teach biochemistry.

3.2.7 Data Analysis

For the data analysis portion of my study, I used the hermeneutic cycle or spiral "… to facilitate understanding and to generate holistic meaning from specific components embedded within qualitative data" (Bodner & Orgill, 2007). I, as the researcher, continuously cycled through the data I collected, any related research, and interpretations that I had made earlier to better understand the phenomenon under study. The hermeneutic cycle closes when "… the specific parts of the data can be interpreted within a greater whole…" (Bodner & Orgill, 2007) to meet the ultimate goal in hermeneutic inquiry "to construct a coherent interpretation of the collected performances, continually revising initial interpretations until they account for all of the available evidence" (Moss, 1994, p. 5).

Since the hermeneutic cycle has not been extensively outlined in Gadamer's work, I incorporated another data analysis method to enrich the process of analyzing my data: a general inductive approach for analyzing qualitative evaluation data (Thomas, 2006), summarized in Figure 3.4. This technique follows the same criteria as Gadamer's hermeneutic cycle: "allow research findings to emerge from the frequent, dominant, or significant themes inherent in raw data, without the restraints imposed by structural methodologies" (Thomas, 2006, p. 238). The key similarity between the hermeneutic cycle and the general inductive approach is the common goal of understanding the larger themes in order to represent all participants' experiences and opinions, using multiple steps of interpretations of the raw data. In my case, this meant that I read through my notes taken during observations, and transcripts repeatedly to condense my data corpus to its quintessential meaning. The general inductive approach provided me with guidelines to reveal the main themes emerging from my phenomenon of choice.

Figure 3.4 highlights the coding process of the general inductive approach. Each step of narrowing categories and merging them into larger themes was enriched by application of the hermeneutic cycle, since multiple iterations through the raw data were needed to understand the phenomenon being studied: in my case beliefs, perceptions, and actions.

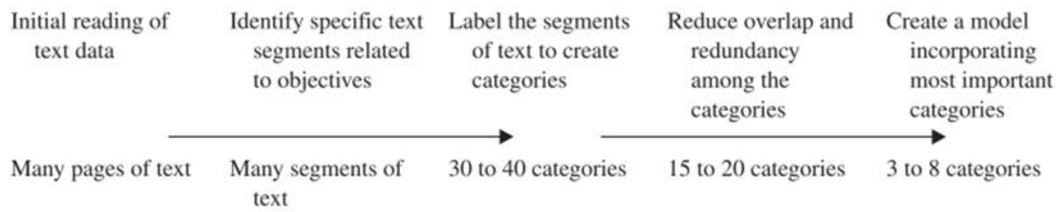

Figure 3.4 The general inductive coding process in inductive analysis. Original diagram from Thomas (2006, p. 242, Table 2)

This method was useful, since it supported and enriched the hermeneutic cycle without interrupting the methodological approach. Furthermore, the inductive approach elaborated upon more possible steps of analysis within the hermeneutic cycle, and enabled me to condense the amount of data emerging from the data. Eventually, major categories will result through this process and overall implications from the data can be drawn.

I will now highlight how I used each of the previously mentioned analysis tools on each of my data sources separately, since both the general inductive method and the hermeneutic cycle fulfilled different roles within my analysis.

3.2.7.1 Observations and Other Data

The data analysis begins with the first encounter and experience with the data in the hermeneutic approach (e.g. Gadamer, 2000; Laverty, 2003). For my study, the first encounter was during the first classroom observation of each instructor. By observing my participants within their professional environments, I gained initial insight into how they used their actions to convey their beliefs and perceptions. Customizing the interview protocol to each participant was an important step prior to my initial data analysis. Thanks to this customization, I was able to later compare participant responses during the interview to the actions participants took during the observed class period.

After each observed class period, I typed up my observational notes. I also watched my recordings to further analyze each instructor's use of teaching methods during their class period. The analysis was of qualitative nature, using the inductive analysis approach as mentioned above to analyze actions used in class (Figure 3.4). Observations were coded using the InqScribe software, which allows allocation of time points to each coded part of the observation analyzed. No verbatim transcription was needed for the observational data sources, since they were not the primary data source and were only collected for clarification purposes. Additional data sources, such as syllabi, in-class materials, and statements of teaching philosophies, where analyzed using the NVIVO 11 coding software. All data collected were coded in NVIVO 11 with the codes provided in Table 3.5. All codes were summarized in a separate worksheet within NVIVO 11 for each participant included in this study. This process allowed me investigate data under a given code from all participants at once to generate patterns of differences and similarities.

3.2.7.2 Interviews

Interviews are a widely known and used method to gain more insight into peoples' situations and thoughts. They have become part of the common culture and the richness of qualitative research. Furthermore, we live in an "interview society", where we focus on the projection of both the self and of others (Atkinson & Silverman, 1997; Ferrarotti, 1981, pp. 19-27). The interview protocol was shaped in a hermeneutic fashion where the purpose and focus were placed on holding a conversation about each participant's 'human life'. Through the transcription of my interviews, I turned the oral discourse into written text that was then interpreted (Kvale, 1996). Through the combination of the hermeneutic cycle and inductive analysis, I was able to build and interpret the text. All interviews were transcribed verbatim through rev.com and checked by me, the researcher, for accuracy and completeness. This process was followed by coding of the data using NVivo 11. For member-checking purposes, each interviewee was provided with the interview transcribed and inferences I drew from the provided personal data sets.

3.2.7.3 Widening the Scope - Adding an Additional Lens to Interpret Results on Biochemistry Teaching Methods and their Broader Impacts on Student Engagement

During the entire analysis process, I wrote reflection memos as described by Corbin and Strauss (2008) about data collection and analysis steps for each participant. This process made me aware of bias, and provided greater understanding of the data collected. I employed a systematic comparison approach to interview documents and other data sources to gain further insight into themes and the actual dimension of the data set, as well as controlling my bias (Patton, 2002, p. 488).

Through the use of various data sources, I was able to gain a rich understanding about my participants' beliefs, perceptions and actions when teaching biochemistry. However, to further elucidate the teaching methodologies used in biochemistry lectures, I needed an additional source to contextualize my results and add more depth to their interpretation. In particular, I wanted to elaborate on in how my instructors possibly incorporated/influenced their students by their choices on teaching methods within their respective classrooms. I needed a lens through which I could view my data to further make inferences on the student populations and possible effects on their learning through the variety of teaching strategies used in biochemistry teaching. When consulting the literature, I found one newly developed approach on interpreting classroom teaching landscapes and their possible impact on student involvement and presumable learning outcomes to be suited well for this study: The Interactive, Constructive, Active, and Passive framework (ICAP), by Chi and Wylie (2014). This framework operates under the assumption of four different cognitive engagement categories through distinct student in-class behavior (student modes of engagement). Within this model, the possible modes of student engagement are either categorized as passive, active, constructive, or interactive, with the passive mode (e.g. listening to lectures) offering the least engagement, and the interactive mode (e.g. in-class discussions, group work opportunities) offering the most involved student mode of engagement. Details on which teaching methodologies corresponded to which mode of student engagement are highlighted in Figure 3.5 (excerpt from Chi & Wylie, 2014, p. 221).

TABLE 1
Examples of Learning Activities by Mode of Engagement

	PASSIVE *Receiving*	ACTIVE *Manipulating*	CONSTRUCTIVE *Generating*	INTERACTIVE *Dialoguing*
LISTENING to a lecture	Listening without doing anything else but oriented toward instruction	Repeating or rehearsing; Copying solution steps; Taking verbatim notes	Reflecting out-loud; Drawing concept maps; Asking questions	Defending and arguing a position in dyads or small group
READING a text	Reading entire text passages silently/aloud without doing anything else	Underlining or highlighting; Summarizing by copy-and-delete	Self-explaining; Integrating across texts; Taking notes in one's own words	Asking and answering comprehension questions with a partner
OBSERVING a video	Watching the video without doing anything else	Manipulating the tape by pausing, playing, fast-forward, rewind	Explaining concepts in the video; Comparing and contrasting to prior knowledge or other materials	Debating with a peer about the justifications; Discussing similarities & differences

Figure 3.5 Examples of learning activities by mode of engagement through the lens of the ICAP model. Original table from Chi and Wylie (2014, p. 221, Table 1)

For example, when listening to a lecture, students can either be passively (only listening), actively (taking notes in own words), constructively (asking questions), or interactively (defending and arguing) involved in the classroom. Through the lens of the ICAP model, student involvement is purely based on the actions students execute during a lecture. However, students can only carry out certain actions if instructors provide the basis for allowing a certain mode of engagement within the lecture, as supported by Chi and Wylie (2014). In relation to my study, I investigated instructors' actions and made claims on the actions of instructors that resulted in particular student modes of engagement, based on the teaching methodologies that instructors used in class. Throughout this study, I use the ICAP framework as a model, since I intended to use it to provide me with an additional layer of insight on what potential impact biochemistry instructors could possibly have on student learning through the particular teaching styles they displayed in class. Chi and Wylie (2014) built their framework on the hypothesis that a greater level of student engagement in class will result in greater student learning. Each mode of engagement gives rise to certain levels of learning, as highlighted earlier in this section. Furthermore, the ICAP framework predicts that the more active are students in the classroom, the more learning occurs in class. Chi and Wylie (2014) state student learning improves around 8-10% with each mode of engagement. Figure 3.6 (excerpt out of Chi & Wylie, 2014, p. 228) illustrates the hypothesized learning outcomes related to each student mode of engagement. Learning gains are suggested to be largest in the interactive student mode of engagement (see last row in Figure 3.6). However, the authors of the ICAP model highlight that it "is a hypothesis about the relative level learning associated with each of these four modes of student engagement (Chi & Wylie, 2014, p. 240). Chi (2009) and Chi and Wylie (2014) attempted to collect empirical data and validate their suggested student modes of engagement and their effects on student learning. They accomplished this by identifying studies from the literature in both lecture and laboratory settings that reported results on the level of student engagement and their learning outcomes aligning with the ICAP postulations, and reinterpreted these interventions using the ICAP framework. The ICAP hypothesis was further validated by work of Menekşe (2012), and extrapolated by Menekşe, Stump, Krause, and Chi (2013). Results from this dissertation support the ICAP student modes of engagement and their associated learning gains.

TABLE 2

Example Activities, Knowledge-Change Processes, Knowledge Changes, Cognitive Outcomes, and Learning Outcome by Mode of Engagement

CATEGORY *Characteristic*	PASSIVE *Receiving*	ACTIVE *Manipulating*	CONSTRUCTIVE *Generating*	INTERACTIVE *Dialoguing*
Example activities	Listening to explanations; Watching a video	Taking verbatim notes; Highlighting sentences	Self-explaining; Comparing and contrasting	Discussing with a peer; Drawing a diagram with a partner
Knowledge-change processes	Isolated "storing" processes in which information is stored episodically in encapsulated form without embedding it in a relevant schema, no integration	"Integrating" processes in which the selected & emphasized information activates prior knowledge & schema, & new information can be assimilated into the activated schema.	"Inferring" processes include: integrating new information with prior knowledge; inferring new knowledge; connecting, comparing & contrasting different pieces of new information to infer new knowledge; analogizing, generalizing, reflecting on conditions of a procedure, explaining why something works.	"Co-inferring" processes involve both partners taking turns mutually creating. This mutuality further benefits from opportunities & processes to incorporate feedback, to entertain new ideas, alternative perspectives, new directions, etc.
Expected changes in knowledge	New knowledge is stored, but stored in an encapsulated way.	Existing schema is more complete, coherent, salient, and strengthened.	New inferences create new knowledge beyond what was encoded, thus existing schema may become more enriched; procedures may be elaborated with meaning, rationale and justifications; and mental models may be accommodated; and schema may be linked with other schemas.	New knowledge and perspectives can emerge from co-creating knowledge that neither partner knew.
Expected cognitive outcomes	Recall: knowledge can be recalled verbatim in identical context (e.g., reuse the same procedure or explanation for identical problems or concepts).	Apply: knowledge can be applied to similar but non-identical contexts (i.e., similar problems or concepts that need to be explained)	Transfer: knowledge of procedures can be applied to a novel context or distant problem; knowledge of concepts permit interpretation & explanations of new concepts.	Co-create: knowledge and perspectives can allow partners to invent new products, interpretations, procedures, and ideas.
Learning outcomes: ICAP	Minimal understanding	Shallow understanding	Deep understanding, potential for transfer	Deepest understanding, potential to innovate novel ideas

Figure 3.6 Additional analysis coding schema, ICAP Model. Chi and Wylie (2014, p. 228)

I used the ICAP model at the very end of my data analysis, after I had conducted observations, collected artifacts and interviews were held. Within this interpretative process, I incorporated results from the observational data as well as interview data.

This analysis step gave insight into the potential degree of engagement each instructor was able to foster. In addition, it also offered a richer understanding about discrepancies and challenges associated with their intentions, based on my interpretation on if their classroom activities give rise to an environment of a given student engagement mode. Adding this step of analysis to my interpretation of the data enriched my understanding of the data that I was able to gain from my interviews and observations. With this view, I framed the results in the context of our current knowledge on teaching and learning through the lens of the ICAP model.

3.2.7.4 Development of Codes

The development of the main codebook to analyze interviews was an iterative process, using the combination of hermeneutic spiral/cycle and the general inductive analysis approach as visualized in Figure 3.7 and outlined above. I first used the inductive analysis approach, to analyze my interviews, observations, artifacts and memos, and generate codes. The majority of codes were generated from interview analysis, since that source of data offered the richest insight. However, main codes that emerged from the interview transcripts were supported by observational data and artifacts. By using the hermeneutic spiral, I iteratively revisited all data sources to ensure no evidence was overlooked and that no emergent themes were left uncovered. Using the inductive analysis approach in parallel, I merged similar codes, identified repetitive codes and excluded codes that did not reflect my research focus. This was done to ultimately eliminate any codes that represented and encompassed similar themes emerging from the data.

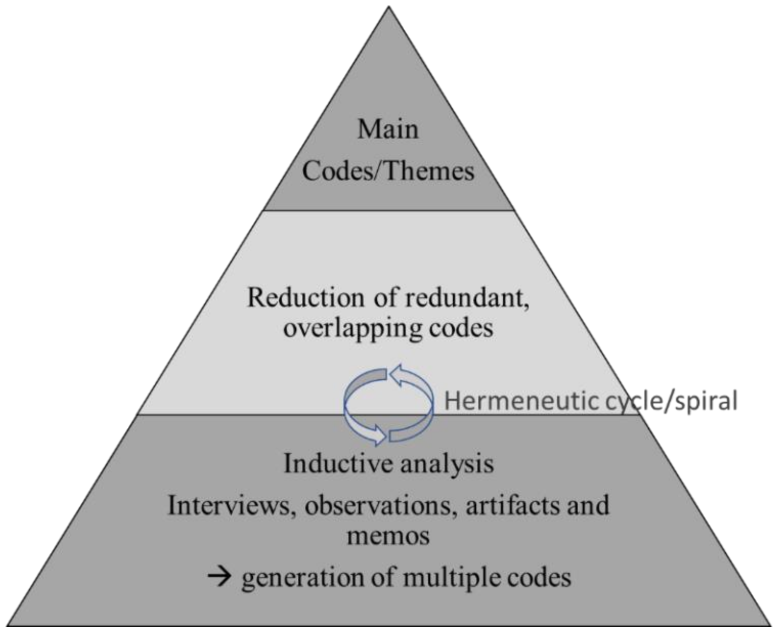

Figure 3.7 Overview on the development of codes during data analysis

Ultimately, 19 main codes resulted from the data analysis process described above. Table 3.5 outlines these codes and their descriptions. All descriptions given in the following table originated from what I observed in the data across all participants.

Table 3.5 Emerging codes from interview analysis

Interview-based code/ Broad themes used in NVIVO for coding	**Description of Code** (from the perspective of the instructor interviewed)
Analogies	Analogies used for teaching mentioned in some ways
Assessments	All types of forms: e.g. Pre-/Post, in class, out of class Trying our different types of assessments, changing assessments Challenges mentioned in terms of assessments Reflecting on assessments (quality, usefulness, …) Instructor's perception on what students think about them What do students think of them (student evaluation/feedback) Gaging success through assessments
Future of teaching biochemistry	Methods used in the future when teaching Trends on teaching biochemistry in the future/ Expectations Changes that need to happen in the future Hopes and wishes for the future in regard to teaching biochemistry Challenges to face when wanting to make changes for the future
Professional development	Workshops on teaching attended Read up on things related to teaching on their own Awareness on availability of resources for professional development centered around education in their field Wanting more Ever written a teaching philosophy Future plans on taking professional development courses, reading up on literature (Improvements to make (reading up on learning theories, …)) Wishes of more or different professional development offers Challenges seen with professional development Support needed

Table 3.5 Continued

Student role	Responsibilities as a student Challenges for students Students' interest to learn Students' motivation Understanding of students' ways of learning
Teacher interest to teach	Interest to teach Motivation
Teacher role	Responsibilities as a teacher Guidance for students Interplay between teacher and students
Teaching – role of importance	Priority of teaching vs. research Professional (in position they are in) vs. personal (own views) importance/role of teaching Challenges that come with teaching obligations for position
Teaching background	Teaching experience in general, courses taught before Why courses were taught Courses created Experience with teaching in general, appointment they are at right now
Teaching beliefs	How teaching should be done, non-methodological, theoretical Why biochemistry should be taught Change of teaching beliefs over time Value of teaching/Reward/Essence Self-expectations Self-portrayal as a teacher and scientist
Teaching beliefs - influences	What influenced their teaching beliefs (experiences, peers, cultural background) Reasons for why beliefs are how they are

Table 3.5 Continue

Teaching goals	What to be achieved in classrooms, when teaching Success of achieving goals? Turn-out in class, proud of achievements in class Being proud of course(s)/ teaching achievements in classes Challenges faced when teaching Awareness of challenges for students, course objectives, learning objectives
Teaching improvements	Efforts made towards improving teaching in general (Non-methodological) improvements, focusing on how one can act differently, be more respectful, mention certain things. Not necessarily focusing on adding more handouts, more powerpoints, … Awareness Necessity Willingness
Teaching methods	Methods that are already used for teaching, typical style of teaching, in different courses; analogies, description of content Definition of active learning Non-traditional teaching methods Effects on student learning, challenges encountered when using the current methods Practices in the classroom (ppt, group work, …) Student perception Change of teaching methods over time, due to different student population, … Barrier of enacting the ones used already Challenges associated with teaching methods used
Teaching methods – creativity	Creating courses, past and future Trying out new methods that have not been used yet Barriers in trying out new methods (technical, students' dislike, personal …) Challenges trying out new methods Changes to course(s), in-time fixes while teaching is going on, material added (e.g. to .ppt) Thoughts on effects on student learning Willingness/Openness to make changes

Table 3.5 Continued

Teaching methods - improvement	Efforts, Challenges associated with these improvements Improvements on teaching related to the course observed Methodological improvements for future Awareness Necessity Willingness
Teaching methods - influences	What influenced their teaching methods used (experiences, peers, cultural background)
Teaching methods – transparency	Transparency of the instructor to his students and telling why a method is used in class If the instructor tells if a specific method is used in class
Teaching preparation	Preparation of classes Preparedness for classes

3.2.8 Role of Researcher

As the qualitative researcher and primary data-collection instrument, I was in charge of the collection and analysis of all data. Within this study, I observed instructors during class periods, took notes while observing, conducted interviews, and transcribed and interpreted all the data.

During my bachelor's studies, I realized I wanted to inspire people with my passion for science through teaching. I received a Bachelor of Science degree in molecular and cellular biology from Heidelberg University in Germany and continued on to obtain a teaching degree in chemistry and biology at the same university. This teaching degree qualifies me to teach students at all high school levels in Germany.

Conveying knowledge through passion starts in the classroom, where concepts ideally become visible and are no longer only hypothetical constructs. The visibility of concepts depends strongly on the way the content is conveyed. I experienced this in a course at Heidelberg University, where I developed a curriculum on how to teach nanomaterials to students at the high school level. During this assignment, I had to learn how to communicate through a multiple-lecture lesson plan. I was exposed to making decisions about which teaching methods were the best to use and which ones did not work as well.

I then taught at a high school for six months, as well as at a university for applied sciences in Germany for one year to hone my teaching skills. These teaching experiences were of great help for the observations I conducted in this study. In particular, they made me aware that different groups of learners and different topics require different instructional techniques. This knowledge enabled me to be sensitive to the aspects of their teaching styles and environments that my participants discussed during the interviews.

I have acquired the content knowledge needed for this dissertation project through various biochemistry and chemistry courses that I have taken throughout my educational career, from earning a bachelor's degree to pursuing a doctoral degree in chemistry. In addition to discipline-specific courses and teaching courses, I also completed doctoral-level courses in psychology, education, and qualitative and quantitative research methods, all of which contributed to my qualifications as the primary researcher.

Since this study was based on interview data, I also benefitted from the previous education-related studies in which I have participated, where interviews were the primary method of data collection. Through this experience, I was able to hone my interviewing and analysis skills, which enriched this research study significantly.

Along my educational path, I was able to combine my passion for science and teaching. Pursuing a Ph.D. at Purdue University in chemistry education gave me the opportunity to investigate the instructor-student relationships from a researcher's perspective. Since I have had experiences as both an instructor and a student I am passionate about being an active part of improving biochemistry education in institutions of higher education.

Lastly, I acknowledge the fact that, within the theoretical framework of hermeneutics, it is essential to be aware of one's own experiences and how they influence the interpretation of text (Gadamer, 2000; Laverty, 2003). This so-called 'fusion of horizons' is a key element of hermeneutics. I needed to acknowledge this fusion throughout the study, especially when collecting and analyzing the data.

The goal of this study was to understand instructors' perspectives on teaching biochemistry without being influenced by my own teaching philosophies. This was difficult due to my role as "researcher as instrument", so I needed to be aware of my biases throughout this study. To achieve this, I continuously reflected on my own beliefs and perceptions as a means to not subconsciously influence my participants. I was aware of the fact that, having teaching experience both at the high school and university level, I brought in bias that might prevent me from gathering data objectively. However, hermeneutics actively appreciates the context of my participants as well as my own. In order to limit my bias and conduct rigorous research, I practiced constant reflection through careful documentation of my own experiences after each observation and interview (Corbin & Strauss, 2008). I repeatedly consulted literature related to my theoretical framework and methods throughout my study to make informed choices and to be aware of the bias of interpretation that I brought into this study.

3.2.9 Validity and Reliability

The main way that I ensured that I collected valid data was through member-checking (Lincoln & Guba, 1985). After each transcription, I shared the transcripts with my participants to ensure that I quoted them correctly and that they were comfortable with what was said and recorded within the transcripts. In addition, I went through the main themes that I saw emerging from the data with my participants individually to see if I reflected their own perspective accurately. This happened ideally during member-checking. If participants were not available or preferred other methods of communication, I emailed them or talked to them on the phone or via Skype, Google Hangouts or any other software they preferred. In total, over half of my participants replied to my member-checking request, of which only two participants requested minor changes to the results and my interpretation. Overall, my interpretation of results was consistent with my participants views. However, to account for everyone's views, every participant's feedback and response was included in the analysis process when interpreting the data. For instance, one of the suggestions Dr. Derrick made was the following:

> First, even if my interview did not convey this, I do feel that in my "Teacher role" I act as a "facilitator for success" as well as being a motivator and communicator as you had indicated. (Dr. Derrick, member-checking, first response)

He pointed out that his interview did not stress enough the teacher roles he felt he fulfilled in the classroom. When interpreting the results, I took that additional feedback into consideration and included it within the analysis process. I also tried to build a strong base of validity by triangulating observations, interviews and additional data sources (Creswell, 2013). In addition, as already mentioned in the section 'Role of the Researcher', after each observation and interview I accounted for bias and possible misinterpretation by practicing constant reflection through the use of memos (Corbin & Strauss, 2008). This process also allowed me to constantly reflect on my data and collect more until saturation was reached (Patton, 2015, p. 271, exhibit 5.8).

For reliability purposes, I performed investigator triangulation (Patton, 2002). I carried out peer-review through asking two more graduate students with similar backgrounds to mine to review the results that evolved during the inductive analysis process, as well as one graduate student with a physical chemistry background. This process was used as a second opinion for my coding scheme to ensure avoiding a possible bias that could have been brought into the analysis process by my coding, which would have hindered me from interpreting the data in its most reliable way. Two out of the three previously mentioned graduate student researchers reviewed excerpts of my codebook, coded data, and raw data to confirm if my coding scheme aligned with the phenomena present in the data. Interpretations were discussed until consensus was reached, to ensure reliability within my data analysis. This method of ensuring validity and reliability aligns with the hermeneutical idea that interpretations heavily rely on the experiences the researcher brings into the study. Everyone who reviewed my data and interpreted my results provided me with a background statement about their educational background and views on teaching and learning. This allowed me to view their interpretation within the context of their experience, education and viewpoints. These statements were also considered when discussing our analysis with one another. In this study, peer review helped to further develop the codebook. In most cases, if discrepancy in assigning codes to raw data was encountered, adjustments were made through either merging codes, or clarification of code descriptions. If multiple codes were used to code a certain set of data by multiple reviewers, codes were discussed together when interpreting and analyzing data (Figure 3.8). This process allowed me to account for bias and ensured reliable coding of data.

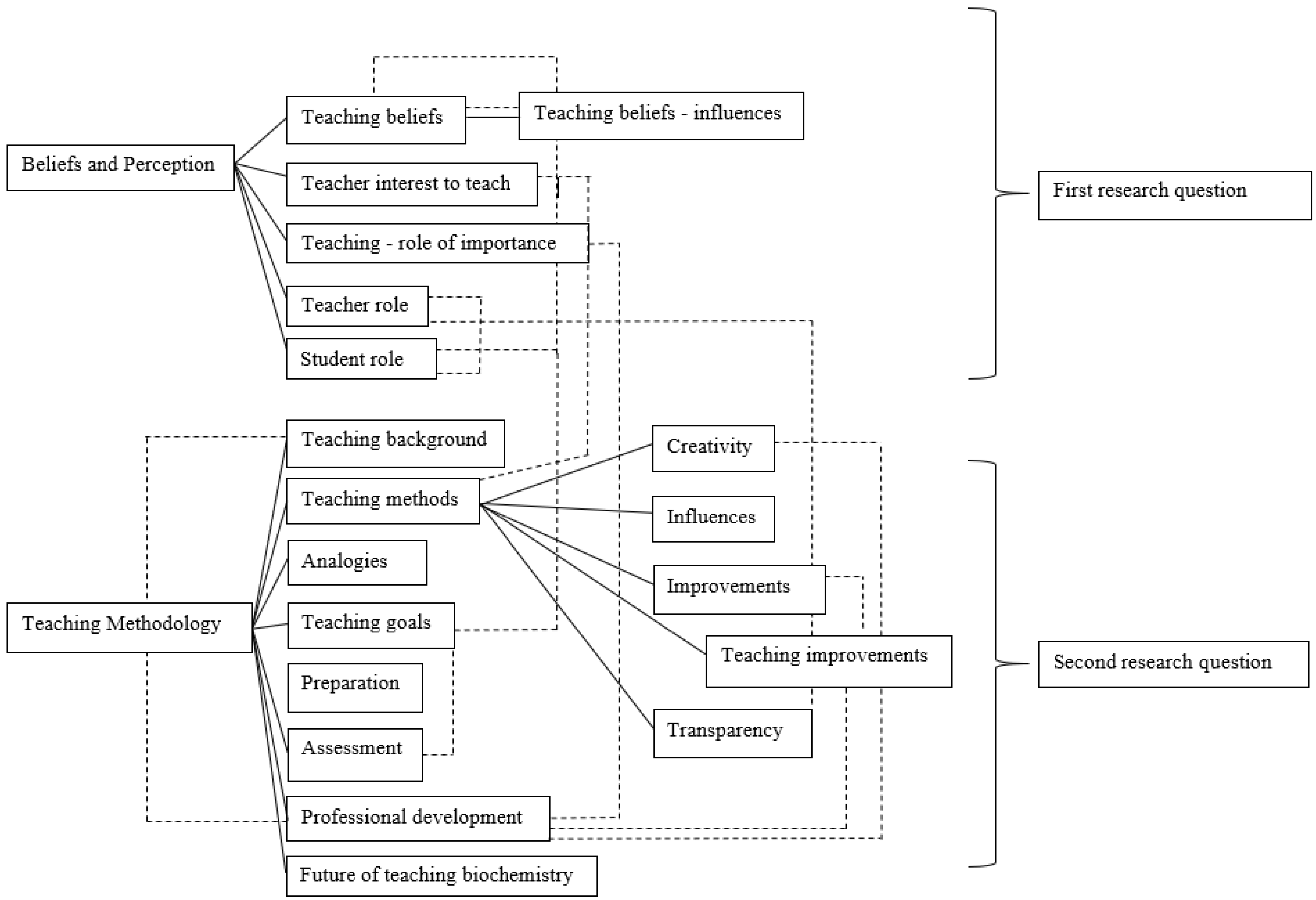

Figure 3.8 Overview on code relationships of major codes developed.

In order to have my data deemed trustworthy, I presented it in a rich and thorough form, by including many quotations to best reflect the interviewees' opinions and views. Along with thorough descriptions of my interpretation and conclusions, I hoped to provide enough information to the reader to relate the cases to their own experiences or situations, to provide the platform for them to use their own judgment about how closely the results apply to related situations in their own teaching practices. According to Guba (1981), results are deemed trustworthy if readers are able to work with the provided descriptions and are able to recognize or reinterpret them.

3.2.10 Limitations

I anticipated several limitations associated with this study:

- Based on whether I was able to conduct observation and interviews remotely or in person, the quality of audio and video varied. However, the benefit of collecting data and enriching my pool of participants outweighed the disadvantages of technical challenges.
- Interpretations of instructors' experiences were led by my own past experiences. As such, I may have only identified a subset of instructors' beliefs and perceptions due to how my past experiences influenced my observational note-taking and interviewing. To account for these risks, I performed the validity and reliability measures described above.

- I was restricted from making broader claims on the beliefs, perceptions, and actions on teaching biochemistry by the aggregated characteristics of the participants I was able to gather for this research study. Therefore, I continuously recruited participants to enlarge my sample size until saturation was reached.

3.2.11 Ethical Considerations

Approval to pursue this research was granted by the Institutional Review Board (IRB) at Purdue University under the protocol title Beliefs and Perceptions About Teaching Biochemistry. The protocol number is # 1702018752 (see Appendix). If any changes were made, an amendment to the already existing protocol was filed through the IRB online program COEUS (see Appendix). Before visiting classrooms or conducting interviews, I sent out information sheets, filed within the IRB protocol, to inform my participants adequately about the study they were involved in. In addition, at the time of collecting observations and/or conducting interviews, I handed out another copy of the information sheets to ensure effective communication of study information. When contacting potential participants at other institutions, I checked with the IRB at the participant's institution to follow all institution-specific guidelines as well when conducting research with human subjects. Additional steps required by off-campus IRBs were taken when necessary.

CHAPTER 4. RESULTS ON PERCEPTIONS, BELIEFS AND ACTIONS INSTRUCTORS TAKE WHEN TEACHING BIOCHEMISTRY

4.1 How to Read this Chapter

To better structure this chapter, I chose to address the results relate to each research question separately. For every research question, I first restate the question itself and the context in which I addressed it. Next, I chose to represent the results in two ways: results addressing a certain research question were summarized in an overview table and elaborated upon in more detail right after each table, to highlight the accompanying summary of salient points. A detailed description of all results including major and minor themes from each table will be presented as well. At the very end of each research question, I follow up with a summary of major results addressing each research question again. Throughout my results chapter, I highlight the origin of each quote, so that it is clear how I made certain claims, drew certain inferences, and extracted the various insights that my participants offered.

Table 3.5 illustrates the major codes identified through the inductive analysis process within this study, as highlighted in Chapter 3. As illustrated in the aforementioned chapter, most data presented in this chapter is drawn from interviews. Artifacts (e.g. teaching philosophies, email communication) are included as needed to support categories and themes extracted from the data set. Each coded interview and artifact was continuously checked for the codes emerging during the analysis process. This represented one way of spiraling through my data, using Gadamer's hermeneutic analysis approach summarized in Figure 3.7, which provided an overview of the approach to data analysis and interpretation of results on this study. Some tables that are incorporated in this results chapter directly resemble codes used during the coding process (e.g.,Figure 3.8), other tables were created based on multiple codes that were combined based on their relationships, illustrated in Figure 3.8. For instance, Table 4.15 was created based on multiple codes, such as “teaching-role of importance”, “teaching goals”, and “teaching methods”. When introducing each table, I will specify which codes were used to further identify categories and themes within the data collected. Those codes often revealed similar themes and were combined according to the relationships outlined in Figure 3.8, unless stated otherwise. Within tables in this chapter, categories and themes were further distilled from the codes in more detail to classify beliefs/perceptions and actions.

While this chapter primarily presents the results emerging from the data, results will be further discussed and set into relation to one and another in the subsequent discussion section. Due to the various amount of results that originated from this exploratory research study, I found it to be beneficial to present all the results first followed by a discussion of these results.

4.2 Addressing the First Research Question

Henderson (2002) argued that teachers’ personal views, beliefs, and perceptions of teaching influence instruction. Beliefs can also drive the teacher’s actions, and teaching experiences can lead to changes in beliefs (Richardson, 1996). I therefore chose to investigate beliefs and perceptions to better understand actions taken in the classroom. Results are presented, addressing the following first research question:

> What are biochemistry instructors’ perceptions and beliefs about teaching biochemistry at the college-university level?

Because of the emphasis of this particular research question, I was especially interested in what instructors' personal beliefs were around the teaching of biochemistry, as well as in how they perceived the influences and factors that ultimately helped shape those beliefs.

4.2.1 Detailed Description of Results Addressing the First Research Question

Within this section, I will highlight categories and themes addressing the first research question in more depth. The following topics about teaching biochemistry will be discussed in more detail:

- Beliefs about teaching.
- Influences of beliefs on teaching.
- Instructor interest in teaching.
- Goals.
- Perceived success and measurement methods.
- Biochemistry instructors' perceptions on their roles in teaching biochemistry.
- Instructors' opinions on students' roles in biochemistry classes.

Each section will start with an overview table on its respective results, which will be presented in more detail below each table.

4.2.1.1 Beliefs about Teaching Biochemistry – an Emphasis on Utilitarianism

The following table will illustrate categories and themes I saw emerging in my data set, centering around beliefs on teaching biochemistry. All beliefs identified addressed, to some extent, the approach that biochemistry should be taught for the greater good. This represented the broader category "utilitarian approach", which revealed further themes that are highlighted below this main category in Table 4.1.

The table generated, originated from the codes "teaching beliefs", "teaching beliefs-influences", and "teaching goals", as illustrated in Figure 3.8. These codes encompassed similar themes that related to instructors' beliefs on teaching biochemistry, that all addressed a similar category, the "utilitarian approach" and were analyzed together.

To help you understand this table better, I will discuss one participant's results and how it can be read and interpreted from the table given below. Dr. Derrick's quotes, for example, represented with an "x" in the first row in the table, expressed the beliefs about how "science is for everyone to understand and enjoy" and "getting the big picture (of the subject taught)" were important for him when teaching biochemistry. Whenever an "x"-appears in the cell of the table, a particular theme (represented by the name of the column) was emerging for a respective participant, and is found on the left of the table. Representative quotes for each "x" are highlighted below the table and further elaborated on.

Adjustments only had to be made for Dr. Derrick after the member-checking process, who believed that "I feel that I place importance on students", "getting the big picture" and "I strive to provide examples in class that enable this goal." Therefore, an "x" was placed for the theme "getting the big picture (of the subject taught)".

Table 4.1 Participants' beliefs on the value of teaching biochemistry for the greater good

Type of institution	Participants	Utilitarian approach (Beliefs of teaching biochemistry for the greater good)						
		Science is for everyone to understand and enjoy	Everyone should have access to knowledge	Science needs to be relevant (e.g. it has to apply to students' everyday life, real world examples)	Science needs to involve (e.g. involve in learning process, make it fun)	Instructor success leads to student success	Getting the big picture (of the subject taught)	Science is challenging
Doctoral granting institutions	Dr. Derrick	x					x	
	Dr. Devora			x				x
	Dr. Duna	x		x			x	
	Dr. Dixie			x				x
	Dr. Donald			x	x	x		
	Dr. Danner			x	x		x	
	Dr. Dana			x	x			
	Dr. Dalton	x		x				
	Dr. Dolly			x				
	Dr. Donna			x		x		x
Master granting institutions	Dr. Magnus				x		x	
	Dr. Manju			x				x
	Dr. Maggie		x	x			x	
	Dr. Mickey			x				
Bachelor granting institutions	Dr. Brigid			x			x	
	Dr. Berry			x	x			x
	Dr. Bobbie			x	x			

When investigating beliefs on teaching biochemistry, the most common belief discussed among instructors involved ideas related to utilitarianism – benefitting as many people as possible for the greater good. This encompassed ideas regarding how everyone should be able to access and enjoy science/knowledge. Dr. Derrick, for example, explicitly verbalized this as his approach to life:

> I have my philosophy of life. It's more or less utilitarianism, which has been expressed as the greatest amount of something called happiness of the greatest

> number of people, I think it is, but I would expand it to the greatest amount of whatever this happiness is for the world in general because I think affecting the world will affect the people who live here. We can't divorce ourselves from that. (Dr. Derrick, interview)

Dr. Donna also emphasized providing real world examples to help student connect better with the material.

> Something that's a major piece of my teaching philosophy. Regardless of who I'm talking to, whoever my audience is, I try to know who my audience is so I can connect. No matter if it's the history of science or I have a whole TMV day on the people who discovered the models of the atoms, very fun, to where do camels get the water to survive in the desert. That's actually context for [inaudible 00:21:11] So I teach all of metabolism in terms of carbohydrate and lipid metabolism in the context of how do diabetics have a service dog to know when their blood sugar is getting low. So, it's kind of phenomenon based but it's always applied. (Dr. Donna, interview)

In addition, to reach utilitarianism, “science needs to involve”, as Dr. Donald emphasized:

> Biochemistry is a subject that has all sorts of medical implications, and probably 95 to 100% of the students in the class are premed or pre-dent or something like that. They're not necessarily interested in biochemistry, but they know it's very important. Professors tend to say, "This is the most important thing. You have to study as hard as you can." I don't like that. I like to get them engaged. They already know it's important, but it's gotta be fun to be able to do it […]. (Dr. Donald, interview)

Dr. Berry phrased her student involvement in the light of having her students struggle in class to master the material:

> My thought on teaching biochemistry is I need to teach students how to learn biochemistry and what the fundamental guiding principles of biochemistry are, so they can go learn the new things that come out in the next 25 years, biochemistry I don't think we've arrived yet. […] I appreciate that it happens in small groups and with students struggling through materials, I think them talking is more effective than me talking. (Dr. Berry, interview)

It goes without saying that approaches to teaching that build on a belief system like those mentioned are rather challenging for students, which was recognized by instructors such as Dr. Berry:

> I try and listen to what they're saying and if I hear things that are wrong, trying to guide them towards the correct idea. Often, I end up saying it just because they've hit the frustration point where they're not learning on their own. They just need to hear what is it? Now that I'm done being frustrated I can move on. It's more listening to what they're saying and less of me talking. (Dr. Berry, interview)

Instructors also believed in the idea of giving student a feel for the big picture in how everything is interconnected in biochemistry and how concepts cannot be seen isolated from one another:

> Oh, what I care about is how it integrates with other pathways and other systems. I teach at a much more integrated level. It's like I'm not going to just look at this in a bubble, in a vacuum. It's like, "Oh, here. Memorize all these reactions." It's like, "For what?" Right? But more how it interacts with other pathways. That's my shtick, because they can go memorize anything on their own. It's more how it's integrated that gets me excited. (Dr. Duna, interview)

Overall, results on instructors' beliefs of teaching biochemistry show a high emphasis on including as many students as possible and making their experiences relevant in the classroom. Many instructors who shared these views also emphasized that science was a challenging concept to understand and getting the big picture was crucial.

4.2.1.2 Influences on Beliefs on Teaching Biochemistry – from Past Educational Influences to Trial and Error Phases in One's Own Classrooms

The investigation of beliefs that centered around the teaching of biochemistry was a challenging endeavor, as instructors usually did not think about what made them teach a particular way. Many differently worded interview questions were used to provide my instructors the opportunity to generate thoughts and memories upon which their teaching beliefs were based and extract the basis on which they built methodologies. Factors that influenced instructors' teaching (as indicated by the participants) were categorized as "non-controllable influences" and "controllable influences", as shown in the table below, Table 4.2. "Non-controllable influences" included familial, cultural, and educational, with educational being the most common theme, as illustrated later in this section. Many instructors voiced the impact of their own education as being an important influence on their current styles of teaching. “Controllable influences” described the choices made when learning about one’s own teaching, either through the experience of teaching or through past experiences in one’s own learning process.

The Table 4.2 was generated, originated from the codes “teaching beliefs”, “teaching beliefs-influences” as illustrated in Figure 3.8. These codes were encompassing similar themes that related to instructors’ influences on their beliefs on teaching biochemistry and were analyzed together.

To help you better understand this table, I will discuss one participant’s results and how it can be read and interpreted from the table given below. Dr. Maggie’s statements related to two themes that emerged in the category “non-controllable influences”, namely “familial influence” and “educational influence”. After member-checking, Dr. Maggie made one addition to the data analysis set provided to her to confirm my interpretation of her views on the influences of teaching:

> I have gained much of my beliefs in teaching biochemistry from years of experience in the classroom. Familial Influence and Educational influence were indeed important, but years of observing what did and did not work both in my classroom and when observing colleagues’ classrooms were seminal in shaping my approach to teaching. I would mark the box under “Controllable influences” to include “Learning by teaching. (Dr. Maggie, member-checking)

Due to this addition an “x” was placed in the theme “learning by teaching” and can be seen in the table below for other participants when certain themes were emerging during data analysis. As before, exemplary quotes will be provided to illustrate each theme in more detail.

Table 4.2 Internal and external influences on beliefs on teaching biochemistry

Type of institution	Participants	Non-controllable influences (influence that was not in their own hands, external)			Controllable influences (influences based on personal choices made)	
		Cultural influence	Familial influence	Educational influence (own education received, role models as teachers)	Learning by teaching (experimenting in one's own classroom)	Learning by learning (experiencing different ways of learning through past education)
Doctoral granting institutions	Dr. Derrick	x		x		
	Dr. Devora			x		x
	Dr. Duna				x	
	Dr. Dixie		x		x	
	Dr. Donald			x		x
	Dr. Danner				x	
	Dr. Dana	x		x		
	Dr. Dalton		x		x	
	Dr. Dolly	x	x	x		
	Dr. Donna	x		x		x
Master granting institutions	Dr. Magnus			x	x	
	Dr. Manju			x	x	
	Dr. Maggie		x	x	x	
	Dr. Mickey			x		
Bachelor granting institutions	Dr. Brigid		x	x		
	Dr. Berry			x	x	
	Dr. Bobbie		x		x	

In order to explain instructors' belief systems in more detail, exemplary cases are highlighted below. In the category "controllable influences", the one most frequent theme that emerged from the data was "learning by teaching". This was true for most instructors who were "thrown" into the job of being an educator, without any instructions and/or education on teaching prior. Overall, looking at all sources of potential teaching beliefs influences among individuals interviewed, themes appeared to be rather diverse.

Dr. Dixie, Dr. Bobbie, and Dr. Dalton were all largely influenced by their familial background and learned teaching on the go. Dr. Dalton further elaborated further on his belief system when he mentioned his daughter as an influential factor in his life:

> Researcher: You also mentioned that your daughter has a learning disability, so probably going with her through the process of different ways of explaining things so she can learn better did inform that process, right?
>
> Dr. Dalton: Yes, I think so. […]. All the time of her growing up, I think it was clear to me that people learn in different ways and you have to kind of adjust your teaching style to fit the learning ability of the kids to learn. That's one aspect of it. (Dr. Dalton, interview)

Here Dr. Dalton noted that watching his daughter learn helped him realize that the ability to learn is a gift that has to be carefully evaluated for everyone and one has to be sensitive to the fact that learning does not come easily to everyone and multiple opportunities have to be established in a class to give everyone a chance to learn their way. In addition to "familial influences," Dr. Dalton's beliefs on teaching biochemistry were shaped by his commitment to always trying to meet students' needs:

> Secondly, I did some teaching over in [oversees] in a rural community, and there again, I think it was clear that not everybody learns in the same way or even with the same language. So, the teaching has to be adjusted accordingly and I have a feeling that probably every lecture is standing up there and trying to gauge whether the students are following the language or whether the language has to be changed in the process. Third, the first place I taught out at [X], taught there for about 10 years, and the faculty members, there was an older arching idea that we, as faculty, were there for the students benefit. Or our goal was basically student oriented, and I think carrying that through is an important part of the situation. Let's see if I can expand on that a little bit. No, maybe I can't. (Dr. Dalton, interview)

Cultural influences were closely associated with educational influences for many instructors (e.g., Dr. Derrick, Dr. Dana, Dr. Dolly, Dr. Donna). As a representative example, Dr. Donna discussed how she grew up in a culture where she always needed to make an effort to explain concepts to her audience in a way they could relate, which made her put an emphasis on application into her teaching:

> […] so, I come from a rural background. My family are a bunch of farmers and so I think that's where the application part comes from. […] my family's farmers. And my cousins, at Christmas are like, "Oh, the chemist. You're so smart." And I'm like, "You do realize you do more chemistry on a daily basis than I do. Out on the farm." […] And so, I think that's part ... Something that's a major piece of my teaching philosophy. Regardless of who I'm talking to, whoever my audience is, I try to know who my audience is so I can connect. No matter if it's the history of science or I have a whole TMV day on the people who discovered the models of the atoms, very fun, to where do camels get the water to survive in the desert. […] So I teach all of metabolism in terms of carbohydrate and lipid metabolism in the context of how do diabetics have a service dog to know when their blood sugar is getting low. So, it's kind of phenomenon based but it's always applied. (Dr. Donna, interview)

Furthermore, her interactions and own educational experiences through her advisor in college shaped her use of application-oriented teaching techniques further: “Yeah, definitely my background in education influences how I teach.” (Dr. Donna, interview) Individual experiences with instructors at college also helped her realize what she valued when learning on her own, and what her students could possibly benefit from when learning biochemistry:

> Specifically, for biochem in grad school. So the reason why I'm so big on the representation, the animation and simulations and stuff like that is because in grad school, I had a biochem professor who was trying to explain ATP synthase without any representation. And are you familiar with ATP synthase? It's my favorite enzyme so the intricacies of it are so beautiful and the engineering and everything like that but he couldn't get it across. And I could not understand what he was talking about to save my life, so I went upstairs and I YouTube'd it and found an animation that I still use to this day that gets the intricacies and the engineering and the energy transfer from chemical potential to mechanical all in one image or one animation. And so that's a direct experience that I had that I try to keep in mind when I teach my students. So, if there's something like a dynamic process, for sure there's animation to go along with it. (Dr. Donna, interview)

As noted previously, many instructors elaborated on experiences from their own education. Dr. Derrick elaborated on his educational experiences as follows, also realizing that he needed to change something in his teaching:

> Well, yeah. So, I was informed by my own experiences and they were very traditional. Professor X would get up and talk for an hour and then you'd go home, and you'd study for a couple of hours to figure out what they said. No, I think we all agree that wasn't a very good way to do it and I think when I arrived here, I thought it would be the same way and I quickly realized it's not like that at all. You really have to engage them and try and try and get them working with each other and talking to each other. (Dr. Derrick, interview)

Dr. Magnus drew from positive and negative examples to shape his ways of teaching:

> […] I had another professor […]. His lectures were not polished at all, which I would say. His exams were extraordinarily impossible to pass, but looking back, I learned more from his class than any other. […] Again, I talked really about being motivated by previous or what influences me, again, looking back on my upper graduate career, a couple professors in particular that I reflected on when I was starting out as teaching, one was my teacher for my freshman biology class. This person was hilarious. […] he was very witty and clever and funny, but I can't say I learned a lot from that class. […] Again, I think it was this idea that writing exams that were very challenging was a learning experience. Taking exams that were very challenging was a learning experience. That was, I think, probably something I got form that. Again, it's probably it's not one of those things that you consciously are aware of. (Dr. Magnus, interview)

Dr. Magnus was also among a few participants who made inferences on their ways of teaching by the ways they learned on their own:

> Again, that comes from my own experience. When I was in college that's the way I would take notes. I had friends who would in the course would come back with four or five, six pages of notes that they took down during class and I would have taken maybe a half a page. All I would have done is sit there and listen. When I understood what the professor was talking about, I would write that down, write down what I understand. I could distill an entire days' worth of lecture into just a half a page of ideas in my own words. That was, I found, really effective. (Dr. Magnus, interview)

One of the major themes identified as influences on instructors' beliefs was their tendency to rely on their own experiences when trying out different ways of teaching in their classrooms. Dr. Duna stated, for example:

> No. It just ... It's very strange because you just get thrown into a room. Sink or teach. You just kind of develop it as you go. It wasn't like oh I went in knowing what I was doing. I had no idea what I was doing. You go and you see what resonates and then if it works you keep doing it. If it doesn't, you stop doing it. You have to be flexible. You have to be willing to change. (Dr. Duna, interview)

It was interesting to see that, although this study involved many participants, the factors identified by participants could be summarized using only a few categories. Major themes that emerged from the data, such as influences from past educational experiences, as well as instructors' tendency to build their belief system through own experiences as students could potentially offer a platform for change of existing beliefs with appropriate measures of PD efforts. I will discuss this idea further in my implications section, where I will link the influences on beliefs and existing belief systems in place with instructors' in-class practices. I will also explore potential ways to motivate the implementation of evidence-based teaching practices further (see Chapter 6).

4.2.1.3 Instructors Interest to Teach – Myriad of Reasons Supporting a Positive Attitude

On the surface there seems to be many reasons why instructors decided to pursue teaching, but they can be distilled into a few common patterns. In this section, I will emphasize identifying the major categories and themes that I was able to distill from the data. Overall, two main categories encompassed participants' responses, "student-centered" and "instructor-centered", as highlighted in Table 4.3 below. In the "student-centered" category, themes emerged that directly benefitted students. In the category "teacher-centered" I summarized all themes that were more of a teacher-centered nature and did not benefit the students.

The table generated below originated from the codes "teaching interest to teach", and "teaching methods" (see Table 3.5). These codes encompassed similar themes that related to instructors' interest to teach, as shown in Figure 3.8. To extract as much information as possible, I analyzed them together.

As previously mentioned, I will highlight one participant's results centering around instructors' interest to teach. In this case, Dr. Maggie's statements indicated her interests to teach were related to both students as well as her own benefits. This instructor mentioned to teach because she can share her fascination about biochemistry with her students (see Table 4.3 "sharing fascination (instructors 'fascination for biochemistry)"), that related to a student-centered motivation on teaching. On the other hand, she also mentioned interest-factors that centered more around teacher-centered benefits such as the themes "love of teaching", and "effectiveness of teaching on learning (interest in teaching outcomes, effectiveness)". After member-checking, she added the following statement, which allowed me to place an "x" for the theme "from hands off lecturer to hands on lecturer (traditional- to non-traditional teaching)": "I might also vote for checking the box under "from hands off lecturer to hands on lecturer." I went from mainly a lecture mode early in my career, to adding more active learning approaches into my classroom. Again, I may be interpreting this category incorrectly."

Inspired by Dr. Maggie's quote above, I want to take the opportunity and talk about the relatedness of the terms *active learning* and *student-centered learning* within this study in more detail, to be explicit about how those terms were used and why. For the purpose of this dissertation, I will use the terms *active learning* and *student-centered learning* somewhat interchangeably. This is consistent with what I observed during interviews with the participants, who seemed to have used these terms interchangeably.

In the table below, present themes that were uncovered during data analysis were marked with an “x” in the table for each participant. Below the following table, I will elaborate further on each theme and major results in this table.

Table 4.3 Instructors interest in teaching

Type of institution	Participants	Student-focused (revolving around students' benefits)							Teacher-focused (revolving around instructors' benefits)						
		Aha moment (moments for students in class when understanding concepts)	Sharing fascination (instructors'fascination for biochemistry)	Sharing knowledge	Educating society (raising informed individuals)	Science is for everyone (reaching all students)	Make a difference/have an impact (on students)	Mentoring (as an essential component to teaching)	Self-education (when preparing classes)	Motivation for own research (through teaching others)	Love of teaching	From hands off lecturer to hands on lecturer (traditional- to non-traditional teaching)	Advancement in position (for one's own career)	Effectiveness of teaching on learning (interest in teaching outcomes, effectiveness)	Feedback/reward (in/outside of classroom observed
Doctoral granting institutions	Dr. Derrick	x				x			x	x					
	Dr. Devora						x					x			x
	Dr. Duna		x				x								x
	Dr. Dixie						x		x	x					x
	Dr. Donald										x	x			
	Dr. Danner								x						x
	Dr. Dana		x							x			x		
	Dr. Dalton		x	x	x										
	Dr. Dolly										x				x
	Dr. Donna	x					x	x			x				

Table 4.3 Continued

Master granting institutions	Dr. Magnus										x				
	Dr. Manju			x							x				x
	Dr. Maggie		x								x	x		x	
	Dr. Mickey		x								x				
Bachelor granting institutions	Dr. Brigid	x							x		x				
	Dr. Berry						x								
	Dr. Bobbie						x		x					x	

Within the "student-focused" category, most instructors discussed sharing their fascination with biochemistry and making a difference in students' lives, as discussed by Dr. Duna:

> I really just taught large enrollment undergrad classes my whole time, which I like because you get a big ... there's a big impact factor. I think that's important. That turned out to be important for me. You know, knowing that what I did actually affected somebody. […] Oh, yeah. Yeah. That's what's really important to me because nobody's going to care exactly what they learned from me, but that I made an impression on them on how to learn, that's more important to me. (Dr. Duna, interview)

Responses were labeled as "instructor-focused" when participants mentioned their personal love of teaching and the related reward associated with teaching, both of which came up frequently. For example, Dr. Maggie stated:

> I love teaching and I love biochemistry. How we work on the molecular level - that we don't keel over on a regular basis needing a reboot - is fascinating to me. The molecular dance that allows us to think, move, and live is elegant, robust, and yet driven by random molecular motions and collisions. How cool is that. (Dr. Maggie, integrative statement for promotion to tenure)

Student feedback was also mentioned as a frequent motivating factor for teaching biochemistry, as stated by Dr. Duna:

> I mean it's a very different reward system than you get in research because it's instant. You can get some instantaneous feedback. With research, it could take months or years or whatever, right? Then you have this personal interaction with these people that you're actually helping them. It's a very different reward system. I value it nearly as equally. (Dr. Duna, interview)

A few instructors also pointed out that teaching helped their own learning. Consider the quotes by Dr. Derrick and Dr. Danner:

> It also, but doing that, it keeps me interested in the field because that's important to be able to do is to stay interested, even when for example my own research program isn't going like gangbusters. It's just knowing that there are other areas out there. There are other groups that are doing amazing things is very important. So, I get a lot of it that way. (Dr. Derrick, interview)

> The other thing is, since I do that every year, I like to change things around somewhat just for my personal benefit, so I don't get bored and learn something new. That's one of the things that I enjoy about teaching that you ... you're sort of educating yourself. You're learning things new again. You have to inform yourself about what's currently being done in that field. (Dr. Danner, interview)

To generalize my results, I want to note that all instructors were enthusiastic and positive about teaching, no matter what role it played in their lives. Their personal view of what motivated them to teach biochemistry varied largely among individuals. Among the most common themes of a "student-focused" nature were the interest to share one's own fascination with students and trying to have an impact on students in general through the teaching of biochemistry. The most commonly shared factors that benefitted them more directly than their students were the process of gaining knowledge through preparing teaching materials, experiencing joy through the love of teaching biochemistry, and receiving feedback through their students that made them feel good about their teaching.

4.2.1.4 Goals in Teaching Biochemistry – More than Just Conveying Knowledge

As part of this study, each instructor shared their syllabus for the classes that were observed. To supplement the learning objectives outlined in the syllabi, participants were asked to discuss their goals in the interviews. The following table, Table 4.4, illustrates the results that emerged from this data source, addressing instructors' goals when teaching biochemistry through their respective teaching styles. Three major categories appeared: "content-focused", "learning-focused", and "broader-impact-focused", with "learning-focused" being the most common category. In this work, "learning-focused" goals involved the application of knowledge and development of skills. As illustrated in Table 4.4, each category encompassed different themes that applied to a respective category.

In this table, Dr. Maggie, as many other participants, stated goals in all three categories identified. She mentioned within the category “content-focused”, that she valued to “convey knowledge”, with a focus on “quality over quantity”. As a “learning focused” instructor, her goals in class also related to the “application of knowledge” and the “development of skills”. In the last category “broader-impact focused”, her goals could be categorized as “raise interest in biochemistry”. Throughout the table, an “x” is placed in categories and themes that were identified for each participant. As a note, the table originated from the codes “teaching goals”, and “teaching beliefs” (see Table 3.5, Figure 3.8).

Adjustments only had to be made for Dr. Maggie after the member-checking process, who believed that she also sets a goal to focus on “quality over quantity”. I added a check-mark to this theme after she gave me feedback on my interpretation of her views on teaching biochemistry. All other quotes remained unchanged after member-checking was completed, since no other participant requested any changes or additions.

Table 4.4 Various teaching goals present when teaching biochemistry

Type of institution	Participants	Content-focused (encourage conveying content)		Learning-focused (encourage learning and the process of learning)					Broader impact-focused (goals beyond the classroom)	
		Quality over quantity (less is more)	Convey Knowledge	Create models in students' heads	Provide learning opportunities	Application of knowledge (apply content taught in or outside of class)	Boost confidence/be comfortable with topics	Development of skills	Equip for future success (overall goals expressed related to students' future success)	Raise interest in biochemistry
Doctoral granting institutions	Dr. Derrick			x		x				x
	Dr. Devora					x		x		x
	Dr. Duna								x	x
	Dr. Dixie					x		x		
	Dr. Donald					x	x			
	Dr. Danner	x								x
	Dr. Dana		x			x				x
	Dr. Dalton					x	x	x		
	Dr. Dolly					x		x		
	Dr. Donna		x			x		x		x
Master granting institutions	Dr. Magnus		x		x					
	Dr. Manju				x	x		x		
	Dr. Maggie	x	x			x		x		x
	Dr. Mickey					x				
Bachelor granting institutions	Dr. Brigid					x		x	x	
	Dr. Berry					x	x	x	x	
	Dr. Bobbie		x			x		x		

Most goals were centered around learning in the context of then being able to apply their knowledge. The themes of "conveying knowledge" and the "application of knowledge" usually emerged together. This phenomenon will be discussed more later, since it interconnects with many other results relating to perceptions and beliefs and actions about the teaching of biochemistry. Here are a few representative quotes listed that were collected in this study. Dr. Maggie stated for example:

> By actively engaging students in the course material, my goal is that they learn biochemistry concepts that are retained after the course is complete. In the group work, my goal is that they also learn important process skills, such as problem solving, critical thinking, and how to efficiently work with others in a technical team. (Dr. Maggie, integrative statement for promotion to tenure)

This further connected her goals to the way she taught the class observed:

> I know this is somewhat of a spin of mine is that I'm much more interested in watching them active learn versus I need them to learn exactly this. I'm kind of like, "Well, they'll ..." I'm trying to as we say magic [inaudible 00:33:30] down to biochemistry. What will be revealed to them will be revealed to them in the process of doing it. (Dr. Maggie, interview)

Dr. Maggie also focused on her goal of the "development of skills" in her classroom through her ways of teaching. This was similarly with Dr. Brigid:

> I have observed that most students entering college believe that learning in science is just memorizing facts and being able to apply algorithms. My goal is to show the students that learning is instead a process through which they should come to understand the source of the scientific "facts" and "algorithms". […] I think some of the important things that they should be getting out of this class is that this is the final class in the sequence, and they need to learn that there's a lot of other information out there that I can't tell them about, but they need to be able to develop strategies to be able to deal with and to be able to learn on their own, and to take their previous knowledge and apply it to what they're seeing in front of them. (Dr. Brigid, teaching philosophy)

The "development of skills" often emerged with the goals of getting students to apply the knowledge gained in class, as stated by Dr. Dalton:

> I would really like the students to be able to think in a biochemical way, to take the material and apply it in a thoughtful manner. […] I'd come back to the idea that if they can learn that material and feel comfortable about knowing the material, understand that it's not so complex, but it's rather simple, then I think I'd done a good job at teaching. (Dr. Dalton, interview)

In this statement, Dr. Dalton referred to his students' learning the skills through listening in class and practicing outside of class. Dr. Derrick also emphasized his students' gaining theoretical knowledge in class. He even emphasized the importance for students to utilize the theoretical models from class outside of class as well:

> Well, what I tell students when I meet with them, what I'm hoping for them to be able to do is to produce a model in their heads that they can refer in order to understand the story. […] So certainly, one goal is I want them to understand and appreciate the structure of biochemistry, how it does a very good job of explaining how energy is produced from the metabolism of nutrients, that sort of thing, on a content level, but in the process of doing this also, I'm hoping that they'll be challenged to think of problems, do some problem solving. […] Then once you know those things, with this model, that I hope that they acquire, I want them to be able to apply it to new situations because that's what they'll do. Whatever they do in life, they'll have to think outside the box and take their knowledge and their background to apply it to new situations. So that's part of it also and that's done partly by giving them problems to solve. There is some problem solving in that class outside of the exams. (Dr. Derrick, interview)

A similar theoretical approach of thinking about the application of knowledge outside of class was expressed by, Dr. Dalton as follows:

> What I'm looking for is so that they can take their biochemistry and feel comfortable enough with it that it's as every day as deciding what they're gonna have for dinner in the evening. So they can take the material and treat it in a way that they feel very comfortable about. (Dr. Dalton, interview)

A more practical statement was given by Dr. Bobbie, who emphasized conveying knowledge in class through applications and the "development of skills": "It's critical thinking skills and basic biochemistry knowledge. I think if they work with those two things, that's a step in the right direction." This statement is supported by her syllabus where she stated:

> Application of knowledge in biochemistry is inherently interdisciplinary. Biochemistry requires knowledge from general chemistry, organic chemistry, analytical chemistry, cellular biology, molecular biology, and genetics to be integrated in order to solve problems of interest in living systems. Integration and application of knowledge are the focus of this course. (Dr. Bobbie, interview)

A frequent theme that appeared in the category "broader-impact-focused" was stressed by several other instructors to within the context of increasing interest in biochemistry.

> So yeah, I think the goal is to get the students interested in the topic enough to engage in it and I believe that. […] but for those students who are interested, I want them to be able to come away from this experience with a new appreciation for something that they might not have appreciated before and I think it does change some student. (Dr. Derrick, interview)

Dr. Maggie highlighted the need to first interest her students in the topics through a light introduction of concepts, and then further deliver material through the application of knowledge and the teaching of skill sets:

> As most students take this course as a requirement for their major, this can be a challenge, particularly in my lower level courses. But if I can get students to appreciate biochemistry as an area of study, it is much easier to motivate them to learn the material. I have found that beautiful animations that tell a biochemical story, or graphics that help students visualize the molecular environment can provoke sense of wonder at the tiny molecular world. Once I have the students interested, my second goal is to engage them in the material so that they learn the concepts rather than simply memorize information. By actively engaging students in the course material, my goal is that they learn biochemistry concepts that are retained after the course is complete. In the group work, my goal is that they also learn important process skills, such as problem solving, critical thinking, and how to efficiently work with others in a technical team. (Dr. Maggie, integrative statement for promotion to tenure)

It became apparent during the analysis that "application of knowledge" was an important goal across instructors. Generally, the discussion of the application of knowledge by the participants could be characterized as theory-oriented (discussed applications in a more theoretical way, outside of class; e.g. Dr. Derrick, Dr. Dalton, Dr. Manju) or practice-oriented (discussed applications in a more practical way to be used in class; e.g. Dr. Maggie, Dr. Brigid, Dr. Bobbie).

4.2.1.5 Perceived Success in Teaching – a Mostly Positive Attitude

To capture my participants' perceptions of their teaching, I asked everyone how successful they felt in their lectures. The table below (Table 4.5) includes everyone's estimate on how successful they thought they were in their classrooms and in achieving their goals when teaching biochemistry. Three categories emerged from all interviews collected: "not feel successful", "feel successful", "feel successful with room for improvement". Instructors who mentioned that they felt successful when teaching biochemistry were categorized as "feel successful". Participants who felt successful but mentioned room for improvement through challenges they faced, for example, were categorized as "feel successful with room for improvement". Instructors who said they were not successful were categorized as "not feel successful".

Check-marks were placed in the table where responses from instructor met a respective category best. The table generated below, originated from the codes "teaching goals" (see Table 3.5, Figure 3.8).

Dr. Maggie was the only instructor who requested a change of category after member-checking was completed. Based on her interview, I first categorized her as "feel successful", since she came off as confident and verbalized less improvements to make in her classroom. After the member-checking process, when I shared my interpretation of her data with her, she said she felt more comfortable with the category "feel successful with room for improvement", which I elaborate on in the following table.

Table 4.5 Success in achieving one's teaching goals

Type of institution	Participants	Perception of success in lecture		
		Not feel successful	Feel successful	Feel successful with room for improvement
Doctoral granting institutions	Dr. Derrick	x		
	Dr. Devora		x	
	Dr. Duna		x	
	Dr. Dixie		x	
	Dr. Donald			x
	Dr. Danner		x	
	Dr. Dana		x	
	Dr. Dalton		x	
	Dr. Dolly		x	
	Dr. Donna			x
Master granting institutions	Dr. Magnus		x	
	Dr. Manju		x	
	Dr. Maggie			x
	Dr. Mickey		x	
Bachelor granting institutions	Dr. Brigid			x
	Dr. Berry			x
	Dr. Bobbie		x	

During the interview process, it was noticed that instructors had different opinions regarding their success at meeting their goals, with most instructors feeling successful in achieving their goals in their classrooms. There were differences. However, in reasons why they felt successful. For example, Dr. Devora stated:

> I think I'm reasonably successful. My students can go forth and get into graduate school or get a job in a ... so I think I'm reasonably successful, you know, sometimes more successful than others. It always depends on the student. Yeah. I would say I'm reasonably successful. (Dr. Devora, interview)

Some instructors felt that they were successful, but immediately pointed out significant room for improvement to better achieve their set goals teaching biochemistry and especially indicated their willingness to bring up possible actions to make changes or pointed out caveats they saw needed improvements in their classrooms:

Researcher: Mm-hmm (affirmative). How do you feel, actually, in being able to achieve the goals that you have that you defined earlier for me in the lecture, how do you feel about that? Do you think you achieve them really well, or is there anything where you're like, "Here are some more changes that I would like to do because those are the things that are not yet perfect"?

Dr. Donald: Yeah, well nothing's perfect. It's always, there's an imperfection. After a class, I'll take one of the problems that wasn't working well for the students, and why was that? Kind of look at it and I can change it for the next time. (Dr. Donald, interview)

Concerns about the improvements that needed to be made to be more successful in the classroom were more frequent across my population of instructors, as also stated by Dr. Brigid and Dr. Donna in their respective interviews:

Dr. Brigid: I think I'm relatively successful. I wish I could keep the students more focused, and I think that's something that we have a difficulty. Now, if you watched the entire video, I yelled at one of the students for using his phone, because he always does that. (Dr. Brigid, interview)

Dr. Donna: I have no idea. I don't think I'm doing that great. So my students are struggling with my exams. The average is typically low D range. (Dr. Donna, interview)

Another perspective that came up during interviews with different participants was strongly voiced by Dr. Maggie who had difficulty deciding whether she was successful (or not). She pointed out that she found it challenging to come up with measurable goals for her class:

> I need to come up with this set of what I would call the basic goals of biochemistry. Of course, I have things I want them to know. I'm not totally without goals, but I'm not a goal-oriented person. That said. That's my caveat… Do I feel like I've attained my goals? Do my students demonstrate ... Have I done any retention stuff? Have I gone to see where they're at a year after my class? I haven't. If I was a true scientist teacher, I would do that. I would say, "Hey, who'd be willing to take a little quick test so I can see what you remember and what you don't remember?" I haven't done that. All I can really talk about is do I feel like at the end of the year have they got a better grasp of how we work on a biochemical level or how life works on a biochemical level. I feel, sure, that they do. I mean and what am I basing that on?

> I'm basing it on what they are able to regurgitate to me on a test, but there are concepts they certainly get that I'm very proud that they get. There are though things that half the class just never gets, which is all like, "Ugh, really?" So there's those frustrations that go on, and so you try different things. I don't know. I don't know how successful I am at ... See, this is why I'm not a goal-oriented person. I would have to be ... I would make these goals and then whether I achieved them or not, how do I know? Right? (Dr. Maggie, interview)

Various perceptions of how successful instructors felt in achieving their goals emerged from the interviews. Overall, the instructors teaching biochemistry nowadays felt rather successful in their achievements, with some instructors reflecting more on the room for improvement than others.

4.2.1.6 How Success in Teaching is Perceived - a Wholesome Perception through the Use of Multiple Resources

During the interviews, after my participants elaborated more on how successful they felt in class achieving their goals, I asked them to share their perception on how they "knew" how successful they were. Varying ways in how instructors replied are reflected in categories that emerged from the data analysis process, as shown in Table 4.6 below. Four main themes were identified: "intuition (instructors' perceptions' on how they "felt" about students getting concepts)", "class attendance", "student performance (usually on tests)", "student feedback (in and outside of class)".

Instructors often mentioned multiple ways on how to measure their success in achieving their goals. Dr. Manju, for example, has an "x" in every cell of the table, indicating that he mentioned a statement in his interview that supported every theme that emerged from the data. Taking this information into consideration, the table incorporates the codes "teaching goals" and "assessment" (Table 3.5, Figure 3.8) which were analyzed together.

Table 4.6 Teaching goals and its measure of success

Type of institution	Participants	Way on measuring success to reach teaching goals			
		Intuition (instructors' perceptions' on how they "felt" about students getting concepts)	Class attendance	Student performance (usually on tests)	Student feedback (in and outside of class)
Doctoral granting institutions	Dr. Derrick		x	x	
	Dr. Devora	x		x	x
	Dr. Duna	x	x		
	Dr. Dixie	x			x
	Dr. Donald		x	x	x
	Dr. Danner			x	x
	Dr. Dana				x
	Dr. Dalton			x	x
	Dr. Dolly			x	x
	Dr. Donna				x
Master granting institutions	Dr. Magnus				x
	Dr. Manju	x	x	x	x
	Dr. Maggie	x		x	x
	Dr. Mickey	x		x	x
Bachelor granting institutions	Dr. Brigid				x
	Dr. Berry			x	x
	Dr. Bobbie			x	x

It was insightful to understand more about instructors' perceptions and beliefs on teaching biochemistry by taking a closer look at the ways they measured their success in achieving their goals in teaching. Overall, "student feedback" as well as "student performance" were instructors' primary ways to measure their success in teaching, as Dr. Donald elaborated further on:

> In fact, several years ago, one of the students who took the MCAT came up and said, "Hey, Dr. Donald, they used the case study with Alex and his glycogen disease. It was so good 'cause I knew it. We'd done it in class." […] Dr. And then the next year, a kid came up and said, "Hey, [Dr. Donald], I'm doing the Kaplan stuff, and they're using Alex case study." (Dr. Donald, interview)

Dr. Donald elaborated on gathering achievement through student performance as follows:

> What I do is, what I use, the index, I haven't said yet, is the ACS has a core exam in biochemistry, and it has a standard core, which is 40 multiple choice questions, and then it has an advanced section. We only do the 40 questions, the core exam, not the advanced one. The advanced one, some of the students would be able to do

> those questions, but I just wanted to keep it to that, 'cause it's a nationally normed exam. That's what's important. My kids will always do, their average is higher than the national norm, but not hugely over. But because there's, and because these questions they've never seen before, but they're over the exact same material. When I saw the ACS exam, when I first saw it, I said, "Oh my god, that's my course. Every question comes from these chapter of Lehninger that I do." (Dr. Donald, interview)

Similarly, Dr. Maggie argued:

> All I can really talk about is do I feel like at the end of the year have they got a better grasp of how we work on a biochemical level or how life works on a biochemical level. I feel, sure, that they do. I mean and what am I basing that on? I'm basing it on what they are able to regurgitate to me on a test, but there are concepts they certainly get that I'm very proud that they get. (Dr. Maggie, interview)

Few instructors said that intuition was their measure of success, and normally when intuition was mentioned it was within the context of other measures of success. Dr. Donna and Dr. Brigid were among the few instructors who put their primary emphasis on gaging measures of success through student feedback. Dr. Brigid noted:

> Some students tell me, "Oh, this is great. This class is great because now I see why I had to learn all that other stuff, why buffers were important, why I had to learn those organic mechanisms, because they all kind of come together at the end in Biochem and Advanced Biochem." (Dr. Brigid, interview)

The way she talked about student feedback throughout her interview made it clear that she was, for the most part, relying on her students' voicing their success, which she then could transfer on to her ways of teaching and how successful they were.

Many instructors who stated that they felt successful in achieving their goals in teaching also states that they used student performance and student feedback as measures of success. This was often accompanied by estimating the achievements of teaching goals through their intuition, as indicated in the table above.

4.2.1.7 Perceptions on Biochemistry Instructors Roles in Teaching – a Little Bit Of Everything and Sometimes More Of One

Another gateway to better understand an instructors' way of teaching is to look at their perception on the roles they fulfill as educators in the classroom. During the analysis process, six different categories appeared that instructors identified with: "communicator (cover material, expectations and such)", "facilitator of success (equip students with tools to understand concepts on their own)", "motivator (be motivated, motivate students)", "guide (guide through ways of thinking in theory and practice)", mentor (advisor outside and inside of class), "challenger (posing challenging tasks, presenting challenging topics)", see Table 4.7 below.

I will use Dr. Derrick as an example to illustrate how the table should be read. This instructor provided a statement during the interview for the three categories "communicator", "facilitator of success", and "motivator". Therefore an "x" was placed in these cells of the table. Dr. Derrick was also the only instructor who requested to add an additional check-mark to the table during the member checking process, in the category "facilitator of success", where Dr. Derrick noted in an email: "[…] even if my interview did not convey this, I do feel that in my "teacher role" I act as a "facilitator for success" as well as being a motivator and communicator as you had indicated.". The codes "teacher role", "student role" and "transparency" (Table 3.5, Figure 3.8) were analyzed together in the following table, as they revealed similar themes.

Table 4.7 Perceived teacher role

Type of institution	Participants	Communicator (cover material, expectations and such)	Facilitator of success (equip students with tools to understand concepts on their own)	Motivator (be motivated, motivate students)	Guide (guide through ways of thinking in theory and practice)	Mentor (advisor outside and inside of class)	Challenger (posing challenging tasks, presenting challenging topics)
Doctoral granting institutions	Dr. Derrick	x	x	x			
	Dr. Devora	x		x	x		
	Dr. Duna	x	x	x			
	Dr. Dixie	x	x	x			x
	Dr. Donald	x		x			
	Dr. Danner		x				
	Dr. Dana		x	x			
	Dr. Dalton	x		x			
	Dr. Dolly	x		x			x
	Dr. Donna		x		x	x	
Master granting institutions	Dr. Magnus	x	x				x
	Dr. Manju	x			x		
	Dr. Maggie	x	x				
	Dr. Mickey	x			x		
Bachelor granting institutions	Dr. Brigid	x	x	x	x		
	Dr. Berry		x	x		x	
	Dr. Bobbie		x	x			

Teacher roles were multi-facetted in how participants viewed their tasks. Many described their roles as what would be best summarized as “motivator” (e.g. trying to provide examples that motivated students, motivated them to learn material, to overcome fear of it being too hard) and “communicator” (e.g. communicate information, factual knowledge), as well as “facilitator of success” (e.g. equip students with tools to understand concepts on their own), as Dr. Duna stated for example:

> You have to understand human nature to be a good teacher. You have to understand what motivates 18-year-olds. Right? 19-year-olds, 20-year-olds. That's kind of what I end up going back on. You got to put yourself in their shoes, not what you think is important. You got to frame it around what they think is important. That's

> where it gets trickier. […] If you tell them why you're doing something, they're much more motivated. Not just because I said so, but this is why I want you to learn. This is why I want you to do this. They're much more willing to follow along instead of do it because I said so. […] Okay. My job is to impart the information. […]. (Dr. Duna, interview)

Besides her emphasis on taking the role as the motivator and communicator, she also stressed the importance of functioning as a facilitator in class. Dr. Duna noted as follows "I want them to learn how to be successful." Dr. Brigid's statement was less "separable" but had components of the role as a "motivator" and "communicator", as well as "facilitator of success".

> Okay, my role and responsibility is to help students understand the material and guide them through the material. I can't learn it for them. They have to have the responsibility of putting in the effort to learn it, and I do understand ... […] I think real learning and solidifying understanding has to happen outside the classroom, because there's a minimum amount of time in the classroom. I can facilitate it as much as possible, but inside the classroom, there's just not enough time […]. Again, and I think this goes back to my thoughts that you have to reinforce what you're learning all the time, and the exercises I give them in the classroom is a way for them to think about how they can think about questions that will reinforce their learning. […] Yes, I think by showing that I'm interested in understanding what they do and don't understand, and helping them become motivated to understand the material. I can help them, but it's not all me. It has to be some them. They have to have some of that internal motivation to do it. I think I can help influence them. (Dr. Brigid, interview)

It was notable that "communicator" and "motivator" correlated with each other in many cases, as can be seen in Dr. Derrick's interview statements:

> Well my responsibility is to be sufficiently knowledgeable about the material that I can help the students learn it. That's one role and another is to effectively communicate that material using whatever methods I feel are effective. That's what I'm there about. […] Well, I will say this, if I don't come across excited about what I'm teaching about, there's no way they're going to be excited. So, I have to get myself pumped up and excited about it. When you teach something for eight years straight, it gets harder and harder. (Dr. Derrick, interview)

Only a few participants verbalized their roles to also be the “challenger” in their classrooms. Consider, for instance, Dr. Magnus as being both a “communicator” and a “facilitator of success”:

> By identifying, my biggest, I see one of my really biggest roles then is to identify that small amount of material, or relatively small amount of material which is most critical for understanding what biochemistry is and then cover that very thoroughly. […] Not so much to teach them everything, if that's really possible. To give them the framework and the background that they can apply that information to understand any topic that they may encounter. […] You're going to learn a lot more by taking the challenging exam than you would from the not challenging exam. I'm really doing my job if I write an exam that you've missed a lot of questions on." The students don't like that. (Dr. Magnus, interview)

Most participants described more than one role as being important to them as instructors teaching biochemistry, among which “communicator”, “facilitator of success”, and “motivator” were the most frequent.

4.2.1.8 Instructors’ Opinions on Students’ Role in Biochemistry Classes – Mainly Being the Learner and Utilizer

I investigated how they viewed their students’ roles in the class as a way to better ground our understanding of instructors’ beliefs and perceptions as well as recognizing possible connections between their roles in the classrooms and the choices they made in their teaching methodology. Four main categories emerged (see Table 4.8): “learner (responsible for own learning), “utilizer (use what is provided and apply)”, “receiver (receive knowledge in class)”, “customer (ask for what is needed)”.

Dr. Bobbie, for example, only saw her students’ role as being a utilizer of the information and knowledge provided during the lecture. Often, instructors provided statements that revealed that they think about their students in multiple ways, taking on various roles. An “x” in the table reveals which category came up during the interview for each participant. The codes and relationships analyzed in this table include “student role”, “teacher role” and “teaching goals” (Table 3.5, Figure 3.8).

Table 4.8 Student role categories

Type of institution	Participants	Learner (responsible for own learning)	Utilizer (use what is provided and apply)	Receiver (receive knowledge in class)	Customer (ask for what is needed)
Doctoral granting institutions	Dr. Derrick	x			
	Dr. Devora	x			x
	Dr. Duna	x			
	Dr. Dixie	x	x		
	Dr. Donald		x	x	x
	Dr. Danner	x	x		
	Dr. Dana			x	
	Dr. Dalton	x	x		
	Dr. Dolly	x	x		
	Dr. Donna		x		
Master granting institutions	Dr. Magnus	x	x		x
	Dr. Manju		x		x
	Dr. Maggie		x		
	Dr. Mickey	x			x
Bachelor granting institutions	Dr. Brigid	x			x
	Dr. Berry	x	x	x	
	Dr. Bobbie		x		

According to instructors, the role of students is primarily to be learners and utilizers, in which students are expected to take the role of the learner and be responsible for their own learning and studying, using that knowledge to study new concepts in biochemistry on their own. Dr. Dixie, who was my only participant teaching a graduate-student course, shared the following insights on her students taking up the role as the learner and utilizer:

> I expect you to know X Y and Z. If that's all you take of it, fine. […] it's up to you to actually do that bit of light work. […] And then I expect you to be able to use everything that we've talked about in class, and you can bring your prior experience in to answer it. […] And I feel like it's the student's job to internalize that, and then be able to put the pieces together. At least at the graduate level. […] But it is up to them to use that information to succeed. (Dr. Dixie, interview)

Her views were common among other instructors who taught undergraduate-level classes (e.g. Dr. Magnus and Dr. Dalton). Dr. Berry summarized her interpretation of student roles in class as follows:

> Hey, guys, it's almost the end of your junior year. Do you realize after next year, you're not going to have a faculty member to ask these questions to and that the reason we do this is so you can learn the material on your own," and to remind them that's the point of a college education to teach them how to learn on their own buy-in. […] The students are the ones learning the material so they're there learning, trying to figure out for themselves how it connects what they've learned before. (Dr. Berry, interview)

Dr. Derrick’s and Dr. Duna’s expectations of students were focused around them being the “learner” in the classroom and primarily being responsible for their own learning success. However, Dr. Donna’s and Dr. Bobbie’s main focus was students’ role being the “utilizer” in the classroom, as they each voiced during their own interviews:

> But the student's role is to be engaged. I try to provide the atmosphere and provide the resources for them to take and be engaged and to help facilitate those connections they've made. (Dr. Donna, interview)

> They need to be active learners, that they can’t learn without doing it themselves and that they need to be trying things even if they are the wrong things and making mistakes in order to learn. (Dr. Bobbie, interview)

Dr. Dana found her students’ to be mainly “receivers” in her classroom by attending her class and taking in knowledge that is conveyed during class time: “But if you come to class, I'll do everything I can to help you learn.”

Different student roles were described among participants in this study, for example, students taking the role of the “learner” and or “utilizer”. In the following chapter, I will discuss what that could mean to better understand the impact of instructors’ methodological choices in their classrooms, along with their ways of thinking about their own roles in a biochemistry classroom setting in my discussion chapter.

4.2.2 Summary of Main Results Addressing the First Research Question

The teaching beliefs of most of the participants in this study centered around a utilitarian approach where their belief system was grounded in benefitting the greater good when teaching biochemistry. Within that belief system, most participants expressed the belief that their course had to be relevant to their students. The biochemistry educators often noted that they believed that classroom content should, ideally, relate to real world examples or students' interests. The instructors repeatedly noted that science needed to involve students in the learning process. Many participants within my study also acknowledged the challenging nature of biochemistry as a scientific discipline, where they stated how it was a difficult subject for students to study and understand.

When investigating influences that could have shaped instructors' beliefs, I found that instructors were frequently influenced by their experiences when they were students, as well as the result of taking on teacher roles within their own families. Within their own schooling experiences, many of them spoke about being influenced – both positively and negatively – by their experiences with teachers they had. In addition to these influences that they could not necessarily control, almost half of participants stressed the fact that the experiences they collected within their families also influenced them strongly. Most reported that influences included fulfilling a certain teacher role in their families, which helped them understand how learning occurred and provide hints about what they could do to help others overcome learning barriers. Many instructors also tended to gain their teaching beliefs through their own collected teaching experiences by making their own choices, drawing conclusions from their own teaching experiences and their perceived effectiveness of these experiences.

Various of reasons were identified on instructors' interest in teaching. These were identified as either student-centered or teacher-centered interest. A major theme within the student-centered category involved instructors sharing their fascination of biochemistry with their students. Many instructors also highlighted their interest in "making a difference" and have a lasting impact on their students. Factors that displayed a more teacher-centered interest were also common among the study population, such as the interest to self-educate during lecture preparation. More than half of the instructors voiced their love of teaching biochemistry as a main interest. Many other lesser themes were identified that will be presented in more detail in my results section and upcoming discussion section.

Among the variety of goals instructors raised for teaching biochemistry, one of the most common categories was centering their focus on learning processes. The development of skills and the application of knowledge were commonly mentioned within this goal. A majority of the participants also mentioned the goal to raise interest in biochemistry. When further investigating these instructor goals, it became apparent that the way instructors talked about goals differed, especially when they focused on the process of learning. Biochemistry educators concentrated more on a theoretical description of the application of knowledge during class, with the focus on applying knowledge outside of, rather than during, class. Other instructors emphasized the practice-oriented way of teaching their goal of applying knowledge in class, with the focus being on in-class activities to achieve that goal. There was a major division seen among the participants in the way they talked about their perception of how their goals were accomplished in class.

All of the instructors, when being asked about how successful they felt in achieving their set goals, felt mostly successful. Specifically, instructors who described their goals on a theoretical level confidently communicated their perception of how successful they felt in teaching biochemistry. Instructors with a more practice-oriented focus were more hesitant in expressing feeling successful with reaching their goals because of additional improvements they had in mind that should be incorporated to make them more successful. Overall, however, instructors seemed to feel more or less confident in the ways they taught biochemistry.

An analysis of instructors' ways of measuring their success revealed interesting insights in their beliefs and perception in teaching biochemistry. Almost all instructors, regardless of a more theory- or practice-oriented way of thinking about their beliefs and perceptions, stated that student feedback, in and outside of class, was a helpful resource they took advantage of on a regular basis. This appeared to be important among instructors who took a more theoretical approach to their teaching; these instructors learned that they could rely also on their intuition about how successful they felt, based on their perception of, for example, the mood their class was in and how students seemed to respond to the material. Many other instructors also focused on student performance during tests, for example, to gather feedback about how successful they felt about reaching their in-class goals. This finding was common across biochemistry instructors and was often accompanied by student feedback as a source to measure success in the classroom.

Instructors were also asked to elaborate on the roles they thought they fulfilled in their biochemistry classes. Most instructors described their roles in the classrooms as being the communicator, facilitator or motivator. Instructors varied on the number of roles to which they referred, but the above three were mentioned the most. Regardless of the instructors' thinking approaches about teaching biochemistry, they tended to share common roles they thought they fulfilled in their classrooms. It became apparent, however, that the ways instructors talked about their roles was more active for more practice-oriented instructors and more passive for theory-oriented instructors. The majority of instructors I interviewed stated that their students' roles should be learners of content and utilizers of resources and utilizing opportunities to learn in classroom settings.

This overall summary of my results extracted main themes that emerged through my analysis. During the distillation of the common components of themes, two different ways emerged in which instructors described certain themes: a theoretical- or practical approach. This impression will be discussed more in my upcoming discussion chapter, where it will also be compared against their actual ways of teaching I observed in their own classrooms.

4.3 Addressing the Second Research Question

As a next step, I investigated the actions of biochemistry instructors who participated in this study when they were teaching in the classroom. I explored challenges instructors faced when teaching biochemistry and why they chose to teach the way they did. This endeavor was further investigated through the following research question:

> How do biochemistry instructors think they teach biochemistry? What guides the decisions they make on the methods they use to teach biochemistry?

4.3.1 Detailed Description of Results Addressing the Second Research Question

This section will look at the categories and themes associated with the second research question. The following topics will be discussed in more detail:

- Ways instructors teach biochemistry and opinion about their styles of teaching.
- Placing the results in the context of the ICAP framework.
- Challenges in teaching biochemistry – current and future.
- The future of teaching biochemistry.
- Professional development of biochemistry instructors – resources used and desired.

Each section will start with an overview table, followed with a more detailed description.

4.3.1.1 Ways Instructors Teach Biochemistry – More Than “Just” Talking at Them

The following table, Table 4.9, offers an insight in how instructors teach biochemistry in a lecture environment. For the purpose of this stage of analysis, it was useful to combine results from all data sources to capture their style of teaching (interviews, observations and artifacts). Four main categories were distilled from the data collected and were as follows: “communication of content (main styles of communication in class)”, “emphasis on content with more student involvement (in class)”, “display of content (media used during presentation of content in class)”, “student-involvement (during class time)”. Multiple themes arose within each category.

Before delving into how the results of a participant can be garnered from this table, I need to address how the table is organized. Every cell that has an “x” in a respective cell means, that a particular method was used by an instructor, whose name can be found on the left side of the table, in the same row as the mark itself. In the top two rows of the table, categories and themes are displayed. Depending on in which row the “x” has been placed, it addresses a certain theme out of a specific category. Cells that have no “x” in it did not apply for that respective participant. In cases where I was able to specify more in-depth teaching methods my instructors used, I made use of abbreviations which replaced the “x”.

Multiple abbreviations were used to specify teaching methodologies instructors utilized in their biochemistry classrooms and were used throughout the following table. To keep it simple, I will list all abbreviations as they mainly appear in the table from left to right. To get an idea on how often certain methods were used or choices were made, I used specifications such as frequent (F) or sporadic (S). Instructors chose to increase the relevance of content presented in class by using case studies (CS). Some instructors gave examples that connected to real world application (RW), or made the content more relevant, in the form of student-relevant applications (SR). Student got involved in class in various ways; either through groupwork (GW) in class or GW with questions and answers (Q/A) were executed, where instructors tried to get their students more involved. GW was sometimes used along with individual work periods (I). Questions posed by instructors could be of rhetorical (R) nature. Actions taken in the classroom of any nature, was either categorized as instructor-motivated (IM), where the instructor took initiative, or student-motivated (SM) within the table below. If particular teaching methods used were rather short in their duration, not more than approximately 5-10 minutes long, I categorized them as “Mini”. Technical teaching tools that instructors appeared to use included clicker questions or questions of similar nature and implementation (CQ). Many different styles of activities and how they were executed were categorized with the following abbreviations:

in-front-of-class activity (IFOC), just-in-time teaching (JIT), hands-on models in class (HOM), molecular model kits (MMK), visualization programs in-class (VP), problem-based learning (PBL), process guided inquiry learning (POGIL), simply problem-solving activities (PS), or think-pair-share (TPS), or worksheets (WS). Activities like these could be variable in kind and or time (V) and sometimes whole class time long (WCT).

Here I describe Dr. Duna's row in the category "communication of content", in more detail to illustrate the organization of the table. As Dr. Duna chose lecturing most of the time, she chose to display her content (see category "display of content") mainly through the use of PowerPoint. Dr. Duna involved her students (see category "student-involvement") primarily through posing sporadic questions to the entire class. Many questions were of rhetorical nature. To have more student engagement in her class, she chose to utilize fill-in-the blank lecture notes, that her students could fill out during class while listening to her and reading her slides.

This table originated from the original code "teaching methods" (see Table 3.5, Figure 3.8).

Table 4.9 Teaching methods extracted from instructors' interviews, observations, and artifacts – categorizing styles of teaching

Type of institution	Participants	Communication of content (main styles of communication in class)				Emphasis on content with more student involvement (in class)		Display of content (media used during presentation of content in class)			Student-involvement (during class time)			
		Flipped classroom	Lecturing	Storytelling	Analogies	Application oriented teaching (application approaches embedded in class)	Less memorization, more thinking/application	PowerPoint*	Videos/virtual visuals used during presentation of material	Board (white board or chalk board) used somehow by students or instructors	In-class questions (to entire class, with or without response from students)	In-class discussions with entire class	Hands-on activities in class	Fill-in-the blank notes during class-time
Doctoral granting institutions	Dr. Derrick		x	x	x			x		x			GW/S/2min	
	Dr. Devora	semi	S			x	x	S			S, more Q/A during GW		During flipped sessions/GW/5-20min; TPS/5min; CQ/10min	
	Dr. Duna		x					x			IM/S/R			x
	Dr. Dixie		x	x		SR		x			IM/F/R		I/HOM/S/10min, GW/lecture	
	Dr. Donald	x				CS							GW/PS/F/2min/CQ	
	Dr. Danner		x			RW	x	x	x	x	IM/S		I/GW/WS/S/5 min	x
	Dr. Dana		x		x			x		x	IM/F		I/GW, VP/F/5min	x
	Dr. Dalton		x							x	IM/SM, S		I/MMK/S	
	Dr. Dolly		x	x		x		x		x	IM/F/R		GW/IFOC	
	Dr. Donna		x	x		x		x	x	x	IM/F/SM	S/Mini	I/GW/ POGIL/S, CQ	

Table 4.9 Continued

Master granting institutions	Dr. Magnus		x	x	x					x	IM/F/ some R			
	Dr. Manju		PBL			x		x		x	IM/F/also R; SM/S	Mini		
	Dr. Maggie		x	x	x				x		IM/SM/F		I/GW, 2.5min/F WS/PBL/ POGIL	x
	Dr. Mickey		x						x	x				
Bachelor granting institutions	Dr. Brigid		Mini			RW		x			x		GW/5-10min/F, WS/POGIL/ Quizz/PBL/V	
	Dr. Berry		Mini				x	S		x	x		GW/WCT, WS/POGIL	
	Dr. Bobbie		Mini /JIT										I/GW/WCT/F/WS	

*Many times, when no ppts were used, if anything had to be shown, a doc cam was utilized.

The goal of this research project was to capture the most common teaching methods and the primary style of teaching Table 4.9, to see how “active” or “passive” a classroom was and to identify any current trend that was apparent when teaching biochemistry. The table should provide an idea regarding how diverse teaching of biochemistry was executed, to build a rich ground for discussing their methods of teaching and relating it to their beliefs and perceptions.

The main categories that emerged from the analysis of my participants’ style of teaching were “communication of content”, “emphasis on content with more student involvement”, “display of content” and “student involvement”. As Åkerlind (2008) concluded from his study, teaching is executed in a teacher-centered or student-centered way. Prosser et al. (1994) stated in an earlier study, that instructors can hardly be placed into one or the other category solely, both extremes are connected by a range of teaching methodologies and styles. As identified within this study, a range of teaching approaches was displayed among biochemistry instructors Figure 4.1.

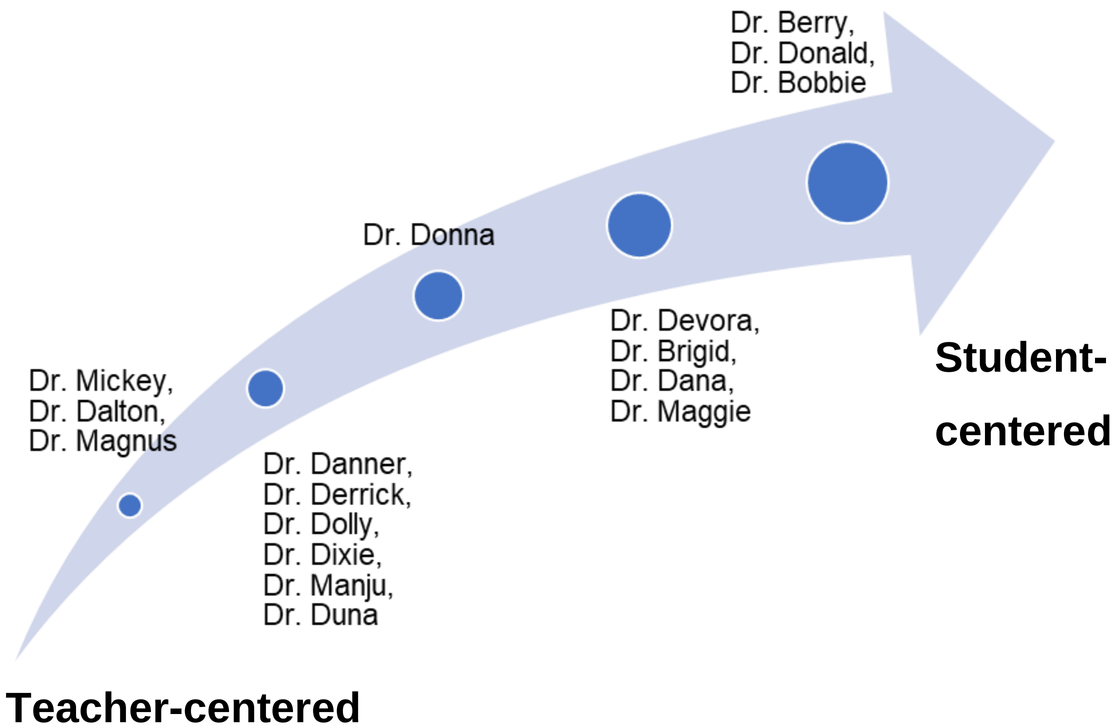

Figure 4.1 Range of teaching styles among biochemistry instructors

This figure was inspired by Kember's model of conception of teaching (Kember, 1997) as well as by the ICAP model (Chi & Wylie, 2014). The instructors were grouped regarding commonalities in their teaching style and methodologies used in the classroom. The first instructor mentioned in each list connected to one of the dots on the curved line leaned more toward a student-centered teaching approach than the last instructor within that same list. Student-centered teaching methods became more dominant and distinct from teacher'-centered instructions from left to right within each of the blocks of instructor's names.

Not There Yet – a Primarily Teacher-Centered Approach

The participants who were more likely to emphasize lecturing to students in a typical class session were characterized as having the most teacher-centered teaching style (Dr. Magnus, Dr. Mickey, Dr. Dalton). When giving their lectures, all three of them would deliver the material to their students by writing in real-time on the white board or chalk board. Here is an exemplary quote from Dr. Dalton, which undermines his motivation behind that methodology:

> What I've done is, I'd say I've been most successful at using a technique which requires just developing the subject matter point by point on the board. […] developing the thoughts on the board step by step so that the students can track the thinking process a little better. […] Yeah, that's right. I've been convinced that, really, a chalkboard is a pretty good way to go. At least for biochem. […] (Dr. Dalton, interview)

After I asked him further why he would use such a traditional approach he mentioned:

> Let's see. What I picture, what I envision happening is I'll write a molecule on the board, and so in the process I'm having to bond together carbon atoms, and I'm having to make a shape out of it, and put on functional groups. Following me, the students are doing the same thing, essentially on their paper. They're making the molecule, they're having to draw the shape in and put the functional groups on, and as they do that, I believe that they're gaining some information about the makeup of the molecule, what is it like? Well it has this particular shape, and it has this functional group at the first carbon and this functional group at the second carbon. So they're having to think it through whether they want to do it or not, they're having to think it through. (Dr. Dalton, interview)

Dr. Magnus also emphasized his more lecture-based teaching style by stating he was using storytelling and analogies while he was teaching as a methodological tool.

> Researcher: Are examples guiding frameworks in your teaching or is it more telling a story or what is it?
>
> Dr. Magnus: It will depend on the topic. Some topics are more story-ended. Some topics my examples, well some might be more metaphor or analogy driven where I use a lot of biochemistry concepts. For example, I find that nearly all biochemical concepts can be explained using automobiles. (Dr. Magnus, interview)

Dr. Mickey stood out from this group because, in addition to his in-time hand-written white board notes, he accompanied the representations he drew on the board with multiple animated visuals in class.

> Learning can be visual, auditory, and kinesthetic, and so one thing I learned early on is I want to try and at least get a little bit of each of those in my classes. Pure lecturing can be visual if I'm using a board, writing things on a board, and it's definitely auditory, and it can be kinesthetic, because you're writing notes […]. The drawback with that we explain a visual process at a level that a [inaudible 00:44:08] can understand, and that's where I think technology has really improved my teaching of biochemistry, is now I can visualize molecular structures, and we can zoom in on specific areas of a molecule. […] In part, because I think it's cool. Again, I think it's fascinating that we have crystal structures, and we can look at a molecule like that. I just think that's, you know, I think that it's exciting, just to be able to look at a molecule and be able to describe, "This is how it works." (Dr. Mickey, interview)

Dr. Magnus and Dr. Dalton involved their students by questions they incorporated jnto their lectures at various points during their lectures Dr. Dalton had more success involving his students and getting questions from his students. Dr. Magnus' teaching was framed by posing questions to get the students' attention and get them thinking, but not necessarily getting student answers back.

> They tend to be passive, so I consciously try to engage them, although, I will often ask a big question and get no response whatsoever. In which case, I could sit there for an hour waiting for someone to answer, which is not an effective use of time, so I just have to go on. I'm hoping that they're answering in their own head not giving an answer. […] Also, I think one thing that I probably do a lot of is making connections. […] I try to engage them, if nothing else, by asking questions, even if they're rhetorical questions, meaning I don't necessarily expect them to answer at least hopefully that they are thinking about these things. (Dr. Magnus, interview)

In addition to engage his students through questions during lectures, Dr. Dalton would bring molecular model kits sporadically to provide his students with an additional opportunity to visualize molecules differently, than only through board notes and descriptions.

Dr. Dalton: […] using molecular models in class is, again, a kind of a tried and true method, and it's worked pretty well for me as well, so we can look at it on the board, and we can look at it in a molecular model form, and physical dimensions. Helps some.

Researcher: So that is what you're still doing in your class?

Dr. Dalton: Yes.

Researcher: […] Is that maybe one reason why those new technologies in terms of having your complete lecture as a PowerPoint, and everything is just projected, and you're not really writing in time, and working through with your students in time, and real time what they actually do the material. Is that why you use more the traditional and hands on ways of teaching how we have been doing it for decades and decades?

Dr. Dalton: […] Yes, I think you're just absolutely right on the nose. […] Let's see if we can take an example. They're learning to differentiate one stereoisomer from another in class. The activity is drawing the structure, recognizing that the functional group sticks out one direction for one molecule, sticks out the other way for another molecule. Then we take a look at the molecular model, and we associate the shape of the molecule with what we've drawn on the paper, put that together. Then the third piece might be to, say, recognize that the protein bonds to one stereoisomer versus another, something along those lines. That might be an example. (Dr. Dalton, interview)

Advancing Toward Student-Centered Teaching – One Step At A Time

The next group of instructors (Dr. Danner, Dr. Derrick, Dr. Dolly, Dr. Dixie, Dr. Manju, Dr. Duna) also displayed a lecture-based teaching style; however, they were more likely to incorporate student-centered teaching techniques into their lecturing. This has been encouraged by the research literature, since it can enhance learning outcomes (Chi & Wylie, 2014; Freeman et al., 2014; Prince, 2004; Wieman & Gilbert, 2015, 2015). Dr. Derrick, for example, relied heavily on lecturing to convey biochemical content to his students, with an emphasis on storytelling and the use of analogies.

> I'd like to think I'm really into storytelling, that each of these topics that we're talking about is like a story and it can be conceptualized as a model and for a student to really understand the concepts, they need to have the model in their head to refer to. […] I use analogies. I use a lot of analogies. So for example, when I'm teaching glycolysis. […] For students who aren't chemists, they might just think it's just a series of almost random reactions that result in metabolism of glucose. As I had to teach it, I had to look into glycolysis and then I had to understand that that's happened for a reason and even if for example, there's a movement of a phosphate between two positions and I talk about chess is that sometimes you don't exactly know why something happened until later and then it's apparent. Students have always told me they appreciate the analogies I use. Some of them aren't entirely appropriate. They're not appropriate analogies, but I think it helps them to some degree and what we're doing here. […] But anyway, we can reduce a lot of what we talked about to a different analogies, whether it's the pumping of protons into the intermembrane space as analogous to pumping water into a dam so that energy can be used later. So, I think that's really effective means and I didn't invent any of this. They're books that have been written on using analogies. (Dr. Derrick, interview)

Even though his teaching was strongly theory driven, Dr. Derrick utilized group work in his teaching in order to incorporate more student engagement. He grouped students who were sitting next to each other in groups of 4-6 students and instructed them to think about a question he posed for about 2 minutes. While they were doing that, he would walk around and see what groups had accomplished and then encourage one or two to share their views and solutions.

> […] because of the room we're in, I will be able to say, "Alright, here's a challenge or a question. Get together. Start talking about it. See what you come up with," and they'll do it. I think they really enjoy it also. (Dr. Derrick, interview)

He would not so much ask questions during his lectures, but incorporate short group work activities, instead, to encourage his students to engage with the material.

Dr. Dixie also used primarily lecturing to convey biochemistry to her students, and flavors it with stories she shared. Dr. Danner and Dr. Dolly and Dr. Manju also stated the usefulness of lecturing, teaching their students through talking them through their reasoning, and explained reasons why they were such an integral part of their teaching methods. Dr. Dolly and Dr. Danner mentioned during their interviews:

> What I'm trying to tell them is that, this using this data, science, but using the data and then let them think critically, and let them use logic, and when you make a decisions later on, that you should bring different perspectives, use the data, and make a decisions. Rather than judging what is wrong and what is right, but you have to measure the all perspectives. (Dr. Dolly, interview)

> For this type of class, it's lecturing mostly. Interspersed with video clips, animations, and in-class activities to loosen it up and break it up a bit. But things like flip classrooms in a class of that size are off limits. I would find it hard to teach it other than making it mainly traditional lecturing course. (Dr. Danner, interview)

This group of instructors represented the beginning of a shift in the ways participants in this study thought about their use of teaching methodologies that was not as apparent within the group of participants elaborated on before. The use of applications came up more and more often in the ways the participants integrated it into their teaching. Dr. Danner and Dr. Dolly each stated:

> I ask students to apply their knowledge gained in class to work on problems related to industrial or medical applications, which keeps them interested and engaged in the topics. These problems emphasize general principles in order to encourage students to develop their ability to qualitatively account for chemical phenomena rather than to memorize details. (Dr. Danner, teaching philosophy)

> We limit ourselves into certain topics, but at the same time, those are all application of what they learned so far. That's where students get excited, because so far they really didn't see any of the hard chemistry being used anywhere that they know. When we talk about carbohydrates, I showed a big picture of a noodle bowls, and why there is obese phenomenon going on, why the people in Asia, they live on carbohydrates and they're skinny, but here if you start eating carbs, people are getting fat. Right? […] So suddenly you can apply those chemistry to explain certain things. And we're just talking about the laws of oxidation today and I showed them, "Okay, here's a fried chicken. When I say, oh this is a fat, what I mean by fatty? What's in there?" So, we draw from molecular, and then start going from there. (Dr. Dolly, interview)

Posing questions during lecture was common in this group of participants, although the questions were mainly rhetorical in nature. Most of these questions stayed unanswered or were posed to get visual affirmation during lecturing. This was observed for professors Dixie, Dolly, and Manju, which was consistent with a still rather theoretical approach to teaching as emphasized in the section above. Exemplary reasons why they used questions during their lecturing were the following, as explained by Dixie and Manju below:

> I'll start proposing something but then I don't know necessarily if my thoughts are matching my words. And it's like, "Am I getting a head of myself, or have I just made too big of a leap and expect you to follow? Am I making sense still?" So, it's sort of a check to reign myself in as well. And when they look really lost, they can't hide it. I do try to look around the room. And if some of them are looking confused, I'll backtrack and go over it one more time. And then they usually look reassured. But yeah, there's just this resistance to admitting that, "I don't really understand that." (Dr. Dixie, interview)

> And then I lecture them, okay because I know that okay for 20 or 30 minutes I lecture them. Then I pose questions to them, okay you ask them the right questions. Or I'll ask them "If you have any questions ask me now." So, I don't mind if there's a disruption when I'm actually talking, and if somebody raises their hand, I'll stop my lecture and I'll answer the question. I will generate the discussion right there. Okay if some student asks me a question, why is this this way? Then I will ask the other students to put out there their opinion about how they can answer it. […] And then we'll discuss the process and how their answer was correct, or why their answer was wrong, and why it was wrong. And how mine is correct, and I'll give them the general answer. Because of these reasons, it is the correct answer. So, it solves the question as well as engages students in an opposed view too. (Dr. Manju, interview)

While both instructors emphasized the use of questions to “check-in” with their students, both instructors got fewer answers on their posed questions than on questions they asked their students for which they provided enough time for students to answer. Dr. Danner made use of posing questions to his whole classroom less frequently than other participants in the study, but made sure to get student responses back and not only rely on visual feedback, if they agreed or not/looked confused or not:

> So, as you saw the lecture that you sat in, the ... centered around the PowerPoint slides, but I also do a lot of talking, I write things on the board, I ask them to do stuff that wakes them up. I always ... Today I didn't, but in general, I like to have 'em do activities. In the big class, you really can't do all that much because you don't have the time, and you have a tight schedule, and you have to cover everything. But just setting aside a few minutes each time, I think, is worthwhile, because it, again, wakes them up, and you get a bit of an idea of how well did that sink in. If you ask them to calculate a ph from a weak acid and only to people get it right, then you have to explain it again. […] There's those in-class problems that I give 'em, but ... And then if there's a numerical answer, or if it's the R form or the S form, raise your hand and tell me what you think. So, you get a rough idea. But then if you ask them what's the Ph, then two people answer, and you don't know what the rest thinks. And I ask them if anyone get anything else, and you want to discuss it, but then in a class as big as this one I'm not sure they would dare to say something, or would they just be quiet instead. (Dr. Danner, interview)

This group of participants tried to engage their students in class. Some instructors were able to do this frequently, others sporadically. For example, Dr. Dixie was able to use hands-on models from time to time in class, if she came up with an idea that could fit the topic.

> I give them pull and peel licorice actually. […] And then it's like, "Okay, we're gonna play with DNA remodeling with this 'cause it's stretchy and really flexible." And then if it tears, they have multiple pieces. And that's worked really well. (Dr. Dixie, interview)

She also reported using in-class discussions from time to time, on either a spontaneous basis or through announced group discussions of assigned papers. However, activities like this would happen less frequently, than in Derrick’s class, where frequent short groupwork activities were used in class, as elaborated earlier upon. What was interesting in her style of teaching was her ability to categorize her posing questions as an active involvement of her students in class and therefore, a student-centered component was always present in class.

> I do it a lot, even when I ... I do it with my graduate students in lab. I'll start proposing something but then I don't know necessarily if my thoughts are matching my words. And it's like, "Am I getting a head of myself, or have I just made too big

> of a leap and expect you to follow? Am I making sense still?" So, it's sort of a check to reign myself in as well. And when they look really lost, they can't hide it. I do try to look around the room. And if some of them are looking confused, I'll backtrack and go over it one more time. And then they usually look reassured. But yeah, there's just this resistance to admitting that, "I don't really understand that." [..] To me, it's just having the students actually participate. Not necessarily like teach themselves or give the lectures, but not just sit there and record or sit there and look at the Power Point. Yeah, basically just not sitting there. And just like, "Okay, you're talking." But to force them to either react or better to engage. And so, part of the, "Are you guys following along, does this make sense," is just to get them to actively affirm that, "Yes, we are paying attention. Yes, it makes sense." (Dr. Dixie, interview)

When she incorporated true activities and more student engagement, however, she did that in separate lessons that she only dedicated for paper discussions, for example.

> Within class. So, they have a week or two to read a paper. And I assign each group a figure or two that they have to present. But they get to discuss it as a group. So, if everyone is lost, they can usually kind of fight their way through it together. If one person understands it then they can explain it. And then they all participate. And I can tell when they're done talking about it because it gets a lot noisier, and there's a lot more laughter. It's like, "You're talking about your weekend, whatever. Stop, we're done." And then I just pick group leaders based on who is the oldest. Who is going to the coolest place for spring break as discussed by your group. And then they represent their group to explain the figure. And I go through enough papers, I have enough figures that everybody gets to take turns being the group leader. And that's actually worked really well because they're more quick to ask each other questions. (Dr. Dixie, interview)

Dr. Manju tried to make it a habit to add mini discussions at the end of lectures to engage students with the material and to further discuss problems and applications posed during lecture:

> Researcher: So, for your class discussion, when you say you do class discussions. By class discussion do you mean you ask them a question about a problem that is related to the content you're just teaching, and then to answer, that's the class discussion style you mean, right?
>
> Dr. Manju: Right, yeah. It's not like an actual giving them a topic and asking them to give a five-minute talk or something like that. But I want them to generate a discussion between them. Because of the time constraints, you cannot have everything, plus you have to finish the

> course, all the things, within the given 16 weeks' time. (Dr. Manju, interview)

Dr. Dolly also added student-centered activities in class somewhat sporadically. An example that reflects her style of activities is provided below. With the first example, she talked about how she introduced metabolic pathways to her students. With the second example, she referred to a group of students who came to the front to act out an enzyme-substrate chain reaction:

> And better than memorizing those enzymes in those steps or what goes in, what comes out, I keep telling them, "Okay, this is a process of carbon oxidation." I kept saying that and they don't see it unless I point out, so I will point the steps. "Look at this carbon, and follow that one if they are being oxidized. And then I lie because, yeah, this carbon didn't change until this point, and then it suddenly changes. What does that mean? That means it's going to produce energy. Instead of showing the step by step, reaction by reaction, and this is the citric acid cycle, I try to go back and forth, what was before, what was after, what we are looking after, what was the goal of this reaction? So that's where I to do, try to keep telling what the big picture was there. And have the students organize that information on their own. (Dr. Dolly, interview)

> And if ... And there are some difficult topics and I repeat a lot. But when I repeat, I don't want to repeat the same thing over and over again, so that's how I decided to use in certain topics that [enzyme] examples. Those are have to learn information, so I'm going to have to repeat that, but if I kept saying the same thing over and over again, it's not going to really take it. (Dr. Dolly, interview)

Observation of Dr. Dolly's class indicated an approach to her classroom that involved her posing rhetorical questions to her students, and thinking of ways to involve her students actively by posing questions to them throughout her lectures. In a manner that was similar to professor Duna.

Danner was a good example of an instructor who tried to incorporate more student engagement, even in a larger biochemistry classroom. One way of engaging students more actively involved incorporating various media into his class to emphasize concepts in multiple ways. Same concepts were reiterated on the board, in a video, on work sheets or through posters in class.

> Dr. Danner: I regularly show PowerPoint slides, animations, and video clips, which students generally find informative. […] I regularly show PowerPoint slides, animations, and video clips, which students generally find informative.
>
> Researcher: […] Why did you use three different basically methodological tools to convey the message? What was you intention and what do you think your students get out of it?
>
> Dr. Danner: More is better. If you see them more than one way, and you're struggling with it initially, maybe the second or third time around is gonna click. You don't have the luxury to do that all the time, so that was maybe ... I don't do that with each and every topic that I have presenting it three ways. Maybe two. What often happens is that I describe things using either the slide or the board or both, then to summarize it up, I show a clip, an animation, or a video. Something like that. And on occasion, there's a handout or an in-class activity.
>
> Researcher: Your intentions and why you switch between techniques. Is that the making them exposed to all the things with the different resources?
>
> Dr. Danner: Yes. Different angles. But also, to mix it up. I don't want to be talking for 50 minutes without interruption. I think that's ... A) It's hard for you to stay on focus, and B) it's hard for them to stay focused. (Dr. Danner, interview)

He would also, from time to time, have work sheets prepared, for student to work in class together. Those activities were around 5 minutes long and solutions were discussed right after the activity was done, by going through the activity step by step with the entire class listening to or answering questions.

> So, as you saw the lecture that you sat in, the ... Centered around the PowerPoint slides, but I also do a lot of talking, I write things on the board, I ask them to do stuff that wakes them up. I always ... Today I didn't, but in general, I like to have 'em do activities. In the big class, you really can't do all that much because you don't have the time, and you have a tight schedule, and you have to cover everything. But just setting aside a few minutes each time, I think, is worthwhile, because it, again, wakes them up, and you get a bit of an idea of how well did that sink in. If you ask

> them to calculate a ph from a weak acid and only to people get it right, then you have to explain it again. (Dr. Danner, interview)

Dr. Duna, who had a rather traditional style of teaching, introduced fill-in-the blank notes to her classroom, to encourage her students to pay more attention in lecture:

> Interactive I just think is being ... Maybe the fill-in-the-blanks is because they're actually having to not just sit there. […] I think I just wanted them to be interactive. I knew I had so much material to get through that they couldn't write everything down, but I didn't want them wandering off. That's how I came up with this skeletal kind of note system where they have to interact, but it's not overwhelming like writing everything down, so they can still listen at the same time. […] Then in the Biochem course I would post the full notes, so if they didn't want to fill in the blank at all they didn't have to. It was just a way of keeping them engaged. That's seem to work. If you have too many blanks, then it goes too slowly. If you don't have enough blanks, they start yakking. There's a fine line. You got to find that. (Dr. Duna, interview)

On a technological side note, all participants referred to who were transitioning, or trying to transition into a more student-centered teaching environment, seemed to use primarily PowerPoint as a tool to communicate concepts.

A Great Start – but Still Room for More Student Engagement

Dr. Donna had an interesting teaching style that was both observed to be and described by her as being in a state of transition. Pursuing an educational research career, she was aware of different pedagogical techniques and the education research literature (Table 4.19) but faced challenges in implementing more evidence-based practices in her own biochemistry classrooms (Table 4.15, Table 4.16). Thus, she relied heavily on lecturing.

> I try to do lots of storytelling in my class, in terms of if they can figure out the story of what's going on, it helps them to learn the material. If they can tell the story of glucose or tell the story of if I'm a type one diabetic, what happens in my body? (Dr. Donna, interview)

She expressed the importance of exposing her students to certain visuals to help them grasp biochemical concepts better.

> So, if there's something like a dynamic process, for sure there's animation to go along with it. I try to use as many representations as possible. (Dr. Donna, interview)

As much as she felt comfortable, she cultivated an environment of engagement in her classroom by frequently posing questions to her students and getting answers to see what they understood and to encourage them thinking:

> What I try to do is a lot of student led questioning, I try to ask questions to help lead the student to the conclusion I want them to make as opposed to me just telling them the answer. The other point that I try to enact that is ... I guess it's just lots of questioning. (Dr. Donna, interview)

Her students would also ask questions and foster from their side of the classroom the same culture of involvement. From time to time, questions would expand into mini in-class discussions that temporarily, cultivated a more student-centered environment. Through sporadic POGIL-inspired group work activities (Bailey et al., 2012), and engagement opportunities through clicker questions, she tried to add more layers of student-centered teaching methodologies to benefit her lecture in multiple ways.

> I also use the clicker questions in class to allow them to get instant feedback from me in terms of what they understand and what they don't understand. And to allow them time to process that information as well. [...] I did what I could in terms of embed clicker questions using [software] because that kind of low hanging fruit for me to be able to teach according to my philosophy of getting instant feedback from students and giving them time to pause and stuff like that. (Dr. Donna, interview)

Her intentions with POGIL were the following:

> In order to develop students' collaborative and critical thinking skills, I will incorporate a Process-Oriented Guided Inquiry (POGIL) approach both in lecture and laboratory. During class, POGIL-style activities enable students to explore data or information and then invent the concept of interest through a series of questions within a group environment. (Dr. Donna, teaching philosophy)

Assessments, which have been studied in the research literature were not elaborated on in the context of this dissertation when an emphasis was made on a certain kind of in-class assessment that helped to understand teaching methodologies better, however, I noted these as exemplary cases. It would be useful here to point out that Dr. Donna integrated group quizzes into her classroom to encourage students to think as a team and choose the correct answers in agreement with each other, comparable to Dr. Brigid approaches. Dr. Donna's POGIL exercises were in many cases embedded in her quizzes.

> So the group quiz, when I actually have time to get it put together before class, I input questions into [software] has a group quiz function to it to where they get questions as an individual and so I give them a certain amount of time to answer the questions in the individual round. And it counts for twenty-five percent of their quiz grade and then the remainder of the time I switch it to group quiz and so that's where they can see everybody's individual response. And then they come together and have one single group answer. So, I see those results in real time on my phone. (Dr. Donna, interview)

Almost There – Closer to Student-Centered Teaching

Student-centered teaching methodologies were more common in the next group of participants, which included Dr. Devora, Dr. Brigid, Dr. Dana, Dr. Maggie. Besides student involvement through encouraging student-motivated questions, more group work activities and active student-engagement were present in these classrooms. Dr. Dana for example had an active classroom where she would almost constantly pose questions to her students and let them finish her sentences, add to what she said or answer a question she posed. In addition, she would utilize visual programs, in about 5-minute increments, to guide her students through a task and let them finish it on their own. Student engagement varied from individual work to group work, but they would work on tasks frequently throughout the entire lecture, as she noted:

> I would do just straightforward lectures, reading from the slide, or then I would try to incorporate some activities of some sort. Anything where the students weren't listening to me talk, but they were instead talking in groups, or asking questions, or doing something on their own. I found that they were happier, and they worked better, and they were learning better, and they seemed to understand things more. So, it's a little anecdotal, but my feeling was that it was a better way for me to teach. For me, that works much better. (Dr. Dana, interview)

Her lecturing also relied heavily on a "conversation" with her students, posing questions to them and answering questions from them.

> We do a lot of activities, things where they have to use their hands. Silly things like building amino acids with pieces of paper and stickers, or enzyme kinetics, where you transfer candy from one plate to another. Sometimes a bit silly, or a bit simple, but it helps them understand the concept, and the advanced students think it's a bit funny, but the students who wouldn't otherwise understand it tend to grasp the concepts. (Dr. Dana, interview)

She further said about the use of questions in class:

> Yeah, I do that just all the time. Basically, it keeps them thinking. And again, sometimes I think I perhaps do that a little too much, and so I think it can probably get a bit tedious for some of the students. But it keeps them mostly engaged, so I often try and ask questions that I think they're going to get wrong, so that when they get it wrong, they realize ... You know, there's that little shock where that's a learning moment. If I can I do that. I've seen other people do that very well in teaching. (Dr. Dana, interview)

She added a structure of small group work increments to her lectures, in which students worked in small groups on problems for 2-3 minutes and then got together with her to discuss the solution as a whole. Worksheets and fill-in-the blank notes gave her the necessary "active" structure to run her classroom like that.

Maggie took student engagement in her classroom even a level further, in as much as students seemed to be involved in every moment of the lecture, may it be during lecturing or activities. Dr. Maggie voiced that she was relying on POGIL as well as PBL learning activities (Savery & Duffy, 1995) to guide instruction. She also tried to bring in the newest technology to give students the opportunity to visualize biomolecules in a different way. This was enriched by her technology and engineering heavy background.

> I think videos are extremely important. There's a lot of dynamics that gets lost when you teach biochemistry with the standard static techniques. I like to use 3-dimensional representations. Either just the regular twirling molecules where you're telling by shading, for people who can see that, or the 3D representations that I use. (Dr. Maggie, interview)

The third instructor in this category was Dr. Brigid. She was also interested in education research and her teaching style was informed by recent literature. She let her activities be inspired by applications and real-world examples.

> […] I talk about diseases. […] I think getting the students interested in real-life things really does help, because we don't have a lot of pre-medical students, but we do have some, and so that gets them very interested. Application is great, and if I can incorporate it, we talk about certain diseases. Like a couple weeks ago, we were talking about phenylketonuria, and why does some of the population have this? How do they test for it? They're really interested in all that sort of things. I think I would like to work more on application stuff, but again, that takes a lot of time, and you have to sacrifice content then. (Dr. Brigid, interview)

Her in-class activities usually involved group activities that lasted for about 5-10 minutes. Even though assessment will not be discussed further this dissertation, I want to point out that one of Brigid's her group work activities was to have them do group quizzes, similar to Donna:

> Then they take the quiz. They go over the quiz again in their groups, because they talk with the other students, and I think the other thing is that having multiple perspectives can often help you understand something, which is why I have the other students, I think, are a resource for learning material because while I might be able to explain it in the way that I understand it, sometimes another student may

> have a better way to get to the right answer. Sometimes the students might have a way to get the wrong answer, too, but then they learn. After the quiz, we go over it, and then often, they'll have another exercise like a POGIL exercise or something where they'll go over it again. That repetition, I think, helps them especially learn content. That is a way to learn content, because in the end, you have to know things. (Dr. Brigid, interview)

In addition to these quizzes, she also had the students do worksheets together, throughout the entire lecture period. Worksheets were based on and inspired by POGIL and PBL learning questions.

> I try to do some active learning every day. I don't lecture all the time. I do some lecture. Lecture is the fastest way to deliver content. I don't think it's the best way to deliver content. Almost everything I lecture on, we have to have an active learning activity, because I want that repetition to get into the students, so they know what's going on. That's another resource for them to study for the test. They have these sheets, these either POGIL exercises or something else […]. (Dr. Brigid, interview)

The last instructor in this category is Dr. Devora. She had a semi-flipped classroom setup, where she used one of her three hours of teaching each week for purely student activities, with no lecturing. She called this her "flipped Fridays". She encouraged her students to work in groups together in every lecture, but on these special Fridays, she made it her mission to implement that style of teaching. Her students sat together in groups of six people. This structure allowed her to incorporate her beliefs regarding having her teaching be application-oriented, emphasizing less memorization and more thinking/application in class.

> Researcher: What makes you divide that week in the way you do, and what makes you be comfortable with the justification that, "I can let that stuff, them learn on their own, and do more practice problems on Friday"? What is the rationale?
>
> Dr. Devora: The rationale is that practice is good, and teaching them how to practice is good, because some of them don't know. I think if it was more, they would become more resistant to it, and so I've created this arbitrary threshold where I think they can handle one class out

> of the week, and I can handle one class out of the week. It takes much more time to prep for Fridays as well, and so, in a week where I've got 20 student contact hours […]. (Dr. Devora, interview)

As an instructor with a heavy interest in education research, she was familiar with student-centered teaching methodologies and also tried to make a habit of incorporating a variety of these techniques, such as think-pair-share for example.

> The different types of activities that I do, I feel like some areas fit better to different types of activities. We do a lot of think-pair-share questions. I call them think-pair-share, because I know if I just ask the class a question, it's only going to be Joshua or Emily, or whom in the front seat are going to answer, and that's it. I call them think-pair-shares, because then I give them a minute to discuss, and then I'm going to call on you guys over here. You know I'm going to call on you. I'll do, maybe, problem sheets, if it's a lot of central dogma stuff. I did some group problem sheets, which I don't do loads of, but I know that there's a lot of terminology there, and the more practice they have with doing that, the better. It really kind of just depends. (Dr. Devora, interview)

During her Fridays, her group work activities could be long and extended. However even during her "regular" lectures, she incorporated group work activities, where students needed to answer a question she posed through PowerPoint slides. She and her TAs walked around and provided support where needed.

All of the instructors highlighted in this group were trying to use less lecturing and more student-centered activities to convey knowledge. For Dr. Dana, lecture was built around her in-class activities. Her classroom was fast paced, and lecture was used to convey enough knowledge to set up the next activity again. However, she also emphasized the use of analogies to connect the students better to the topics taught, which was previously seen with instructors using a less activity-oriented lecture style.

> One of the things as I get them to try and make an analogy, we do use that a lot in class, so explain a biochemical topic in terms of an analogy that they could explain to their friend, like using cars on a road. That seems to help make sure that they help understand the concept. Sometimes then they can't go back and remember all the terms, but do they understand the concept? (Dr. Dana, interview)

Dr. Maggie utilized lecturing in her classrooms, supporting the concepts she conveyed through stories and analogies. She put a large emphasis on the fact the she tried to work hard on reducing her talking more and more, which was a trend within the group of instructors discussed in this section:

> That particular lecture felt like a laundry list of things we have to go to before we can get into stories, which, you know, it's not optimal. I do try and do group work, not in that particular lecture, but I do try and do group work. I've written a bunch of POGIL-esque. They're not strictly POGIL, but that type of style of learning so that the students can construct their own knowledge. […] And there certainly are days where you just have to get through a bunch of material, and it's taking notes, and we do that. I try and break it up more with bigger periods than a minute, two minutes, like where they actually ... There are classes where they are working with each other the whole time. Like I am not lecturing at all other than summarizing at the end. […] Well, some of it's pacing. You know I just know, oh, here's a chunk of lectures so I'm going to need something to break that up and what can I do with it? Some of it is conceptual. Oh, this is an extremely important concept. I would like them to really learn this well, so let's do an active learning exercise associated with that. Pacing from a sense of not letting them fall asleep too much, and then the other is what are the really important concepts I want to get across and so I would like to reinforce those with an active learning sort of thing. (Dr. Maggie, interview)

Dr. Brigid tried to stay away from lecturing as much as possible and relied on activities to involve her students and engage them with the material. She tried to only have mini-lectures where needed for students to get information, as pointed out above. In Dr. Devora's classroom, two thirds of her classroom time relied on lecture - conveying concepts her students needed to understand al and apply later, during her "flipped Fridays".

> I call the Fridays flipped Fridays, meaning that there is content that you're supposed to be covering on your own, but sort of recognizing that a lot of them won't do it. I try to go through most of it on the Monday and Wednesday […]. (Dr. Devora, interview)

Student-Centered Teaching in Biochemistry – in all Shapes and Forms

The three participants that included Dr. Berry, Dr. Donald, Dr. Bobbie in this last category, shared a level of student engagement that was high and they each tried to use methodologies that were more student-oriented. Inspired by her beliefs that students need to memorize less memorize and think more during lectures, Dr. Berry implemented POGIL in her classroom and minimized lecturing. Her students worked together in groups of about four on worksheets during class time, with her and her colleague in the classroom to moderate the discussion.

> I appreciate that it happens in small groups and with students struggling through materials, I think them talking is more effective than me talking. I try and listen to what they're saying and if I hear things that are wrong, trying to guide them towards the correct idea. Often, I end up saying it just because they've hit the frustration point where they're not learning on their own. They just need to hear what is it? Now that I'm done being frustrated I can move on. It's more listening to what they're saying and less of me talking. (Dr. Berry, interview)

This team-teaching approach helped her cover all of her groups and check-in with groups frequently during a class period. Students were encouraged to share their answers on the board with the entire class. At the end of a lecture, the class would get together, and the instructor went over major learning points for that day or provided clarifications where needed:

> You do end up doing lectures someday. Just need to say, let's orient the system. Even saying things like FAD is used to do carbon, carbon because I'll go off and talk about it FAD is used to do single electron oxidation reactions, NAD is used two, it's a hydride. They're like, oh now I get it. It doesn't say it so you have to say it. There are times you have to lecture, but yeah. In general, I like it a lot better. (Dr. Berry, interview)

Dr. Donald implemented a full flipped classroom in biochemistry. His lecture was dominated by clicker questions presented through PowerPoint. In increments of two minutes on average, his students would answer a question in groups of about six. He would then bring his class together again and talk about the solution, pointing out what he had seen when he walked around the room while they were working, keeping students engaged.

> Dealing with a huge number of students, this is a great way, because they're involved during the class. They're all participating. One class, if I start right with a calculation, I'll have a title slide, and right at the bottom of the slide, "Get your calculators out now." And boom, we go into a calculation. I want them to know that they know it. You kind of have to [inaudible 01:00:36], when I make up the clicker questions, you can start off with some that are fairly obvious, and get in more and more deeper. That's what I wanna, I wanna get people getting the right score right away, and then getting in where it's a little harder, where they have to think. If they're thinking biochemistry, my god, that's wonderful. […] I'm not at the podium all the time. I'm walking around, talking with students. And if a table has their hands up and the LA's can't get to them, I go there, and we figure things out. Doing that with students, it makes me feel good. And it's helpful. They see that the old professor is really talking to them and helping them through. (Dr. Donald, interview)

He basically never really lectured, other than pointing out important concepts during the discussion of the solutions. He incorporated case studies in his questions, to have his students apply concepts to other scenarios.

> That's what I want my kids to be able to do, is when they see something that they have never seen before, instead of pulling a blank, start looking for the things about it that they know so they can get in to solving it. Because a lot of times, when students are unprepared and I population up a new question, there's that blank look on their face, "I don't know what this is about." You wanna get them to the point where they don't have that. They've done the material so that when it comes up, they can start going to the places in the text and stuff, how they could get to the area to solve the problem. Then the case studies, I usually have, oh, in three lectures, I'll have two case studies, 'cause you have to present the case. A lot of them are medical. (Dr. Donald, interview)

He also mentioned that his questions were guided through problem solving approaches.

> That was the start of the transformation of being able to get, to be able to do biochemistry in the classroom rather than lecture at students. To have the students actually actively participate in problem solving, analyzing case studies, data, and using clickers to answer the questions. (Dr. Donald, interview)

Dr. Bobbie had her classroom organized similarly; however, it was not a true flipped classroom setup. She had her students work in groups of two on assigned problems from a worksheet handed out in class. She assigned group work rather freely and encouraged them to work together but did not force them to do so. She walked around constantly in class, checking their work. If she saw that many students were struggling with the same concept, she brought them together again and discussed the issues in form of a just-in-time teaching intervention, giving a brief lecture and some reminders as needed.

> I would say mini lectures but driven as much as possible by student questions. What I spend a lot of time doing is trying to prepare a set of exercises or questions or activities for the class to gauge the class so that then I know what do they now understand that we don't have to cover much and what are they struggling with. Like where is their hang up. Sometimes that's on an individual basis, but sometimes like you saw the group has misconception that I have to get in there and say, "Wait time out, you are all forgetting this key thing. You have to look at the units, if you forget the unit you are going to get the wrong answer," so stuff like that. (Dr. Bobbie, interview)

An interesting observation that went along with instructors using more student-centered teaching methodologies was, that the more they did group work or other student-oriented activities, the less the instructors relied on PowerPoint presentations.

> For me I could do that, I could take the PowerPoints from the textbook and give a PowerPoint lecture but what good does that, I don't see how that helps the students understand it better. I mean maybe a little bit but not in a significant way and not in a way that you can apply to other questions. (Dr. Bobbie, interview)

Instructional strategies focusing on student-centered teaching that were mentioned by my instructors discussed in this section were common practices reported in the research literature as being effective active learning strategies (Van Dyke, Gatazka, & Hanania, 2017).

4.3.1.1.1 Instructors' Opinion About Their Styles of Teaching – a Realistic View

The following table summarizes how instructors defined their ways of teaching. Before the interview started, participants were asked to provide a brief summary, consisting of one or two sentences, about their teaching styles. Quotes listed below in Table 4.10 were drawn from recruitment emails, where all instructors had to answer how they would describe their pre-dominant style of teaching in the class observed. This action was inspired by two research studies that guided my way of thinking about probing beliefs and perceptions (Brickhouse & Bodner, 1992; Richardson, 1996). Richardson (1996) pointed out that perceptions and beliefs are connected and interrelated with one another and that when they're investigating these topics, it was important to get a good understanding of actions taken in the classroom. Brickhouse and Bodner (1992) concluded how beliefs and actions can sometimes be disconnected and instructors can struggle to put their beliefs into action in their own classrooms, suggesting the need to further investigate the instructors' individual interpretation of their teaching styles.

Below Table 4.10, I critically viewed each of their provided quotes. I compared those with what I have observed in their classes, topics we have talked about during the interview and additional artifacts they provided.

Table 4.10 Instructor quotes on their style of teaching in the classes observed

Type of institution	Participants	Written statements
Doctoral granting institutions	Dr. Derrick	The course is taught in a fairly traditional manner, but I try to insert a break midway through the period to allow the students to work together for 5-10 minutes on a problem or question.
	Dr. Devora	A mix of everything. Traditional lecture, semi-flipped, problem-based learning, teamwork, project work.
	Dr. Duna	Traditional and interactive lecturing style… lecture but ask occasional questions in class, answer questions as we go along.
	Dr. Dixie	I would describe my teaching style as a more interactive lecturing style - I try to promote questions and discussion during every class. That being said, I’m not always successful in getting people engaged, and then it feels more like a traditional lecture.
	Dr. Donald	My class is total flip...NO face to face lectures. All the "lectures" exist as narrated PowerPoints that are spiced with Thought Questions. Face to face time is all problem solving and case studies. Doing Biochem with students rather than lecturing at them.
	Dr. Danner	Lecturing with a few in-class activities
	Dr. Dana	Interactive lecturing style with group and individual activities. Often use computers in class for activities.
	Dr. Dalton	I teach in a traditional lecture style.
	Dr. Dolly	It is mainly in lecture format– but I would be hesitant to call it as “traditional lecturing” as many interactive things are happening. I do not like to call my class in one style or another.
	Dr. Donna	Probably interactive lecture. […] This semester I'm going to try to do more case studies group work with them. We will see how it goes.
Master granting institutions	Dr. Magnus	Traditional lecture.
	Dr. Manju	Traditional lecturing with class discussion along with problem-based learning
	Dr. Maggie	I have a mix of lecture, group work, and problem-based learning. During lecture, I try to break frequently for the students to try out problems.
	Dr. Mickey	For lecture, I use traditional lecturing. […]
Bachelor granting institutions	Dr. Brigid	My style of teaching is a mixture of different styles. Sometimes I lecture. Sometimes I use POGIL. One of my favorite things is to do multiple choice quizzes (Reading Assessment test--RATs) and then have them use IF_ATs to do a group quiz. I don't think that lecture only is a particularly effective way for them to learn the material, but sometime I do use it to present the material. I don't really used what I understand to be the "flipped classroom", other than that I insist they do the reading. (By the time they are juniors and seniors--they should be doing the reading).
	Dr. Berry	This year we are teaching it using a POGIL approach. We do mini-lectures but the majority of time is spent with the students working in small groups.
	Dr. Bobbie	Problem-solving during class with explanations/discussion.

Below is my interpretation of each participant's definition of teaching style. The written statement provided by most instructors was consistent with the views discussed in the interview and what was seen in the classroom observations. Participants are listed below in the same order as shown in Figure 4.1.

Not There Yet – a Primarily Teacher-Centered Approach

- Dr. Mickey: He summarized his teaching as a traditional lecture style. He had a strong emphasis on lecturing when was observed, as well as during the interview. He pointed out that that was the style he identified the most with.
- Dr. Dalton: He briefly summarized his teaching as using a traditional style. He had a strong emphasis on lecturing when being observed, as well as during the interview.
- Dr. Magnus: He briefly summarized his teaching as traditional through lecturing. His definition mirrored what I observed when gathering my data.

Advancing Toward Student-Centered Teaching – One Step At A Time

- Dr. Danner: He also described his teaching style along the lines of what I have observed, and my data revealed: "Lecturing with a few in-class activities".
- Dr. Derrick: His perception about his ways of teaching were consistent with what I observed in his classroom and what he reported during the interview. The only discrepancy I saw was that he estimated that he used a bit more

time for in-class activities than I observed. His group work activities were usually about 2-3 minutes long, at most.

- Dr. Dolly: Dr. Dolly viewed her style of teaching in a fluid way. She made a point of saying that she chooses not to call her approach to teaching as one style or the other. In her mind, many activities involve her students, including the way she presented her lecture material and talked to her students during lecture. She did say that she views her teaching through the lens of lecturing mostly. The only discrepancy I saw between her description and what I observed and gathered from the data was that she possibly overestimated the level of student engagement she was able to establish in her classroom.
- Dr. Dixie: She viewed her classroom as a more interactive and engaging environment, since she posed questions that encouraged her students to hold discussions in class. She admitted though, that her lectures usually followed a rather traditional lecture style, due to challenges she faced when teaching biochemistry.
- Dr. Manju: Dr. Manju emphasized the use of lecturing mostly during his class time. However, he pointed out that discussion and PBL were integrated as well. Dr. Manju always tried to incorporate discussions and applications, which he referred to as PBL. The items described emerged during his lecture and also during the interview, where he mainly talked through applications and problems.

- Dr. Duna: She viewed her teaching style consistently with how I interpreted it. She emphasized her teaching in a traditional way, however pointed out that there were also interactive components in her teaching. This was true for the fill-in-the-blank notes she provided as well as her tendency to occasionally ask questions of the students, as well as get questions back. The interactive component was limited, though, with her class using mostly instructor-student interactions and less student-student interactions.

A Great Start – but Still Room for More Student Engagement

- Dr. Donna: Her style of teaching can be described as "probably interactive". With her frequent instructor-posed questions in class and her efforts to have a conversation going with her class, as well as the activities she integrated, her views on her style of lecture were aligned with what I have observed in her classroom and what she has stated during the interview.

Almost There – Closer to Student-Centered Teaching

- Dr. Devora: She summarized her teaching style consistently with to what I observed and talked about in the interview. Her "mix of everything" fits well with her actions in the classroom and the versatile activities she offered to her students.
- Dr. Brigid: Dr. Brigid emphasized that she used an array of teaching tools in her biochemistry classroom, which were observed in her teaching. During

the interview, she focused more on these methods of teaching and elaborated more on their utility.

- Dr. Dana: She described her classroom as “interactive” and encouraged her students to work in groups and individually, often with computers. This accurately reflected the teaching methods observed when visiting her classroom. Her statements made in the interview aligned with the observed teaching style and her described way of teaching.
- Dr. Maggie: The mixture of teaching methods Dr. Maggie referred to were consistent with what was observed in her classroom and described in her interview.

Student-Centered Teaching in Biochemistry – in all Shapes and Forms

- Dr. Berry: Her exploratory style of teaching and her adventurous nature of trying out new methodologies in her classroom led her to implement a POGIL classroom this year to teach biochemistry. The emphasis on group work and the implementation of mini-lectures were observed in the classroom observation and interview.
- Dr. Donald: Since he had a totally flipped classroom, he had a significant amount of face-to-face time with his students. He viewed his class as an action-and-practice-oriented class, rather than sitting-and-listening. “Doing” biochemistry was key for him that was reflected in both the observation and during the interview.

- Dr. Bobbie: She discussed her style of teaching using a problem-solving orientation, involving group or whole class discussions as needed. This is also what was observed during her lecture and in her interview.

Even though minor over- or under-estimations were encountered, the instructors had a rather realistic view of their style of teaching when teaching in a biochemistry classroom (compared to what was observed in their respective classroom and discussed in the interviews). Of course, all descriptions and definitions are subject to daily changes in teaching due to adjustments that have to be made or other circumstances that have to be met, as noted by Mack and Towns (2016) in their investigation of physical chemistry instructors' "beliefs about the purposes for teaching undergraduate physical chemistry courses". To account for capturing instructors' typical methodological style of teaching, each participant was asked to describe their typical style of teaching. Participants also verified that the lecture observed represented their usual style of teaching for that particular student cohort and in that course setting. All information provided was compared to their interview transcripts and artifacts provided.

4.3.1.1.2 Instructors' Perceptions on Active Learning Within Their Classrooms – a Multitude of Definitions

After looking at instructors' opinion on their pre-dominant style of teaching, I asked them during the interview, how "active" they view their classrooms to be. I posed two questions to them, as seen in Table 4.11 below. The first question aimed at what they viewed as "active engagement" for their students in their classrooms. The second question tried to reveal how "active" they thought their classroom was overall. Both questions were posed when we talked about their pre-dominant styles of teaching and how that was executed in their classrooms. The table below will illustrate responses I got from my participants. Quotes originated from their respective interviews and are from participants solely unless indicated otherwise. Sometimes, names are indicated in the table below, to highlight questions I asked as the researcher and which parts participants have answered.

The table generated below, originated from the original code “teaching methods” (see Table 3.5). This code encompassed results that related to instructors’ interpretation of active learning when teaching biochemistry.

To help understand the quotes provided in the table below for both questions, and break them down into smaller pieces of information, I have provided two tables following the table below, to provide a simplified overview of the results, before further elaboration (see Table 4.12, Table 4.13).

Table 4.11 Definition of active classrooms and if classrooms provide active learning opportunities

		Quotes*	
Type of institution	Participants	What does active learning mean to you in your classroom?	How active is your classroom?
Doctoral granting institutions (continued).	Dr. Derrick	Active learning could take several forms in the class. It might involve students individually answering questions posed by the instructor during class, students working in groups to discuss a problem before giving a response or students doing online research on a topic during class to answer a question. In the metabolism class that I taught, I would pose one or two questions during the period that the students would need to discuss in small groups. These questions often extended a concept that was addressed in the lecture by requiring the students to answer a problem or question that related to the concept.	I do not consider my classrooms to be very active at present. I agree with the argument that having students work out a problem on their own or in groups helps them acquire critical thinking skills and helps them acquire a fuller understanding of concepts than simply giving them the information in a lecture.
	Dr. Devora	I think that active learning requires definition for a workshop, and other than that, it's so subjective. […] Are they actively learning? Do you mean are they learning? Is learning not active? You could get into so many conversations about that. I feel like you, as a motivated learner, could actively learn some content topics, whatever, while sitting there listening to me, for example, and taking occasional notes. For other students who would do that, and that level of note-taking in my class, that does not constitute active learning, so it's different for different people. […] I think, in terms of a classroom, what is active learning? […] you just peel off the activities that you do. It's like, "Oh, well, we do group discussions, and we do peer collaborations on case studies." It forces you to put labels on things. "We do think-pair-share." I'm just like, "Is it really think-pair-share?" You know what I mean, though. We do this, we do that.	Researcher: Do you think you execute active learning in your class? Dr. Devora: For some people, yeah. Some people are actively learning, and other people are not. […] It's different for different students, I think, what will actually make them learn. For some people, taking notes while I'm lecturing is active learning. For some people, they are going to need to take a break and draw out multiple examples of a diagram, or they're going to need to have a conversation with somebody else, whether it's me, whether it's a TA, whether it's going to a help session. It's different for different people.
	Dr. Duna	[…] Interactive I just think is being ... Maybe the fill-in-the-blanks is because they're actually having to not just sit there. It's not as passive as it could be. I guess just the answering questions. Asking and answering questions.	[…] It's about as interactive as I get is if they ask questions and I try and answer them. Or if I'm doing a demo and I have somebody come help me or something. You know? […] It's pretty traditional I would say.

Table 4.11 Continued

Doctoral granting institutions (continued).	Dr. Dixie	To me, it's just having the students actually participate. Not necessarily like teach themselves or give the lectures, but not just sit there and record or sit there and look at the Power Point. Yeah, basically just not sitting there. And just like, "Okay, you're talking." But to force them to either react or better to engage. And so part of the, "Are you guys following along, does this make sense," is just to get them to actively affirm that, "Yes, we are paying attention. Yes, it makes sense."	Whether that's a paper or a literature discussion or an in-class exam even, because I hate coming back in the evenings, no one likes a night exam. So, I just try to make everything happen during. And you build on time for questions and anecdotes and stories about people in the field. It's like, this is a really contentious point because ... And that's sort of a mental break for everybody. And you can incorporate some of that more active learning, but it takes the burden off that it needs to be totally revolutionary. And so you can kind of give yourself some breathing room until you find your balance.
	Dr. Donald	The kids are not asleep. […] Active learning takes place in phases. Phase A. Students have to get introduced to a coherent group of material (usually text chapters, or parts of them), my narrated Power Points which are the material with Thought Questions followed by a quiz they can repeat. This has to be done before Phase B = active class using the material they come to the face to face class to solve problems and analyze data. Phase B is important because use doing the subject helps solidify the knowledge in Phase A. Phase C is prep for the Exams, students studying on their own (plus or minus with friends), which demonstrates how much learning they accomplished. (Dr. Donald, Follow-up email to interview question about active learning)	In the active class room the problems to resolve or calculate are discussed between the students at the tables which results in individual answers from group work with iClickers. Peer to peer instruction goes on here, but the iclicker response is by the individual not the group. (Dr. Donald, Follow-up email to interview question about active learning) […]. Just a more active class, more clicker problems and stuff like that in class, face to face. That's what's important. […] You can see and hear the activity. I use a hand-held sound level meter: when they are perplexed the discussion is 40-45 db, when it gets really active it goes to around 60 db before they have to put in their iclicker response. […]. They can get louder to 70 or so db when something happens the they are talking loud and clapping. Otherwise, I have no scientific way of assessing activity. In my class it is rare to see a student doing nothing much, the LAs or myself are on those right away to get them into the action. (Dr. Donald, Follow-up email to interview question about active learning)

Table 4.11 Continued

Doctoral granting institutions (continued).	Dr. Danner	Doing things. Not just absorbing things. It can be as simple as doing problems that are not just regurgitation things from lecture. Working on projects. Hands-on things. That's what I'm trying to do, for example, with this visualization project that I keep talking about.	Researcher: Do you think that your classroom, even though you say you do a lot of lecturing, with the activities you have, do you think it's already active? Dr. Danner: As best as it can be. I don't know how you would ... There's probably a fluid transition from one extreme to the other. It's not as active as I'd like it to be. There's still a lot of students in there, I don't know how much goes in there and how much gets retained.
	Dr. Dana	Anything where the students' minds are actively engaged in a problem or a question. When they are learning, they're not being taught. So, when are doing the thinking in some way. Whatever it is that encourages their minds to be doing the thinking is what I'm trying to ... That's what I try to have happen, in whatever way I can do it.	Researcher: You don't want to lecture just to them. You want to make them ... You don't consider active learning as that much of a teaching part from your side then? Dr. Dana: Yeah, partially. Or I guess I bring the activities, but the students are doing the learning, so, yeah.
	Dr. Dalton	Dr. Dalton: Yeah, yeah. Let's see if we can take an example. They're learning to differentiate one stereoisomer from another in class. The activity is drawing the structure, recognizing that the functional group sticks out one direction for one molecule, sticks out the other way for another molecule. Then we take a look at the molecular model, and we associate the shape of the molecule with what we've drawn on the paper, put that together. Then the third piece might be to, say, recognize that the protein bonds to one stereoisomer versus another, something along those lines. That might be an example. Researcher: When you write your notes on the board and talk through them in detail, and I saw you do that, do you also think that it is an active process your students go through when they take the notes and think with you through that? Dr. Dalton: Yes, absolutely.	[…] it's an active form of learning, I guess.

Table 4.11 Continued

Doctoral granting institutions (continued).	Dr. Dolly	Dr. Dolly: The students are thinking about it, why we are talking about it. Researcher: Okay. Dr. Dolly: It's not necessary physically active and be in the act of something. Being a demonstration, not like that. But students are trying to connect with issues outside, or inside, the classroom. And I see that. And I don't think you get that in online classes. Researcher: And so active, is also for you, when the students nodding at you, and participating in the non-verbal communication that also ... Dr. Dolly: That, as well as bringing up the questions from outside of classroom.	At least the parts of that I enjoy, yes. Because students who never really engage, but at least I try. […] As far as engaged part, and also students ask questions in the middle of lecture, and I really enjoy that. Sometimes a student says, "I know this may not be, right now, relevant to what ... But, how about this?" And those are great, pointed questions. And the other thing, student says, "But in my cell bio classes, my professor said this." And I was able to explain it.
	Dr. Donna	Not sitting there ... Active learning is engaging with the material and not passively sitting there thinking that you just quote things to me. Talk at you.	So, what I would like is to have days where they're literally ... I'd like to have case studies, I'd like to have more days where they're just thinking trough the material. More application days where I shut up and let them think through the material. […] POGIL activity.

Table 4.11 Continued

Master's granting institutions	Dr. Magnus	I try to engage them, if nothing else, by asking questions, even if they're rhetorical questions, meaning I don't necessarily expect them to answer at least hopefully that they are thinking about these things. Although, frequently I will ask like this one came out today, what do you point out that in a fatty acid ... a polyunsaturated fatty acid double bombs run every third carbon. I said, what if they were on every other carbon? Then I say, "Well, where did you learn about this in organic chemistry?" At that point, everybody covers their face. No one wants to have to admit that they don't remember anything from organic chemistry. I know they learned this in organic chemistry, but I also know that they probably mostly all forgot it. I'm not expecting to know the answer. Although, usually some, at least one person will get the answer. I'm not expecting them to know the answer, but I just want them to think about the fact that what we're doing here relates to what they've learned before and if I can force them to make that connection even if they're not doing it on their own. I guess in that context, if the students are mentally engaged in what's going on then that's an act of learning, even if they're not necessarily physically engaged. I think a lot of people will define active learning environments are one where the students are actively asking the questions or involved in discussions. Lots of give and take. My class, certainly like I said, doesn't have as much event as others do. If I can have the students be thinking about these things in their own head, then perhaps it's active but in a different way.	Researcher: That's interesting. In your classroom, would you say that with asking questions and having them always alert with you by responding to you, if they have questions, would you define that as an active learning classroom? For you is your classroom active? Dr. Magnus: In that regard yes, it would be. Although, there are I know a lot of people have classes and structure their courses in ways that are much more interactive than what I do. I don't want to pretend to be the best example of what we would call an active classroom.

Table 4.11 Continued

Master's granting institutions (continued).	Dr. Manju	Student participation in class discussions and presentations. My method is engage students in active discussion during the class, as well as ask students to write research reports and presentation (in pair or group) on the topics of their choice related to biochemistry. (follow-up email after interview)	In my class we had very spirited discussions on the specific topic I am teaching. For presentation: peer evaluation and they graded based on class participation: how they answered the questions as well as quality of presentation (slide preparation, knowledge). […] 1. My class room is fairly active when there is a topic of interest specifically related to the medical field or interesting research article or news item is brought by a student or by me. 2. I would describe my classroom is active learning with limitation, many a times topic has to completed and tests/exams or other projects often hamper the student enthusiasm. Every biochemistry topic cannot be turned into active learning, specifically when it comes to amino acid structure, protein structures or simple reaction mechanisms involved or lipid and nucleic acid chemistry. Organic chemistry is the basis of biochemistry so often when it comes to organic aspects of the biochemistry. (follow-up email after member-checking)

Table 4.11 Continued

Master's granting institutions (continued).	Dr. Maggie	Dr. Maggie: My approach to active learning has been very much patterned after the POGIL approach that I went to a workshop ... I don't know how many years ago. Many years ago. The active learning and how they approached it and pattern recognition where they would give information and then the students had to construct their own knowledge. That really, really appealed to me. I like an active learning type of a classroom. Dr. Maggie: Where it's not lecturing and where the students are doing stuff. That they're active. Researcher: Like physically? Dr. Maggie: In some cases, yes. I mean group work I don't know that they're all physically active, but they're discussing.	In group activities there's that same idea of constructing knowledge of helping to teach the others in your group about things, about the engagement with the material. I watch them, and I almost cry because they're all busy talking about science and they have interesting things to say, and they're trying to figure these things out. They're interested then in the answer since they've invested some brain cells in trying to think up answers to things. That's, I think, why active learning became to me an objective in teaching.
	Dr. Mickey	As I mentioned earlier, lecture, to listen, process, and to take notes, that is an active learning process, so I think what I do is active learning. It's just on what I would call the traditional side of active learning, and the new methods that are coming out, I'd, you know, I'd ... done a little bit of a disservice to themselves by not acknowledging that lecture is a form of active learning.	I think my classes are actively learning, are all active learning.

Table 4.11 Continued

Bachelor granting institutions (continued).	Dr. Brigid	Active learning is where the students are given a task, and they have to come up with a reasonable result or answer on their own, maybe with some help from me […].	I think science is always a conversation, and if you can help the […] conversation, that's good. It's something that stimulates them to come up with an answer, and at the same time, promoting their understanding of the particular topic, so they have to be able to conceptualize what's going on. […] Yeah, this is mostly in group work. Active learning […] in group work, that is what's going on.
	Dr. Berry	Active learning is when the students are busier than the instructor is. They are mentally engaged with the material and do actively doing […] things with it. Like about the small group work is it's really hard to fall asleep. In a lecture, even my own notes I can see my handwriting trailing off. I think active is very much them minds on, hands on thinking about it.	I think it is the change is more that I was doing that about half the time where I would do kind of a mini lecture and then they would do the activity and basically the mini lectures they've either gotten shorter or moved to the end, as opposed to at the beginning. Which actually goes back with that initial teaching […] philosophy of having them struggle first and then have them resolve by the end.

Table 4.11 Continued

Bachelor granting institutions (continued).	Dr. Bobbie	Dr. Bobbie: They need to be active learners, that they can't learn without doing it themselves and that they need to be trying things even if they are the wrong things and making mistakes in order to learn. Dr. Bobbie: I don't know, they are individuals doing, I mean trying to struggle with the material themselves, right? I mean active way. Researcher: Struggling in terms of like practicing or just thinking about it or really executing it on paper? Dr. Bobbie: All of the above right; you can learn by reciting, you can learn by doing, you can learn by writing. The studies say writing it down is critical, so writing down is going to help you remember way better than if you just walk through it in your head but walking through it in your head is important too. If I can recite in the shower how to solve a free energy problem, then probably on the test I'm going to know how to do it. Dr. Bobbie: […] Knowing the difference between I know it or I know something about it is the difference between really understanding it and having the concept and the content clearly in your mind versus, so the active learner will get to the point where they truly know it. Probably you can tell either they know it or they get stuck and come ask for help you know?	Researcher: You said also on motivation for you why you do this so much active learning that you say I want to see what they can do because if I only lecture I cannot see what they can do? Dr. Bobbie: Right. I want to know what they know and see what they can do so that I can challenge the best of them to get better and the weak ideally to get up to confidence.

To better understand the definitions and ways of active learning, I will present below several examples that originated form Table 4.11. The following table, Table 4.12, summarizes the quotes provided from Table 4.11, addressing the first question: What does active learning mean to you in your classroom?

Table 4.13, below, summarizes and reflects the results listed in Table 4.11, in regard to the second question posed in the aforementioned table. Summarizing those results provided another level of depth to the statements and how instructors viewed active teaching.

Based on the summaries provided below in the two following tables, I grouped all instructors in three different categories:

- A More Thinking-Focused Way of Active Learning.
- An Activity-Oriented Way of Thinking About Active Learning.
- Active Learning in and Outside of Class.

Table 4.12 Defining ways of active learning in the classroom

	Participants	Key components participants voiced what active learning meant to them
Doctoral granting institutions	Dr. Derrick	Answering questions Discussions Group or individual
	Dr. Devora	Listening Note taking Doing activities Dependent on the learner what is active learning for them
	Dr. Duna	Asking Answering questions Fill-in-the blank sheets
	Dr. Dixie	Being active through reacting and engaging Participation through visual ques
	Dr. Donald	Being awake, alert
	Dr. Danner	Hands-on involvement by In-class: Doing problems Outside of class: Doing projects
	Dr. Dana	Actively engaged minds Students do the thinking
	Dr. Dalton	Students listening to lecture Drawing, looking at models
	Dr. Dolly	Listening to lecture Bringing questions to class
	Dr. Donna	Engaging with material Not passively listening
Master granting institutions	Dr. Magnus	Listen Engage them through questions – make them think about them without them answering necessarily or asking the questions
	Dr. Manju	In-class: Engage students in active discussions, hold presentations Outside of class: write research reports
	Dr. Maggie	Actively discussing Doing stuff Not lecturing
	Dr. Mickey	Listen Process Take notes Lecture as a form of active learning

Table 4.12 Continued

Bachelor granting institutions	Dr. Brigid	Come up with results Doing task
	Dr. Berry	Mentally engaged Actively doing stuff with the material
	Dr. Bobbie	Reciting Doing Writing Struggle with the material

Table 4.13 Overview on perceptions on one's own classroom environment, and if it is active or not

Type of institution	Participants	Classroom is providing an active learning environment	Classroom is providing an active learning environment with limitations	Classroom is providing a traditional learning environment (with a major focus on lecturing)
Doctoral granting institutions	Dr. Derrick			x
	Dr. Devora		x	
	Dr. Duna		x	
	Dr. Dixie	x		
	Dr. Donald	x		
	Dr. Danner		x	
	Dr. Dana	x		
	Dr. Dalton	x		
	Dr. Dolly	x		
	Dr. Donna		x	
Master granting institutions	Dr. Magnus		x	
	Dr. Manju		x	
	Dr. Maggie		x	
	Dr. Mickey	x		
Bachelor granting institutions	Dr. Brigid	x		
	Dr. Berry	x		
	Dr. Bobbie	x		

A More Thinking-Focused Way of Active Learning

In this section, I will present examples of instructors who emphasized active learning approaches in which the classroom environment is dominated by having the students listen and think rather doing physical activities in class.

Dr. Dixie highlighted in her interview that active learning, for her, was based on visual cues with her students, seeing if they understand concepts and possibly engaging in conversations.

> Yeah, basically just not sitting there. And just like, "Okay, you're talking." But to force them to either react or better to engage. And so, part of the, "Are you guys following along, does this make sense," is just to get them to actively affirm that, "Yes, we are paying attention. Yes, it makes sense." (Dr. Dixie, interview)

Similarly, Dr. Dolly argued:

> The students are thinking about it, why we are talking about it. […] It's not necessary physically active and be in the act of something. Being a demonstration, not like that. But students are trying to connect with issues outside, or inside, the classroom. And I see that. (Dr. Dolly, interview)

Dr. Magnus, with his more traditional lecture style pointed out:

> I try to engage them, if nothing else, by asking questions, even if they're rhetorical questions, meaning I don't necessarily expect them to answer at least hopefully that they are thinking about these things. […] I guess in that context, if the students are mentally engaged in what's going on then that's an act of learning, even if they're not necessarily physically engaged. I think a lot of people will define active learning environments are one where the students are actively asking the questions or involved in discussions. Lots of give and take. My class, certainly like I said, doesn't have as much event as others do. If I can have the students be thinking about these things in their own head, then perhaps it's active but in a different way. (Dr. Magnus, interview)

Engaging students mentally for him was a form of active learning, as he defined it. He did point out, that classrooms could be more active/interactive than his own, but, as he described it, his form of instruction was more active than passive. His attitude was similar to Dr. Mickey's view of active learning:

> As I mentioned earlier, lecture, to listen, process, and to take notes, that is an active learning process, so I think what I do is active learning. It's just on what I would call the traditional side of active learning, and the new methods that are coming out, I'd, you know, I'd ... done a little bit of a disservice to themselves by not acknowledging that lecture is a form of active learning. (Dr. Mickey, interview)

For him, lecture is a form of active learning that he regrets is not being emphasized as much anymore in classrooms, since he thinks much more emphasis is put on student involvement through activities nowadays.

Dr. Dalton's definition concentrated on having students listen to his lecture, with a small emphasis on using models in class as well:

Dr. Dalton: […] Then we take a look at the molecular model, and we associate the shape of the molecule with what we've drawn on the paper, put that together. Then the third piece might be to, say, recognize that the protein bonds to one stereoisomer versus another, something along those lines. That might be an example.

Researcher: When you write your notes on the board and talk through them in detail, and I saw you do that, do you also think that it is an active process your students go through when they take the notes and think with you through that?

Dr. Dalton: Yes, absolutely. (Dr. Dalton, interview)

Dr. Dana, with a rather fast-paced and more student-centered classroom environment, also emphasized the "thinking" part as being active learning for students.

> Anything where the students' minds are actively engaged in a problem or a question. When they are learning, they're not being taught. So, when are doing the thinking in some way. Whatever it is that encourages their minds to be doing the thinking is what I'm trying to ... That's what I try to have happen, in whatever way I can do it. (Dr. Dana, interview)

An Activity-Oriented Way of Thinking about Active Learning

This group of participants emphasized particular actions that should be taken by students in order to have active learning occur in their classes. Dr. Derrick demonstrated a theory-oriented approach to teaching (Table 4.9). At the same time, he stated that he was not incorporating active learning as he would define it (Table 4.13). His active learning definition is dominated by involving students in questions and discussions:

> Active learning could take several forms in the class. It might involve students individually answering questions posed by the instructor during class, students working in groups to discuss a problem before giving a response or students doing online research on a topic during class to answer a question. In the metabolism class that I taught, I would pose one or two questions during the period that the students would need to discuss in small groups. These questions often extended a concept that was addressed in the lecture by requiring the students to answer a problem or question that related to the concept. […] I do not consider my classrooms to be very active at present. I agree with the argument that having students work out a problem on their own or in groups helps them acquire critical thinking skills and helps them

> acquire a fuller understanding of concepts than simply giving them the information in a lecture. (Dr. Derrick, interview)

Similar physical activities Dr. Derrick mentioned, where also outlined by Dr. Duna:

> […] Interactive I just think is being ... Maybe the fill-in-the-blanks is because they're actually having to not just sit there. It's not as passive as it could be. I guess just the answering questions. Asking and answering questions. (Dr. Duna, interview)

However, for Dr. Duna, who also wanted her classroom to be potentially more active, deliberately added fill-in-the blank sheets to her teaching. And she believed her classroom was already as active as possible (Table 4.13): "It's about as interactive as I get is if they ask questions and I try and answer them. […]." (Dr. Duna, interview)

Dr. Devora's definition was special in the way she noted that active learning was based on what each student thought would make them active and engaged in the material. For one particular student, listening to them was actively engaging, for the others, walking around in the room was more appropriate to achieve active engagement and learning.

> Dr. Devora: I feel like you, as a motivated learner, could actively learn some content topics, whatever, while sitting there listening to me, for example, and taking occasional notes. For other students who would do that, and that level of note-taking in my class, that does not constitute active learning, so it's different for different people. […]
>
> Researcher: Do you think you execute active learning in your class?
>
> Dr. Devora: For some people, yeah. Some people are actively learning, and other people are not. […] It's different for different students, I think, what will actually make them learn. For some people, taking notes while I'm lecturing is active learning. For some people, they are going to need to take a break and draw out multiple examples of a diagram, or they're going to need to have a conversation with somebody else, whether it's me, whether it's a TA, whether it's going to a help session. It's different for different people. (Dr. Devora, interview)

Dr. Donna emphasized the importance of engaging her students in activities. That for her was a true active learning engagement: "Not sitting there ... Active learning is engaging with the material and not passively sitting there thinking that you just quote things to me. Talk at you." (Dr. Donna, interview)

Since she did not believe her classroom was active enough, yet, she also emphasized:

> So, what I would like is to have days where they're literally ... I'd like to have case studies, I'd like to have more days where they're just thinking trough the material. More application days where I shut up and let them think through the material. […] POGIL activity. (Dr. Donna, interview)

Her case will be discussed later in more detail (Table 4.16) since she would prefer to incorporate more activities but also shared challenges she was facing to implement these.

Dr. Maggie emphasized that lecturing is not active learning for her, and her students need to "do stuff".

> Dr. Maggie: Where it's not lecturing and where the students are doing stuff. That they're active.
>
> Researcher: Like physically?
>
> Dr. Maggie: In some cases, yes. I mean group work I don't know that they're all physically active, but they're discussing. […] In group activities there's that same idea of constructing knowledge of helping to teach the others in your group about things, about the engagement with the material. I watch them, and I almost cry because they're all busy talking about science and they have interesting things to say, and they're trying to figure these things out. They're interested then in the answer since they've invested some brain cells in trying to think up answers to things. That's, I think, why active learning became to me an objective in teaching. (Dr. Maggie, interview)

Dr. Brigid and Dr. Berry had similar views of the extremes of how "active" active learning has to be to be effective for students. Both pointed out the importance of cognitive engagement and incorporating activities into the classroom:

> Active learning is where the students are given a task, and they have to come up with a reasonable result or answer on their own, maybe with some help from me […]. […] I think science is always a conversation, and if you can help the […] conversation, that's good. It's something that stimulates them to come up with an answer, and at the same time, promoting their understanding of the particular topic,

> so they have to be able to conceptualize what's going on. […] Yeah, this is mostly in group work. Active learning […] in group work, that is what's going on. (Dr. Brigid, interview)

> Active learning is when the students are busier than the instructor is. They are mentally engaged with the material and do actively doing […] things with it. Like about the small group work is it's really hard to fall asleep. In a lecture, even my own notes I can see my handwriting trailing off. I think active is very much them minds on, hands on thinking about it. (Dr. Berry, interview)

Dr. Bobbie highlighted the interplay between different forms of engaging with the material, but most importantly, struggling with the material in different ways to learn:

> Dr. Bobbie: They need to be active learners, that they can't learn without doing it themselves and that they need to be trying things even if they are the wrong things and making mistakes in order to learn. […] I don't know, they are individuals doing, I mean trying to struggle with the material themselves, right? I mean active way.

> Researcher: Struggling in terms of like practicing or just thinking about it or really executing it on paper?

> Dr. Bobbie: All of the above right; you can learn by reciting, you can learn by doing, you can learn by writing. The studies say writing it down is critical, so writing down is going to help you remember way better than if you just walk through it in your head but walking through it in your head is important too. If I can recite in the shower how to solve a free energy problem, then probably on the test I'm going to know how to do it. […] Knowing the difference between I know it or I know something about it is the difference between really understanding it and having the concept and the content clearly in your mind versus, so the active learner will get to the point where they truly know it. Probably you can tell either they know it or they get stuck and come ask for help you know? (Dr. Bobbie, interview)

A similar emphasis was made by Dr. Berry, as well as Dr. Brigid. Dr. Berry stated:

> I think it is the change is more that I was doing that about half the time where I would do kind of a mini lecture and then they would do the activity and basically the mini lectures they've either gotten shorter or moved to the end, as opposed to at the beginning. Which actually goes back with that initial teaching […] philosophy of having them struggle first and then have them resolve by the end. (Dr. Berry, interview)

Active Learning In and Outside of Class

Dr. Danner and Dr. Manju had unique ways of thinking about active learning in biochemistry classrooms. For them, active learning does happen just through activities in class but also outside of the classroom. Dr. Danner, for example, said:

> Doing things. Not just absorbing things. It can be as simple as doing problems that are not just regurgitation things from lecture. Working on projects. Hands-on things. That's what I'm trying to do, for example, with this visualization project that I keep talking about. (Dr. Danner, interview)

Furthermore, he elaborated on some worries he had, similar to Dr. Duna's views:

> Researcher: Do you think that your classroom, even though you say you do a lot of lecturing, with the activities you have, do you think it's already active?
>
> Dr. Danner: As best as it can be. I don't know how you would ... There's probably a fluid transition from one extreme to the other. It's not as active as I'd like it to be. There's still a lot of students in there, I don't know how much goes in there and how much gets retained. (Dr. Danner, interview)

Dr. Manju stated:

> Student participation in class discussions and presentations. My method is engage students in active discussion during the class, as well as ask students to write research reports and presentation (in pair or group) on the topics of their choice related to biochemistry. (Dr. Manju, follow-up email after interview)

All definitions extracted from the participants interviews met some level of Bonwell's and Eison's (1991), King's (1993). and Corno's and Madinach's (1983) definitions of active learning; in some ways being "cognitively engaged" and/or interacting with the material meaningfully. As pointed out above, the emphasis on either the interaction with the material or the engagement of the mind varied from instructor to instructor. Overall, it seemed as if instructors who already tried to implement some level of student engagement into their classrooms (e.g. Dr. Danner, Dr. Donna) were more critical towards their level of active student engagement than instructors who mostly execute traditional instructional methods (e.g. Dr. Dixie, Dr. Dalton), as seen in Table 4.13. Through analyzing their definitions of active learning, it became apparent that the more student-centered the orientations of the instructors, the more "active" their descriptions of active learning were, mentioning activities and active ways of students engaging in tasks or with each other to gain knowledge. The idea of "struggling" with the material came up, in particular, among instructors who were student-centered.

4.3.1.2 Placing the Results in the Context of the ICAP Framework – Engaging Students More

In order to situate my results in the context of current literature and the current views existing on student engagement in the classroom, results were interpreted through the lens of the ICAP framework, introduced by Chi and Wylie (2014). This lens enabled me to categorize each teaching style in a more defined way and situate the intended student engagement within the literature. Chi and Wylie (2014) categorized engagement from the perspective of the students, based on what students do and how actively involved they are in the classroom when executing certain activities. Students' level of involvement is based on instructors' styles of teaching. In my research, I interpreted students' actions from an instructors' perspective. Through the presence of certain teaching methodologies that were present in an instructors' teaching, I made inferences to what this might mean for their student engagement.

In this section I will introduce the ICAP framework's view on active learning, drawing from three other papers that provide a more detailed definition of active learning. Bonwell and Eison (1991), King (1993) and Corno and Madinach (1983) all described active learning as a form of learning where students have to be "cognitively engaged" and interact with the material meaningfully. This is also the definition the ICAP framework relies on when describing the work on this construct within the context of active learning. Before situating this work within the lens of the ICAP framework, the following section presents participants' views regarding what active learning is and how active classrooms should be.

In order to gain more insight into the level of student engagement instructors teaching biochemistry potentially offered, I interpreted the results through the lens of the ICAP framework by Chi and Wylie (2014). The interpretation was based on Figure 3.5 (see page 102), which represents their original Table 1, where they listed the activities students would likely do when being in a certain mode of engagement. Since I came from the perspective of the instructors' side and which methodologies they implemented, I looked at what they did and how that could possibly map on to students' action in the classroom, and therefore encourage them to be involved in a potential mode of engagement. Figure 3.5, on page 102, worked as a scaffold to categorize my instructors' teaching style by mode of engagement for their students. Table 4.14 summarizes in detail which teaching methodological aspects were categorized into each mode of student engagement if applicable.

In Kember's model, which I use throughout this study as the basis for building the foundation of "student-centered" teaching, the focus of attention moves away from the teacher and toward the student. Kember (1997) notes: "The role of the teacher shifts towards that of helping the student to learn. The emphasis is on student learning outcomes rather than upon defining content." His definition of "student-centered teaching" relies on the following statement from a previous publication: "You've got to be able to make an environment where students really want to learn. If you do that, they are much more likely to understand why they learn. And then I think after that, the teacher should be a resource person, generally to guide the students (Kember & Gow, 1994, p. 63)." Kember's model assumes that "student-centered" means that students demonstrate their understanding by applying their knowledge. Therefore, Kember's model (1997) uses the term *student-centered* in a similar context to the ICAP framework use of the term *learner-centered*. The ICAP model uses "learner-centered teaching," as an approach to the classroom environment in which the learner becomes active in class, thereby building on definitions of active learning by Bonwell and Eison (1991), King (1993) and Corno and Madinach (1983), who all described active learning as a form of learning where students have to be "cognitively engaged" and interact with the material meaningfully.

This rather open-ended definition of active learning allows me to connect the terms *active learning* and *student-centered* teaching or *student-centered learning* with each other within the context of the interviews and observations made during this study. For many of my instructors it seemed that increased "student-centered teaching" meant increased "active learning" opportunities, although there were differences in how each participant phrased their definition of active learning, as can be seen in Table 4.11.

4.3.1.2.1 Potential Platform of Teaching Provided – Leaving the Platform of Passive Student Engagement

The table below summarizes instructors' teaching styles by mode of engagement for their students, using the ICAP model. To generate inferences, all data such as interviews, observations and artifacts were analyzed to gain insight into the potential platform for student engagement the instructors could possibly provide during teaching a biochemistry lecture. The categories used at the top half of the Table 4.14 resemble the four different student modes of engagement of the ICAP model: passive, active, constructive, interactive.

The following table provides several layers of depth to reveal the grouping of the participants teaching styles with the respective ICAP student mode of engagement. First, in the first left column named “summary of teaching style leading up to certain ICAP category, mainly based on observations”, I briefly summarized each participants’ respective teaching style. Those results originated from my analysis shown in Table 4.9. That summary then provided the foundation to disseminate teaching components that reflected a certain student mode of engagement within their teaching styles (see last four columns in the table below). Eventually, after identifying components that mapped on to student modes of engagement in each teaching style for each participant, I looked at the overall teaching style for each instructor. For this, I investigated what student mode of engagement was encouraged the most by the frequent use of certain techniques, and provided an overall impression which student mode of engagement each instructor potentially provided most (see column “summary of main ICAP platform of potential student engagement provided by the instructor). The student mode of engagement that was primarily enforced during lecture through the instructor’s style of teaching was highlighted in bold in the table below. Within the table below, if cells were left blank, the data collected did not support that specific mode of engagement. To help you understand Table 4.14 to categorize instructors potential of their style of teaching in lectures using the ICAP framework better, I have generated Figure 4.2 that shows all instructors grouped by their potential student mode of engagement that they potentially provided predominantly. The figure can be found below this table. After the figure, I will discuss how the results of Table 4.14 can be viewed.

Table 4.14 Predominant aspects highlighted (from observations, interviews and artifacts) to categorize instructors potential of their style of teaching in lectures using the ICAP framework

Type of institution	Participants	Summary of teaching style leading up to certain ICAP category, mainly based on observations	Summary of main ICAP platform of potential student engagement provided by the instructor	ICAP categories Possibly enabled student mode of engagement seen in teaching methods used by instructors			
				Passive	Active	Constructive	Interactive
				Receiving	Manipulating	Generating	Dialoguing
Doctoral granting institutions	Dr. Derrick	Uses PowerPoint mostly, utilizes additional screens mounted close to each group table, as well as white boards mounted next to the TVs for group work. Mostly lecturing off of his PowerPoint with prompted questions in between, extremely short group work challenges dispersed through class.	The instructor goes through his slides, creating short challenges of group-work activities during his lecture. His main class period is dominated by lecturing. Short group activities give the students more opportunity for manipulation of thoughts/concepts, which create an **active mode of student engagement** mostly. The level of how passive or active the lecture portion is received by the students is up to the learner more or less, since group work is assigned rather "freely" and in short increments. The short group-work entities are possibly giving room for constructive engagement.	Lecturing to students via projecting slides.	The instructor provides extremely short group challenges by asking a question and letting students work on it for about 2 minutes. Students may repeat what they have just heard or take notes during lecture given.	Short group work activities offer the opportunity reflect and explain concepts to each other.	-

Table 4.14 Continued

	Dr. Devora	She uses PowerPoint slides sporadically and has an emphasis on longer group work or student-centered activities during class-time. She mostly asks her students questions during group work activities, but also when the entire class is listening.	Her lecture style provides the students with a platform of **interactive student engagement.** Since her students are most of the time working in groups, the platform of close peer-interactions is given, as well as the potential for discussion where student defend and argue their positions. With her continuously walking around and helping them to solve problems, she encourages working on tasks and questioning if material was well understood.	Minimal lecturing dominates her classroom teaching.	E.g. during her whole class activities such as CQ (to be precise hot seat questions), her student have the opportunity to take verbatim notes and copy solution steps.	Her various group work activities allow her to provide her students with the opportunity to ask questions, as well as reflect out-loud.	Since she spends a significant portion of her lecture time on group work, her students are provided with the platform of cultivating a discussion among each other, defending and arguing on biochemical concepts, that she and her Tas check on while rotating between groups.

Table 4.14 Continued

	Dr. Duna	She uses in her lectures powerpoint with accompanied fill-in the blank Powerpoint handouts for students. She does ask her students questions.	Duna's lecture style is traditional, with her mostly talking and going through material However, with her providing fill-in-the blank lecture notes as well as asking questions and being questions asked, she does give the platform for more **constructive engagement** in her lecture. However, depending on the students' intrinsic motivation, they possibly are in different student engagement modes still.	Lecturing makes up the biggest part of her style of teaching.	Rhetorical questions, interspersed with sporadic content questions accompanies her style of teaching. This encourages students taking verbatim notes and being at an active level of engagement.	Sporadically, students are asking questions in class that are answered by the instructor. Fill-in-the-blank print-outs for lecture encourages this mode of engagement.	-

Table 4.14 Continued

	Dr. Dixie	She uses PowerPoint mostly and lectures heavily. She checks in with her students verbally and visually, if they understand her a lot. She is open to questions during class and some questions lead into short whole class discussions, since she engages everyone to participate. She does provide sporadic student-centered activities such as present models or offer paper discussions. She does assign whole class periods to student-centered teaching, rather than mis up her lecture with different student-centered teaching techniques.	She has more lecture sessions than student-centered activities, so her overall **student mode of engagement is active**. Her student-centered teaching activities give a potential platform for students to engage actively and constructively. Her teaching style does have potential to reach interactive student engagement, however, it is more likely to occur spontaneously than intentionally in class (e.g. students bring up questions and other are interested to contribute which will result in a class discussion).	She mostly lectures in class from her PowerPoint slides. She keeps a close eye contact with her students and checks in on them with many rhetorical questions. Her lectures are fast paced.	Her lecture style encourages students to take notes.	Most of the constructive student engagement is possible during her group work activities. Student ask some questions during class.	Some of her rather group work activities give the opportunity to defend a position and debate and discuss in more depth, such as her paper discussion sessions.

Table 4.14 Continued

	Dr. Donald	He poses many clicker questions to his students and shows them on a screen through PowerPoint. Each student group table has an individual screen also. Every question is discussed in the group where instructor and TAs walk around and answer questions. Students talk among each other as well.	This student-centered teaching style is giving a platform for **constructive student engagement**. The instructor does give a platform to all students individually to ask questions during their discussion face about the posed clicker questions. Answering of clicker questions is rather fast paced, which probably provides less time to discuss answers further. They work in groups and discuss possible answers. Most of the questions are asked during the group work face, less during clicker question face or explanation face by the instructor.	When the instructor goes through answers they have just voted on via clicker questions, he talks about why the answers are wrong or right and lectures on the concept further, for a short time (1-2 min)	The platform for this student mode of engagement is mostly given during presentation of answers on clicker questions discussed. Students have the opportunity to take verbatim notes.	Instructor receives and gives out questions during group work activity to solve projected clicker questions. Students integrate their knowledge through reading up on the question as well as asking questions to their peers and instructor.	The opportunity for students to discuss in groups the answers among each other gives the platform for defending and arguing one's position as well as asking comprehensive questions.

Table 4.14 Continued

	Dr. Danner	Makes use of the blackboard, PowerPoint, videos, handouts and in-class questions are part of his lecture style. When students work on problems, they are encouraged to work in groups. He works with whole class problems on the board and discusses answers from worksheets.	This instructor does mostly create a platform of **active student engagement** in his classroom. He has student-centered learning components in his classroom and a versatile way of presenting the material, which keep students engaged. His main focus, however, is lecturing. The level of engagement is more up to the students, since they are only encouraged to work in groups during sporadic activities. This leaves room for constructive interactions. The interactive mode of engagement is not as actively enforced and more up to the students themselves during activities. Activities are short, therefore less time for interactive engagement.	Lectures and shows video as well as uses the board to describe concepts in multiple ways.	His lecture provides his students with opportunities to take notes, especially through his versatile way of presenting the material as well as through his on-board whole class exercises.	Activities in class with student worksheets. Instructor walks around and helps students, answer students' questions. Students ask questions during lectures as well as activities. During lecturing, he also used fill-in-the-blank opportunities for students.	-

Table 4.14 Continued

	Dr. Dana	She uses PowerPoints, white boards located at each group table for group work and computer programs in her lectures. She poses many short questions to her students during her lectures (fill-in-the-blank questions) and has multiple group work activities spread through her lecture.	Her lectures are active and of fast pace. She constantly tries to engage her student with questions or group work activities. Her teaching style does encourage Active and for sure **constructive mode of engagement** the most. Some group work activities leave room for Interactive engagement, depending on her students' involvement and interest to work with their partner. The time spend on task is short and does probably not leave room for in depth discussions.	Short periods where she only lectures without asking students questions and instructing them on an activity.	Manipulation of molecules on their PCs through individual and group activities.	Lecture interspersed with many questions (fill-in-the-blank style). Visualization programs to manipulate.	-

Table 4.14 Continued

	Dr. Dalton	He writes on blackboard with chalk and talks through his notes while he does so. He checks in with his students visually a lot and asks his class question to check if they understand what he is presenting or need more clarification. He gives the platform for asking questions back, students use it. Rarely does he use hand-on activities in class, such as molecular model kits.	The instructor writes freely on the board and tells his students about the concepts. He keeps eye contact and asks if anyone has questions or understands it. The level of how passive or active the lecture portion is received by the students is up to the learner more or less. He is mainly lecturing, and students are mainly taking notes and copying what he is writing, so therefore his main mode that he is probably enforcing is **active student engagement.** The interspersed Q/A give minimal room for constructive engagement.	His teaching style is mainly dominated by him lecturing and talking through his notes, which he puts on the board for students to copy while he is talking through them.	The instructor is giving the students the opportunity and is also expecting them to copy what he is writing on the board.	Instructor asks continuously in lecture if all is understood or anything needs clarifications. Students ask questions during lecture freely, but more sporadically.	-

Table 4.14 Continued

	Dr. Dolly	She uses her PowerPoint to be projected on a white board. She writes with a white board pen onto her "slides", talks through her slides in detail and poses multiple differently-natured questions to her students. Depending on the topic, she does have small student demonstrations she acts out with the class in front of the class.	Her style of lecturing is mainly dominated by talking through her slides intensively, prompting many differently natured questions to her students throughout her explanations. From an observational perspective and through the lens of the ICAP framework, I would say that her lectures are dominated by an **active student mode of engagement**, however, through student questions as well as them taking notes and following her presentation, she does give room for constructive engagement.	She mostly talks through her slides and checks in with her students visually if they are on board and understand everything.	Instructor poses a lot of suggestive, rhetorical questions to her students during class. Students are mostly encouraged to listen.	If she provides students with whole class demonstration exercises, she involved students and let them act out a biochemical concept in front of the class. This is mainly led by her talking through it, but she involves her students being part of the activity.	-

Table 4.14 Continued

	Dr. Donna	PowerPoint lecturing with a high amount for Q/A interplay between instructor and student is the dominating lecture style for this instructor. Student-lead questioning while presenting case studies, group work activities in class (quizzes), clicker questions as well as POGIL inspired questions are her student-centered learning approaches.	Her lecture, with her main feature of a continuous interplay between questions and answers during lecturing, is probably mostly leading to an **constructive student engagement** environment. Depending on the students generated question, and their responses, lecture can vary from passive to constructive. Sporadically, her students are given the time to discuss their opinions and viewpoints on solutions with each other, which would promote an interactive mode of student engagement.	She is using a fast amount of her time during lecture to convey content through PowerPoint lecturing.	Through her versatile ways of providing information, through case studies, videos, animations and such, she possibly gives her student the possibility to take verbatim notes.	This instructor highly encourages student questions during lecture and has a constant question/answer teaching style active in class, which opens the platform for students to ask questions. This is also allowing the opportunity for students to take notes in their own words.	Her group quiz activities in class could possibly provide students the time to discuss solutions with each other, in order to choose one for the group that they will then submit.

Table 4.14 Continued

Master granting institutions	Dr. Magnus	He uses the whiteboard to write on his thoughts during lecturing. Free speaking and free writing while he lectures is his style. He keeps looking at his audience, throughout talking, checking in on them with questions. He poses rhetorical and non-rhetorical questions to his students.	His teaching style is dominated by **active student engagement.** He does freely lecture and explain things as he teaches biochemistry concepts. Through prompted non-rhetorical questions, he possibly opens up the platform to constructive student engagement from time to time.	Lecturing while capturing his thoughts on a white board.	He does not provide notes, so students are encouraged to write along.	He emphasizes that students have to take their own notes to learn, so students are encouraged taking their own notes in their own words during class along with his board notes.	-
	Dr. Manju	PowerPoint lecturing and further explanations on white board with frequent teacher motivated questions. Occasionally, he involves students further by asking follow-up questions on their responses.	His style of lecturing is mainly dominated by talking through his slides intensively, prompting many differently natured questions to his students throughout. From an observational perspective and through the lens of the ICAP framework, I would say that his lectures are dominated by an **active student mode of engagement.** This being said, his efforts on follow-up questions on student answers give potential room for constructive engagement.	He is using a fast amount of his time during lecture to convey content through PowerPoint lecturing.	Instructor poses many rhetorical questions to his students during class. Students are mostly encouraged to listen and taking verbatim notes.	Sporadically, students are asking questions in class that are answered by the instructor and followed up with more questions from his side that gives the platform for self-explanation and reflecting-out load. He calls it “discussions” in class.	-

Table 4.14 Continued

	Dr. Maggie	She uses a work-sheet, in collaboration with her students, to work out through problems (group-work, then instructor guided solution). She uses the doc cam extensively. Her lecture is an active group work endeavor with a Q/A structure. Mostly questions from her side, many from the students' side and answers from both, her and the students. The students pick	The range of mode of engagement is versatile. She does lead the in-class questions and answers in her lecture, however, her students do sometimes work individually and often in groups together, solving problems, so **constructive engagement** is probably the dominant mode of engagement. For interactive mode of engagement, a platform is given in her lecture, which does depend on her students' willingness to participate. The group work activities I observed were rather short in their nature which provide less time to create an environment for discussions.	Her lectures are rather short and guided with questions and student interaction. So, there is only a minimal platform for passive mode of engagement.	When talking through problems and explaining solutions, she gives the students the opportunity to take verbatim notes as well as copying solution steps as she is outlining them.	The instructor does provide her students with many opportunities to ask questions, during her lecturing and explaining a problem, as well as during the time when students work assignments in class. Her fill-in-the-blank worksheets give also students another level of constructive engagement during lecture.	-

Table 4.14 Continued

	Dr. Mickey	He uses the white board, videos as well as doc cams in his lecture. He does check in on his students with questions and encourages questions from their side. The intensity on how much questions he and his students ask vary from lecture to lecture.	With his style of lecturing, he does promote a positive and encouraging atmosphere. Through showing the same concepts in different ways, he creates a platform of **active** and constructive student engagement. His student engagement is mostly active, since his major teaching style is lecturing, accompanied by a variable amount of questions from his and the students' side. As listed with other instructors, depending on the students' motivation, their level of engagement does potentially vary. A platform of interactive engagement is not encouraged, since no group work is actively assigned and discussion are hardly present as teaching methodology in his lecture.	He uses the white board and lectures as he writes his notes on it.	Through his lecturing style he encourages students to take notes during class on what he says and writes.	His lecture is, on a varying basis, interspersed with questions form his side and the students' side, therefore the level of potential constructive student engagement does vary.	-

Table 4.14 Continued

Bachelor granting institutions	Dr. Brigid	She has a continuous cycle of mini lecture and group work activities; may it be through group quizzes or worksheet activities. She uses PowerPoint to present questions and content knowledge to involve her students in questions and reiterate what was worked on during class activities.	Her lecture style provides the students with a platform of **constructive student engagement**. With her continuously walking around and helping them to solve problems, she encourages working on tasks and questioning if material was well understood. Student are encouraged to work in groups. The extend to how much they are having conversations varies due to short term group activities and students seeking interaction or not. Mini lectures happen frequently during class.	Minimal, since she is only providing her students with sporadic mini-lectures.	During mini lectures, students have the opportunity to take verbatim notes.	During problem solving tasks, she was walking around and providing her students with thoughts and help on the problems to be conquered. Students are provided with the opportunity to ask questions, the instructor continuously was wondering around the room and assisting groups.	During some longer group work activities, a platform for discussion might be created and empower an environment of defending and arguing scientifically .

Table 4.14 Continued

	Dr. Berry	She uses POGIL this semester with a college to teach biochemistry. Her classroom is dominated by mainly group work activities, where she and her co-teacher walk around and check-in with groups, help their understanding of the material and ask questions to guide their understanding and productivity. Mini lectures are executed mostly at the end of lecture as a wrap up tool.	Her lecture style provides the students with a platform of **interactive student engagement**. Since her students are most of the time working in groups, the platform of close peer-interactions is given, as well as the potential for discussion where student defend and argue their positions. With her continuously walking around and helping them to solve problems, she encourages working on tasks and questioning if material was well understood. POGIL as a style of teaching is also encouraging dialoguing between students, which is characteristic for interactive engagement within the ICAP model.	A short period during lecture is devoted instructor-centered teaching.	Even during short periods of mini lectures, instructor poses questions to students and encourages answers. This potentially can give students the opportunity to take verbatim notes and repeat their answers.	This instructor highly encourages student questions during group work activities lecture and maintains a constant question/answer teaching style active in class, which opens the platform for students to ask questions. This is allowing the platform for students to take their own notes, reflect out load and explain concepts to their group members and the instructor.	Since their group work activities are rather long (most time of class) and each group is visited multiple times during an activity, the platform for deep engagement in discourse is given and peer interaction largely enhanced.

Table 4.14 Continued

	Dr. Bobbie	She uses the white board and a handout for each class she is teaching. With these supporting items, she is teaching her class by working on problems with her students, first student group work, then in class presentation of answer. She does mini-lectures if she realizes multiple students are confused about a concept they need to know for solving the problems presented.	Her lecture style provides the students with a platform of **constructive student engagement**. With her continuously walking around and helping them to solve problems, she encourages working on tasks and questioning if material was well understood. Student are encouraged to work in groups, some do work on their own, so there is a potential for interactive engagement, however, it might not be as reinforced as her teaching style would have the potential for.	Minimal, since she is only providing her students with sporadic mini-lectures.	Manipulation of tasks assigned to student groups could occur during solving problems assigned.	During problem solving tasks, she was walking around and providing her students with thoughts and help on the problems to be conquered. Students are provided with the opportunity to ask questions, the instructor continuously was wondering around the room and assisting groups. Since no notes during lecture were provided, students were encouraged to take notes on their own words for clarification on questions and answers.	Since her group work activities are longer and spread throughout her entire lecture period, discussions are likely to come up when students solve problems.

The figure below was generated to help visualize the results in a simpler way. From top to bottom in each engagement mode: the first instructor names listed underneath a style of student engagement resembled that style most adequately and allowed enough student engagement in their classroom to meet this particular style most of the time when teaching biochemistry. This does not represent a major distinction between my participants but rather gives a sense for the variety of teaching styles even within a certain group of student engagement.

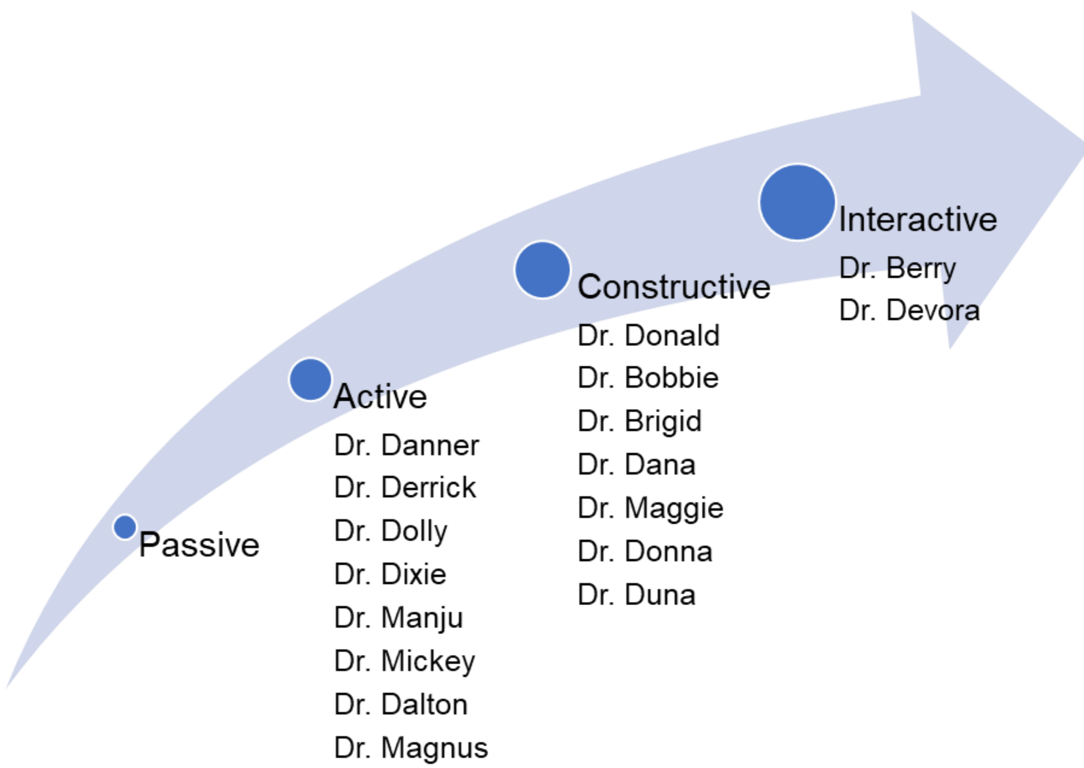

Figure 4.2 Predominant student mode of engagement sorted by teaching styles instructors provided potentially

As shown in Figure 4.2 a majority of instructors provided evidence of teaching styles that supported a potential active mode or constructive mode of student engagement.

Only two out of the instructors met the criteria within the ICAP model to be grouped into the interactive mode of engagement, which is the most advanced mode that students can engage during class-time, and therefore learn the most, presumed by the ICAP framework (Figure 3.6). In this mode of engagement, students were encouraged to take part in discussions for example. However, many participants were able to be categorized into the second most active mode of engagement for students, the constructive mode of engagement. In this mode of engagement, students were given the opportunity to be more alert and engage more with the material through fill-in-the blank notes, which were deemed within the ICAP framework to be part of the constructive mode of engagement. In addition, many of my instructors were "only" providing an active mode of engagement for students, where a big emphasis during lecture was still on listening and taking notes.

I was able to extract teaching methodologies that were used that have the potential to enhance the level of student engagement if implemented in the classrooms observed. This was especially true for classrooms where group work and activities were not yet present, but the start of more student engagement was seen. Admitting that these assumptions are based on speculation, I would still like to set the gained insights on potential student mode of engagement biochemistry classrooms provide into perspective what they could potentially provide in the future if certain teaching methods that support a specific mode of engagement were used more often and more extensively. For example, when looking at Table 4.14, Dr. Derrick's teaching style was categorized mainly as active engagement. However, he did show potential for constructive student engagement, since he already tried to incorporate small group work interactions and activities in his classroom. Figure 4.3 tries to show on what level of student engagement some biochemistry instructors would potentially be able to move up to, regarding the signs that were already visible in their classrooms. This is based on speculation of the potential that I saw in the classrooms, which could possibly encourage a more involved student mode of engagement. Instructors were only listed in Figure 4.3 if a higher level of student engagement was potentially enacted in the classroom due to certain teaching methodologies practiced. The way instructors are listed in this table has no relation to their degree of advancement in that particular mode of engagement.

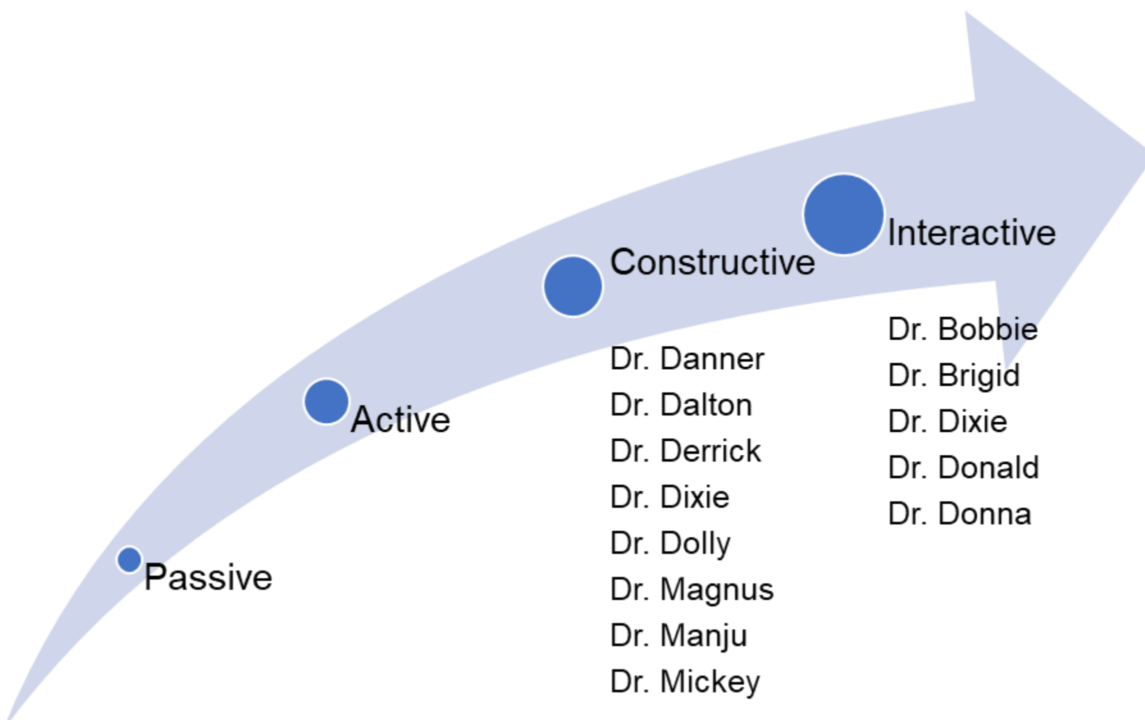

Figure 4.3 Tendency for potential room for student engagement in classrooms observed

When comparing Figure 4.2 with Figure 4.3, instructors whom I identified their predominant student mode of an engagement as active (Dr. Dalton, Dr. Danner, Dr. Derrick, Dr. Dixie, Dr. Dolly, Dr. Magnus, Dr. Manju, Dr. Mickey) could, based on my beliefs, move up from the active student mode of engagement to the constructive student mode of engagement). As shown in Table 4.14 under the respective ICAP categories, instructors commonly showed signs of more student engagement, that could potentially, in my belief, encourage a constructive student mode of engagement. Instructors showed signs of either having students ask questions (Dr. Dalton, Dr. Dixie, Dr. Manju, Dr. Mickey), or encouraged students to take notes on their own (Dr. Magnus, Dr. Danner), or showed the start of potentially integrating more discussions in class (Dr. Derrick and Dr. Dolly). In Figure 3.5, the constructive student mode of engagement is described as providing the ability to generate something by the students. Taking notes in their own words, asking more questions, small discussions and short group work are all methods that could provide that mode of engagement. All those teaching methods would have to be done more extensively in class for instructors to provide more student engagement and reach the next student mode of engagement, however, because I saw signs that indicated, if done more in class, a more engaged teaching environment, I found it worthwhile reporting.

The following instructors, I believe, could move up from predominantly providing a constructive mode of engagement to an interactive mode of engagement: Dr. Brigid, Dr. Bobbie, Dr. Dixie, Dr. Donald, Dr. Donna. Instructors that I cannot see move into a higher student mode of engagement would be Dr. Berry and Dr. Devora, who already incorporated teaching methods that engage students on the interactive student mode of engagement. Dr. Dana, Dr. Duna and Dr. Maggie have not revealed the use of any teaching methods that would engage their students on a higher level of student mode of engagement. Dr. Dixie instead, showed the use of several teaching methodologies that could potentially support a constructive student mode of engagement (through encouraging more student questions) or interactive student mode of engagement (through giving room for discussions). Participants for whom I believe I can potentially see the platform to move towards the constructive student mode of engagement, if certain teaching methods were more often and extensively used in lecture. Dr. Dixie, Dr. Donald, Dr. Donna and Dr. Bobbie made use of short discussions in class. Dr. Brigid tried to incorporate longer group work activities. Longer discussions and group work could potentially provide the students with more opportunities to have dialogues in class and exchange ideas including defending and debating those ideas. “Dialoging” is a key aspect through which the ICAP model describes the interactive mode of engagement (Figure 3.5). Overall, it was interesting to speculate and see that over half of my participants have the potential to incorporate a higher level of student engagement.

4.3.1.3 Challenges in Teaching Biochemistry – Current and Future

4.3.1.3.1 Challenges with Current Style of Teaching – Missing Tools for Implementing Student-Centered Activities

Engaging students is not an easy task to be incorporated into anyone’s teaching style. An instructor faces many obstacles when trying to do so. With this in mind during the interviews, I examined the challenges associated with making changes to current teaching styles.

Challenges faced when teaching biochemistry were diverse for the instructors in this research study. The challenges that emerged from the data were categorized into three main categories: challenges faced outside of the classroom, challenges faced inside of the classroom, and general challenges when making changes to teaching.

To help illustrate the information in the table, I use Dr. Derrick as an example, who has two entries in the table and the results presented in the table were all that his interview revealed. In the category "challenges outside the classroom", he verbalized in the interview the challenge to know if the students were reading the material outside of class and therefore understood it. In the category "challenges inside the classroom", his interview statements revealed his struggles with the implementation of group work, as the table entry reveals. None of his interview statements did align with any of the themes in the first category.

The table generated, originated from the codes "teaching-role of importance", "teaching goals", and "teaching methods". These codes were encompassing similar themes that related to instructors' challenges faced with their current style of teaching. For that reason, they were analyzed together. Teaching methods mentioned in this table refer back to what my participants have elaborated on specifically during the interview.

Table 4.15 Challenges faced with current style of teaching

		Challenges outside the classroom	Challenges inside the classroom		General statements - Making changes to teaching	
Type of institution	Participants	Outsourcing learning to students	Engaging students	Delivery of content	Student population	Time is research
Doctoral granting institutions	Dr. Derrick	Accountability to read	Institute group work			
	Dr. Devora	Give everyone the opportunity to take the course – established online version of course; not everyone can do online learning	Institute group work with a big class	So much content, opportunities to practice are challenging Building on prior knowledge when it is weak	Various majors in class, getting all on board, not losing the weak or strong ones Being equipped with the adequate prior knowledge for the class Population must be prepared for active learning	Flipped classroom is work intense
	Dr. Duna		Fill-in-the-blank sheets for individuals			
	Dr. Dixie	Experience with success	Engaging in discourse	Amount of PowerPoint slides can be overwhelming vs. Deliver content		

Table 4.15 Continued

	Dr. Donald				Population must be prepared for flipped classroom	Flipped classroom is work intense
	Dr. Danner			Change examples to motivate yourself Deliver amount to not fail students		
	Dr. Dana		Diverse background students bring into class Make group work more challenging Balance, group work/individual work Improve Q/A, make it challenging		Diverse background students bring into class	Improvement on teaching is time intense
	Dr. Dalton			Make lecture more interactive, more visualizations vs. Get through content		
	Dr. Dolly		More follow-up, more in-depth questions during lecture			
	Dr. Donna		Engage more people in class	Too much content, no idea where to cut		Teaching improvements take time

Table 4.15 Continued

Master granting institutions	Dr. Magnus		Increase student participation, asking questions, answer questions			
	Dr. Manju	Accountability to read	Establishing a productive discussion environment – but people do not always show up, and groups are not accountable for another	Content is too much to cover in class, put it online, but then only a third reads it (see category outside the classroom)		
	Dr. Maggie		Engage more people in class Create and implement more POGIL exercises	Still lectures too much/ too much content to deliver		
	Dr. Mickey			Using lecture can be challenging for students – intensive listening time	Student population is not the right one for more engagement in class, e.g. POGIL	
Bachelor granting institutions	Dr. Brigid	Rough student evaluations on student-centered teaching methods. Challenge if college is not supportive.	It is hard to focus students on case studies	More application, but that sacrifices content Only POGIL would not convey all the knowledge necessary	"Students are reluctant to change"	
	Dr. Berry	Accountability to read		Sometimes you have to lecture	Getting students to buy-in to the structure of the class	
	Dr. Bobbie	Rough student evaluations on student-centered teaching methods. Challenge if college is not supportive.	Reach all student with questions asked Institute group work		Student perception of student body limits methodology to be used	

In the Category “challenges outside of the classroom”, instructors mostly biggest concerns were with regard to the theme “outsourcing learning to students”. Within this theme, instructors voiced the concern of getting students to be accountable for the reading they should be doing outside of class to be prepared for group work activities, as highlighted through quotes by Dr. Derrick and Dr. Manju:

> In [course X] and in [course Y], I'm putting together a story based on a lot of different sources. I feel, they don't have time to go to all these sources and read all these primary papers or whatever. So, I'll help them out. I think some of that's necessary, but maybe the journey, having them go through the process a bit themselves will make it stick better. So that's a balance I haven't figured out. How much should they be doing themselves? (Dr. Derrick, interview)

> And it's always 30% of people read it, and 70% don't read it, because I already know lesson one, and they don't. So that's the challenge to make them realize. I try to put as much information as I can on the [online platform] separately rather than just giving my lecture notes or something like that, so they can prepare themselves for the next class. It never happens, you know? (Dr. Manju, interview)

Dr. Berry had similar issues, however, she seemed to be successful with finding solutions by implementing reading guides, to have her students read before class.

> I think what it does is it puts preparation on the students in when I lecture they tend not to read before they come to class because they know I'm going to tell them what they need to know and so they'll just take notes instead of reading before they come. What was transformative was the use of reading guides where instead of [inaudible 00:17:38] you need to read exactly this section. Instead of it being these 20 pages, it'll be focused on these five pages, but I'm going to ask you questions before you come to class and I'm going to basically be doing class specifically on those parts of the chapter. For example, when we did membrane transport last week, we didn't cover everything in the chapter. We focused on a couple of examples; so getting them to focus their reading on specific portions. They actually will prepare for class. (Dr. Berry, interview)

Another set of concerns voiced by some instructors were the student-evaluations one would get when implementing a student-centered classroom environment.

> I tried to do some of this stuff, and the students didn't like it because it wasn't what other people were doing, and therefore I got bad student evaluations. (Dr. Brigid, interview)

Dr. Bobbie stated:

> Dr. Bobbie: Because they aren't prepared because no one else has done this for them. If I wanted to get good teaching evaluations I would give a lecture.
>
> Researcher: Yeah. You mentioned that when we were, when I was observing your class you said that the teaching evaluations are not as good as compared to if you were to just give a straight lecture. Do you think that that comes from just challenging them more and they don't appreciate that part?
>
> Dr. Bobbie: Yeah, I know that's what it comes from, but I also know that when they go somewhere else and they find out that they are biochem is better than other people's, their understanding of it is way better and they are like returning for their class in med school and so forth that then they are proud of it. Pass their, when they pass their exam or when they get their first publication early because they really know the material and they understand it and they can do it and write about it and so forth. Then they are happy and proud about it, but while they are going through it it's tough. (Dr. Bobbie, interview)

Related to challenges inside the classroom, participants discussed "engaging students" and "delivery of content". One concern raised was instituting group work. This concern was voiced from two different angles.

Dr. Derrick voiced his concern with not having the right toolbox to improve his group work engagement:

> I think one of the challenges that I still have is the nature that all students have the ability to get support from each other because you might have some students who know each other already and they work together, but then there were some others who for whatever reason don't have that support group and they're at a disadvantage if they won't come to see me, which they usually don't. So unfortunately, from what I've heard, you really can't institute work groups. The students hate that if they said, "Oh, we'd have to work with X when we don't know this person," or whatever. So I don't know really the solution to that, but I think teaching comes from many places and from each other as well. So ways to increase that would be helpful I think. (Dr. Derrick, interview)

Dr. Manju voiced the disappointment that his students were not interested in working with each other since they did not know each other. He was also not sure how to overcome that boundary:

> Dr. Manju: Let's see I want them to discuss among themselves, but it takes a little bit more time. Because if I ask, "Why this guy's not there?" "Oh, I don't know I'm not his friend, he's just in my class." So, their personal interaction if it's there more then it will be much better.
>
> Researcher: Okay. So you basically also say that because they don't know each other necessarily, and don't feel so comfortable maybe talking to each other, group work is also more challenging in terms of that?
>
> Dr. Manju: Exactly, yes. (Dr. Manju, interview)

Dr. Bobbie voiced a similar concern:

> Although sometimes it's not like that, group work ... That particular class group work they were like no. Like, "We don't like group work," terrible. […] Especially not random group work. They liked group work with their friends but not, if I had randomly assigned them they have a real it's like, "Don't make us do that, that's awful." (Dr. Bobbie, interview)

Dr. Devora pointed out that it was particularly challenging to institute group work in a big class like she was teaching.

> Dr. Devora: […] because I'm not getting optimal engagement. I don't know what optimal engagement is. It might not be 100% engagement but creating a system where the students feel like it is as effective as I believe it is, because some of them are just flat out like, "Group work isn't good, and so-and-so isn't doing whatever." […]
>
> Researcher: […] But then, I mean, you have now a class of like two to 300 students, and you still do this group work.
>
> Dr. Devora: Yeah, it's really hard. It's really hard. (Dr. Devora, interview)

Another obstacle involved the challenge of engaging students to be more activities in class. Dr. Donna faced the challenge of peer instruction in class and students' resistance to that:

> Yeah so, me just standing up in the front of the classroom talking at them is not them learning. And that's something that I struggled with in terms of getting my

> students to understand that. So especially at the upper level class, they expect to be lectured at. So that's been a struggle for me in terms of balancing the amount of direct instruction versus peer instruction that I have them do. (Dr. Donna, interview)

As mentioned before, Dr. Derrick was struggling with the question of how much he could trust his students to inform themselves, without him checking again and reiterating in class:

> […] I'm putting together a story based on a lot of different sources I feel, they don't have time to go to all these sources […] maybe the journey, having them go through the process a bit themselves will make it stick better. So that's a balance I haven't figured out. How much should they be doing themselves? (Dr. Derrick, interview)

> Dr. Dana worried about her activities, if they were challenging enough:

> Some students in the evaluation think it's a little too much, or they say the questions occasionally are too simple, and they don't need that much time to discuss in groups. So I think I need to look at the questions I ask, and have a list of questions that are much more challenging for the group work. So, I think I could improve on that a little bit. I think the activities are very useful, and I think the one-on-one computer work where they're doing something on PyMOL or that works very well for the more introverted students in class, the group activities favor the people who like to talk, and the shyer ones I think are not comfortable with that, so some individual activities ... A better balance I think would help with some of the shy students feeling comfortable in the class. I'm conscious of that because I'm a little on the extroverted side, but the introverted students don't like group work all the time. It doesn't mean we're not going to do it, but I need to have a balance. (Dr. Dana, interview).

Many instructors also raised the concern of how difficult it was for them to speak to the students, so they would be engaged –asking the right questions or getting them to “buy into” the activities provided, as mentioned by Dr. Berry, Dr. Brigid and Dr. Maggie. For example, Dr. Berry stated:

> I think the biggest challenge for our class is getting students to buy-in. […] We look at saying what and so trying to get student buy-in in the sign posting is always a challenge. My plan on Monday when I'm back up is to say, "Hey, guys, it's almost the end of your junior year. Do you realize after next year, you're not going to have a faculty member to ask these questions to and that the reason we do this is so you can learn the material on your own," and to remind them that's the point of a college education to teach them how to learn on their own buy-in. […] we still get resistance (Dr. Berry, interview).

Another challenge inside the classroom was the delivery of content. With many topics to cover in biochemistry, there was hardly any room to practice concepts.

> Dr. Manju: Because of the time constraints, you cannot have everything, plus you have to finish the course, all the things, within the given 16 weeks' time. So, it's tough, you can't have more discussions giving them just discussing the topic or asking them to give a presentation in that one. […] .
>
> Researcher: […] you mentioned earlier that you thought that these very brief and very short problem-solving questions that you basically have in your class that the reason they are so short is because you have to go through so much material, right?
>
> Dr. Manju: Yes, so much material. (Dr. Manju, interview)

Dr. Devora had a more relaxed view on shortening her lecture content when it came to her student-centered heavy teaching style:

> Researcher: Do you feel ever you have to cut back on content that you teach while doing all these active learning techniques?
>
> Dr. Devora: Yeah. I don't care. You teach them how to learn, they can teach themselves. It doesn't matter, so I'll just cut something out. Now, I don't want to cut out photosynthesis. I'm not a plant scientist, and it's not just because there's plant people here in the College of Ag, but it's more because that's the other half of carbon metabolism. For me, it helps you understand this if you've learned. (Dr. Devora, interview)

However, instructors also voiced positive effects from more student-centered teaching methods, where content was removed, but student learning increased:

> Researcher: Do you ever fear, oh my god, we didn't cover this part and they really need to know that to move on? Is that ever something that makes you be a little bit -
>
> Dr. Berry: Yeah. That's what I end up supplementing. I end up supplementing because I don't feel the content is always exactly what I want to emphasize. You're right. There is some content lost, but we actually use the exact same sets of running our tests as we used to. They're just better able to answer the questions than they used to be. We see the quality of the answers go up. (Dr. Berry, interview)

Even instructors with a student-focused teaching approach voiced the obstacle of having to walk a fine line between too many activities and conveying enough material.

> Application is great, and if I can incorporate it, we talk about certain diseases. Like a couple weeks ago, we were talking about phenylketonuria, and why does some of the population have this? How do they test for it? They're really interested in all that sort of things. I think I would like to work more on application stuff, but again, that takes a lot of time, and you have to sacrifice content then. (Dr. Brigid, interview)

Some instructors thought, that lectures were most appropriate to deliver content in their biochemistry classes, as Dr. Derrick and Dr. Mickey each stated.

> […] I'm familiar with the idea there of having the students work on problem solving in the class where you're available to help them out. I just never in my own mind, I couldn't figure out how to get it to work. I still feel, maybe it's my traditional upbringing. I still feel that I should be there to provide the content or at least. (Dr. Derrick, interview)

> I'm a traditional lecture person. To me, that's efficient. It gets things done quickly and efficiently. (Dr. Mickey, interview)

When talking about these issues, some instructors expressed differences between the teaching of general chemistry and biochemistry. Dr. Donna brought up an interesting conceptual difference between those two courses and why she felt less able to implement active learning in her classroom, compared to her general chemistry classroom:

> Dr. Donna: I think I do a better job in my gen chem class of doing more group instruction.
>
> Researcher: […] Yeah okay, I think you already answered the question how your teaching practices changed with that one example where you said, "Well, my POGIL did not work out the way I wanted it to." Does your style of teaching vary amongst different classes when you teach different?
>
> Dr. Donna: Yes, very much so.
>
> Researcher: Why and how so? Can you give me some examples?
>
> Dr. Donna: So, for gen chem I do more of a scale up approach to instruction so there's a little bit of direct instruction but for the most part, they're

> exploring the concept in class or they're applying it. There's very little direct instruction. So, there's lots of modeling activities, there's lots of understanding the concept that's behind what's going on. And then for ... But I also have a lot of support in that class, so I have a TA in lecture, I have two learning assistants and I have a SI instructor for forty-eight students. […] So, all of my classes are based on learning objectives. So, I have learning objectives for every unit and so I pick and choose what I want to do with them. So, the activity I do with them pretty much covers a lot of the objectives for that day. And then I do a little bit of intro stuff, it's also a seventy-five-minute class. So I do fifteen minutes at the beginning and fifteen minutes at the end and then we are working with the material the rest of the class. Very very rarely do I lecture the whole time. I actually don't know if I've ever lectured the whole class.
> […] […] So that's what I've been struggling this semester to try to figure out is how to help my students apply information and helping teach them that skill and I'm not there yet. […] I feel confident in my collection of what I can get rid of in gem chem and what I need to focus on in gen chem versus what I can cut and what I can focus on in biochem. (Dr. Donna, interview)

For her, teaching general chemistry came easier and fitted more into a natural progression of transforming her classroom. This was, as expressed in her teaching philosophy, merging her classrooms more and more into an actively engaging environment. For her, methodological knowledge did not transfer between these two courses.

For Dr. Dalton, studying chemistry needed more practice than studying biochemistry, therefore, less activities were naturally needed in biochemistry than in chemistry classrooms.

> Dr. Dalton: In most other classes, I also teach nursing chemistry, which is much different. Let me see, the biggest difference would be that it's not as content heavy and a lot more practice examples and problems done in class, that would be the biggest difference.
>
> Researcher: Where does that difference come from? Why is that chemistry class so practically oriented and biochem not?
>
> Dr. Dalton: The nursing chemistry is kids who've never had chemistry before, basically. Or they had chemistry in high school. […] So, they're at a level where the ... Let's see. Say they're gonna learn chemical

> reactions, the subject chemical reactions is not very extensive in terms of having to learn new facts, but being able to balance a chemical equation takes some practice. For that reason, I think. (Dr. Dalton, interview)

Similarly, Dr. Duna stated: “I mean in Gen Chem there's a lot of problems to solve. Right? I mean its concepts but within a discrete example they can solve.” (Dr. Duna, interview)

Some instructors also saw challenges with the new technologies introduced in the classroom that could overwhelm students, for example, since so much content could be delivered in such a short amount of time through the use of PowerPoint, as highlighted through quotes by Dr. Dixie and Dr. Mickey:

> Presenting facts from a textbook through a PowerPoint lecture can be an efficient way to transmit information, but in many cases important details are omitted or too much information is presented at once, and the links between the material presented and how it actually impacts students at a basic level is lost. (Dr. Dixie, interview)

Even for instructors who were not using PowerPoint in their lectures, they identified challenges for their audiences when only conveying content through lectures.

> That said, I do occasionally get some things like, you know, for a while I was using PowerPoint slides, and students asked that I stop using those. Again, it was very fortunate. I had a class where I was writing on the board and lecturing, and then I started using PowerPoint. They told me, "Go back to writing on the board," because it slows me down. (Dr. Mickey, interview)

Another concern that was brought up focused on how lecture content could be changed to keep the material interesting, in particular for instructors who might teach a course over and over again and have to stay motivated (e.g. Dr. Danner).

Another main set of concerns involved equipping students with what they needed to survive in an active learning environment, as voiced by Dr. Berry, Dr. Bobbie, Dr. Brigid, Dr. Devora, Dr. Donald, and Dr. Mickey. Quotes from Dr. Berry, Dr. Bobbie, Dr. Donald, and Dr. Mickey are given below:

> […] they need to get the big picture by doing the reading assignment and then you focus on a narrow part in class. Which might make some people uncomfortable, but as I said, my goal is not to teach them all of biochemistry. You have to embrace that first and say, I can't teach you everything. I can teach you how to learn it. (Dr. Berry, interview)

> They also, I mean some of them I think feel like it’s too much that they are not ready. They are not, that they are really not bringing a skill set that has prepared them for this kind of learning and I think they are, I think some of them are right. I mean I think they are right. (Dr. Bobbie, interview)

> The key ingredient I think is that now we're starting to have students that go through gateway courses and have done flipped gateway courses, so they're more ready to get into total flipped. (Dr. Donald, interview)

> To do POGIL right, the student has to do a lot of the work themselves, and I learned early on that a lot of first-generation students aren't quite ready for that yet, so that, yeah. That's why I moved away from that fairly quickly. (Dr. Mickey, interview)

The last theme I distilled from my data within this context dealt with the well-known fact that time spent on teaching in taken away from research. Instructors emphasized the extensive amount of time it takes to implement active learning environments; although, they would like to change and improve activities, as noted through quotes by Dr. Donald:

> My basic thought is, if your job is only teaching biochemistry, which is not the case in most universities, then something like what I'm doing could be done. But if you're still managing a couple of research grants, and you have way over half your time doing research, and you might not be doing the experiments, but you're getting all the stuff that your graduate students and post docs need, then this is hard to do because the flipped takes time. (Dr. Donald, interview)

Dr. Donna voiced that fact that she misses resources she could use to save time:

> And so, I reached out to get her power points because again, I don't have time to completely start from scratch with anything. And I got her power point, I got part of her activities, so I embedded a modeling activity as homework in the class […] (Dr. Donna, interview)

The overall concerns raised by participants involved a lack of knowledge of how to appropriately implement evidence-based practices in their classrooms. Often, they were missing the “tool-box” to draw from and change up their methodologies or simply have examples to pull from and use in their classes. Concerns were also raised about transferring skillsets from general chemistry to biochemistry in order to successfully implement active learning strategies. Concerns were also expressed that were related to students’ ability to learn on their own, not knowing where to edit the material to incorporate time for any activities, and the time-intensive task of making changes to incorporate more student-centered activities were also brought up. Concern about getting students to prepare adequately for class among different types of learning styles was holding many of the participants in this study from being more exploratory with respect to student-centered teaching methods.

4.3.1.3.2 Challenges Regarding Future Improvements towards the Implementation of More Student-Centered Teaching – Tools and Usefulness

This next table (Table 4.16) summarizes the obstacles and challenges instructors faced that prevented them from incorporating more student-centered teaching methodologies into their classrooms and originated from the codes “teaching methods-improvements”, “teaching methods-creativity”, and “future of teaching biochemistry” (Table 3.5, Figure 3.8). Three categories were identified: “professional influence”, “personal reasons”, and “making changes to teaching” (a more general category). Overlapping challenges were identified between this and the previous table presented, which will be highlighted within this section of my results chapter, below this table. This time, I summarized comments provided by my instructors, instead of using marking an “x” in the appropriate cell.

Using Dr. Maggie as an example, I will discuss the results from her interview to assist in the understanding of the table. Dr. Maggie’s comments during the interview, within the first category “professional influence”, related largely to the theme “delivery of content”. She emphasized that time was limited and student-centered teaching takes time and content needed to be delivered. Dr. Maggie requested, after member-checking, that the themes “logistics (class size, population) was also relevant for her, she stated in an email: “I would add “Logistics” to my table, as I find large classes limits how well I can implement group activities. I find that effective group activities tend to need a lot of feedback. If I have a class of over ~35 students, I tend to do fewer of the more intensive group work activities for logistic reasons. I do shorter activities, where I can give feedback at the regular intervals to the whole class.” Because of her request, I added a comment, summarizing her views, under the theme “logistics”. No other participants requested any changes or additions after member-checking was done. Within the second category, “personal reasons”, Dr. Maggie valued personal interactions highly in class (see theme “human interactions valued”) and voiced her concern transitioning into a flipped classroom setting, since she did not believe students learned outside of class that well. Her interview quotes did not provide any data to support the third category, which is why there are no comments to be found for her in that section of the table.

Table 4.16 Reasons discussed on the hesitation of the implementation of more student-centered teaching methods in class

		Professional influence, that was experienced as challenges					Personal reasons, that were experienced as challenges			General statements - Making changes to teaching (motivations to why challenges were faced)	
Type of institution	Participants	Failed implementation by others	Negative word of mouth about implementation	Lack on knowledge about methods	Delivery of content	Logistics (class size, population)	Afraid to fail	Unknown effects on student learning	Human interactions valued	Time is research	Not in charge of making changes
Doctoral granting institutions	Dr. Derrick		About flipped classroom	No idea how to make students work in groups together	Doubt on success of outsourcing learning		Personal failure No idea how to make students work in groups together				Left to department
	Dr. Devora							Totally flipped classroom would cause major discomfort for students, ultimately impair learning			

Table 4.16 Continued

	Dr. Duna			On alternative student-centered teaching methods Flipped classroom	Students are not their best teachers, flipped classroom would not work		Personal failure Fear of failing students No idea how to make students work in groups together		Loss of human dimen-sion through online learning		
	Dr. Dixie						Personal failure			Teaching improve-ments take time	
	Dr. Donald				Student-centered learning takes time, content needs to be delivered				Hesitant towards online classes		
	Dr. Danner			Flipped Classroom	Fear of managing crowd to stay on task and get through material	Too many students to do student-centered learning, flipped classroom	Afraid of making them learn in groups				

Table 4.16 Continued

	Dr. Dana									Teaching improve-ments take time	
	Dr. Dalton			Lack of knowledge on flipped classroom for example	Student-centered learning takes time, content needs to be delivered					Teaching improve-ments take time	
	Dr. Dolly	Saw failed flipped classroom examples		e.g. flipped classroom, direct feedback from students missing during lecture		Class too big for e.g. discussions			e.g. online learning		
	Dr. Donna				Student-centered learning takes time, content needs to be delivered					Teaching improve-ments take time	
Master granting institutions	Dr. Magnus				Student-centered learning takes time, content needs to be delivered						

Table 4.16 Continued

	Dr. Manju			On alternative student-centered teaching methods, such as flipped classroom	Student-centered learning takes time, content needs to be delivered	e.g. afraid to try out flipped classroom if class size is too big, or students are not ready				Teaching improve-ments take time	
	Dr. Maggie				Student-centered learning takes time, content needs to be delivered	Big class size restricts amount of activities			e.g. no flipped class-room, students learn in class		
	Dr. Mickey	Saw failed flipped classroom examples			Student-centered learning takes time, content needs to be delivered				Direct feedback from students missing during lecture when student-centered learning in place (group work)		

Table 4.16 Continued

Bachelor granting institutions	Dr. Brigid				Student-centered learning takes time, content needs to be delivered Fear of managing crowd to stay on task and get through material, using POGIL, case studies			Doubt on usefulness of watching videos over and over again in flipped classroom learning Books are more useful than videos			
	Dr. Berry				Students are not their best teachers, flipped classroom would not work Also she wants her students to learn reading, so will stick with reading guides	PLTL implementation: logistical issues; students want faculty to lecture				Student-centered teaching development takes time	
	Dr. Bobbie				She has good results the way she does it now					e.g. flipped classroom is too time consuming in preparation	

The category “professional influence”, encompassed themes I saw that were influenced by any interaction instructors had that influenced the choices they made for future implementation of a more active classroom setting. For some instructors, the failed implementation of student-centered methods was enough reason to not try it in their classrooms. For instance, Dr. Dolly and Dr. Mickey saw a failed implementation of a flipped classroom setting that made them more resistant moving toward a flipped classroom setup, let alone implementing it (e.g., Dr. Dolly, Dr. Mickey).

> If I want to try, and if it's a reasonable, I think I have in some modified ways, but we have seen demonstrations of a FLIP classroom, and I don't think I'm in for it. (Dr. Dolly, interview)

> When I was at [XYZ] College, there was an organic faculty member who used something similar. It wasn't called POGIL. […] but kind of the same idea as the POGIL system. I was not involved in that class, […] and I had the fortunate ability to see her students before that and then after she tried that, for several years, both before and after, and there was no difference in the level of student […]. The students who came out of the POGIL-like system tended to be a little less prepared students who came out of her traditional lecture type. Yeah, a little less prepared. They didn't quite have the breadth of knowledge that the students in her traditional lecture format had. (Dr. Mickey, interview)

However not only seeing techniques being implemented less successful, but also only hearing about it was enough to convince instructors not to try out these techniques in their classroom.

> I mean, right now, it's largely anecdotal. My neighbor across the street in another department at the university says, "Oh, yeah, those flipped classrooms don't work at all," and stuff like this. He's pretty high up in the administration, but that doesn't mean he knows what's going on. Maybe it's too early to tell. I don't know. I mean, redesigning teaching is something that's been going on ever since teaching started. So, I don't know the answers. (Dr. Derrick, interview)

Another reason for experiencing more obstacles with student-centered teaching methods was due to instructors not knowing enough about these less traditional teaching methodologies. During the interviews, the instructors discussed student-centered teaching methodologies they heard about and they felt reluctant to try it out in their classrooms. In many cases, instructors brought up the flipped classroom setting and voiced their concerns. For example, Dr. Duna talked about not knowing enough about alternative teaching methods in general:

> I don't know how I would do group work in Biochemistry necessarily. I don't even know how that would work. Are they going to teach each other glycolysis? I have no idea how that would work. You know? […] (Dr. Duna, interview)

In addition, Dr. Danner, Dr. Dalton, Dr. Dolly, Dr. Manju also voiced the concern about not knowing enough to implement a flipped classroom setting. Dr. Danner, for example, raised the issue of his class being too big to implement such a drastic change as a flipped classroom environment:

> But things like flip classrooms in a class of that size are off limits. I would find it hard to teach it other than making it mainly traditional lecturing course. […] I can't flip the classroom, so that would be a no-no. […] It's too big. And I don't know too much about it. As a student I once a long time ago experienced something like this where, it was a seminar course, and groups of students had to present to the rest of us on topics and there was an exam at the end. The big concern there was some students aren't as good as others. They'd do a shitty job at presenting something to you, and then you get tested on it, then you're screwed. That would be one concern. But I think you can work around it by interfering if needed or checking on stuff beforehand. I don't – […] That was sort of a flip class. I don't think that was done intentionally as a teaching technique. It just panned out that way. In the big class, I don't think you can do that. I would have to learn how to do it. What other techniques are out there? Do I need to know any that - (Dr. Danner, interview)

The possible implementation of group work was also a challenge instructors struggled with. For instance, as voiced by many in the previous section about challenges faced within their current style of teaching (e.g. Dr. Derrick).

On a professional level, instructors voiced their concerns about meeting their responsibility to deliver the content in their classes, when instituting more student-centered teaching, which in their opinion took time. Many instructors voiced that concern, such as

Dr. Dalton, Dr. Donna, Dr. Magnus, Dr. Manju, Dr. Maggie, Dr. Mickey, Dr. Brigid. Dr. Dalton said the following as an example:

> Dr. Dalton: Yeah. There's a lot to be said for group work, and of course we do that in the lab, but I've never been able to figure out how to cover the material and still take time for working through a set of problems as a group or whatever for some kind of group work. It's a challenge that I've never, maybe I've just never put in enough work to get over it, but ...
>
> Researcher: You've never tried it, really, because you were never sure how to implement it, is that true?
>
> Dr. Dalton: That's it, yeah. […] The implementation has to do with getting through ... Let's see, let me put it a different way. I always felt that doing group work would mean having to give up on some of the material that I felt needed to be taught. (Dr. Dalton, interview)

Dr. Mickey also voiced uncertainty about how successful it would be:

> Science is content-based. We're heavy on content, and I'm always a little worried about flipping classrooms. Will I get through the content that I need to get through so the students have that good understanding when they leave? Will I be able to get through all that content with the classroom? (Dr. Mickey, interview)

Dr. Duna was also skeptical towards the implementation of student-centered teaching:

> Researcher: Okay. From all the other, making the lecture ... I mean regardless of the amount of students that you have to teach actually in 339, if we look at making more active, more interactive, more than talking to each other, what are the reasons that prevent you from implementing that?
>
> Dr. Duna: Because I don't think that what they're saying to each other is necessarily correct. That's [inaudible 00:38:45] the problem.
>
> Researcher: Them communicating knowledge to each other, you don't think that-
>
> Dr. Duna: But they don't have the knowledge to communicate. That's my problem. Right? […] Right? I mean they're going to sit there and pass misinformation to each other. It just seems ... I don't know. (Dr. Duna, interview)

Within that context, instructors also emphasized the concern of not having enough time in the classroom to have students learn and implement a multitude of student-centered learning techniques, since the content still must be delivered in class. This concern was similarly expressed within the context of challenges they faced with their current style of teaching and methodologies they used. This was even true with instructors who already provided a largely student-centered classroom environment (e.g., Dr. Donald). Dr. Derrick raised the concern that the could not trust students to learn outside of the classroom, as also stated under Table 4.15. These concerns were similar to the ones Dr. Dixie brought up. Other instructors voiced the concern about students not being the best learners and not being able to grasp the material on their own outside of class, as voiced by Dr. Derrick in the table mentioned above.

Moreover, instructors also raised concerns that they were afraid of letting students be more in control of their learning in the classroom and not being able to manage the crowd and have students stay on task to make this a rewarding experience, which was raised by Dr. Danner and Dr. Brigid for example. However, the contrary was also true for one instructor, who raised the fact that she felt comfortable in how she was running her student-centered classroom right now and she did not see the need to make changes to her teaching. However, Dr. Bobbie was an instructor who already carried out student-centered teaching in her classroom with confidence.

In the context of logistical reasons preventing the implementation of more student-centered methodologies, instructors voiced their concerns regarding the class sizes they were teaching. Dr. Danner did not think that a more active classroom environment could be implemented with the class size he was teaching in the biochemistry course observed.

He especially pointed out the flipped classroom setting, as mentioned earlier in this section. Other instructors, such as Dr. Berry thought that class size did not matter to make activities a part of your teaching:

> I don't think that class size should limit what you do. I think you can do active learning. You have to tailor them and might need to develop different, like I might use the manager time keeper secretary roles more strictly in a bigger class but because they're small I can circulate more. […] I don't think class size - I think you can do it, it's just a matter of whether you're willing to figure out how to make it work for your population. We do shuffle groups on a pretty regular basis to try and even things out. (Dr. Berry, interview)

In addition, Dr. Manju also voiced the issue of his students not being ready yet for such a chance and that much autonomy. This was also pointed out as an obstacle to face when I presented their challenges they faced with their current styles of teaching, earlier.

Instructors also discussed the fear of failing and the concern of implementing student-centered methods, (Dr. Dixie, Dr. Danner, Dr. Derrick, and Dr. Duna), as personal challenges they faced, as voiced by Dr. Derrick and Dr. Duna separately:

> […] but I'm familiar with the idea there of having the students work on problem solving in the class where you're available to help them out. I just never in my own mind, I couldn't figure out how to get it to work. […] It could be a disaster. So I am concerned. (Dr. Derrick, interview)

> Right now it's ... I mean I'll change it on the fly if it feels wrong, and I'll do it but it's working. I don't want to break it. Let's put it that way. (Dr. Duna, interview)

These concerns also extended to instructors not wanting to fail their students when implementing something new that might not work (e.g. Dr. Duna) However, Dr. Bobbie brought up the fact the more student-centered teaching she had implemented, the better she felt about their learning experiences:

> I was worried about the students that we lose all of that right. The students that don’t get baffled or no struggle and never really understand like how to learn. They don’t get the material, they don’t get the content either so that’s sort of a failure on

> our part. I think those students are fewer and fewer the more freedom I allow them, the fewer of those there are. (Dr. Bobbie, interview)

During the discussion of possible teaching methods instructors heard about or would like or not like to try, the topic of online learning came up. Some instructors raised the concern of the loss of a human dimension in their classroom (e.g. Dr. Duna, Dr. Donald, Dr. Maggie). An exemplary quote by Dr. Dolly summarized many concerns:

> Again, I'm more of human powered interaction, is important in this teaching. When you're doing FLIP, you have to get that understanding then at home. And I don't think it's going to work well in biochemistry. It’s new concept that they need to learn how to organize it in classroom. So, I think FLIP can be used in other context, maybe, other subjects, but not here. (Dr. Dolly, interview)

Many of these concerns were related to the absence of the feedback component that was missing when not seeing students directly responding to what the instructors has told them during lecture, as mentioned by Dr. Dolly for example:

> There would be ... Yeah. The other thing is that instant feedback that I keep looking for students, nodding, or not nodding. Without it, I'm not going to be able to go on. It's the instant feedback that I think it's important. Also, couple of my colleagues have taught online, and that's what they're missing. It's the least rewarding experience that they had. (Dr. Dolly, interview)

One of the other common themes that emerged was centered around the idea that making teaching improvements takes too much time that should be invested in their research (e.g. Dr. Dixie, Dr. Dana, Dr. Dalton, Dr. Donna, Dr. Manju, Dr. Berry, Dr. Bobbie). This was similar to challenges raised when making changes to their current style of teaching (Table 4.15).

One instructor raised an interesting point by noting that significant changes towards teaching was up to the department and it’s teaching committee, which offered another challenge to instructors making possible changes to their style of teaching:

> I have had ideas, but I haven't ever pursued them, no. I mean, part of it, what held me back was perhaps just not really having a good understanding of the needs of the department and whether whatever I was thinking about would satisfy any needs that we had. I pretty much have left that to the curriculum committee to decide and well, of course we meet as a faculty to discuss things, but the curriculum committee makes many of the decisions about gaps and whatnot. (Dr. Derrick, interview)

This is hinting at another factor that has not yet been discussed– the support by peers and the department. In most cases, the department was not discussed as the determining factor for making changes to styles of teaching. That was one main reason why it was not further discussed within the context of my results.

Concerns voiced regarding the future implementation of student-centered teaching methodologies were again manifold. Many concerns were centered around the successful implementation of group work. Another dimension was added when instructors voiced their concern regarding implementation of student-centered teaching in large classrooms. Furthermore, instructors were unsure how to give students more autonomy over their learning during class and outside of class. Teaching methods that were primarily mentioned focused on flipped classrooms and group work. Instructors seemed to convey uncertainty around student-centered learning techniques and their role in supporting student learning.

During interviews, instructors provided further details on the changes they had already underwent in terms of their teaching styles, student-centered teaching or teacher-centered teaching. In the context of seeing instructors' readiness and willingness to try out new methodologies, especially student-centered methodologies, it was important to see what changes instructors already tried, to get a more holistic understanding of their individual story. When looking at that set of responses collected in this study, three major categories were identified: "moved to student-centered learning techniques", "moved to teacher-centered learning techniques", and "no major changes made to teaching techniques".

To better illustrate the layout of the table, which was primarily originated from the codes "teaching methods", and "teaching methods-creativity" (see Table 3.5, Figure 3.8), I will describe Dr. Dalton's table entry. Dr. Dalton was categorized as "moved back to teacher-centered learning techniques". As illustrated more in detail below Table 4.17, Dr. Dalton made use of a visualization software during class previously. Due to challenges implementing that methodological tool effectively, he moved back to traditional lecturing and writing his notes on the board, drawing out structures himself.

Table 4.17 Changes towards student-centered teaching methods instructors had implemented thus far

Type of institution	Participants	Moved to student-centered learning techniques	Moved back to teacher-centered learning techniques	No major changes made to teaching techniques
Doctoral granting institutions	Dr. Derrick	Incorporated group work		
	Dr. Devora	Oriented her lectures towards specific learning goals that are implemented through various activities in class, flipped Fridays		
	Dr. Duna	Incorporated fill-in-the-blank notes		
	Dr. Dixie	Incorporated some paper discussions		
	Dr. Donald	Complete conversion to flipped classroom		
	Dr. Danner	Incorporated mini-in class exercises		
	Dr. Dana	Incorporated computer-based activities		
	Dr. Dalton		Moved away from using visualization software in class as more interactive visualization technique	
	Dr. Dolly		Got rid of students solving problems on board	
	Dr. Donna	Incorporated a mix of Clicker questions, POGIL inspired exercises		
Master granting institutions	Dr. Magnus			No major changes were made
	Dr. Manju	Incorporated more examples in lecture and verbal involvement of students		
	Dr. Maggie	Incorporated POGIL activities, fill-in-the-blank notes		
	Dr. Mickey		Tried out POGIL, think-pair-share	

Table 4.17 Continued

Bachelor granting institutions	Dr. Brigid	Incorporated more activity-based learning, in every lecture she teaches: group work, worksheets, group quizzes		
	Dr. Berry	Reduced amount of lecturing, integrated more group work, e.g. POGIL		
	Dr. Bobbie	Incorporated group work worksheets and mini-lectures		

Most of the participants during their career had made changes toward implementing more student-centered methodologies in their teaching. Only a few moved back toward more teacher-centered methodologies or did not make changes to their teaching. The instructors who went back to a teacher-centered teaching style tried out various methods to involve students more. For example, Dr. Dalton tried out visualizing tools and software to have a more interactive lecture. However, it took too much time and he did not master it well-enough to use the methodology well and still be able to convey all concepts he felt he needed to with that more "involving" methodology:

> Not a big ... Okay. No, I don't think a big change, a little change. The change went from presenting material as a lecture to presenting the material with questions for the students as we go along, first. Second, developing the thoughts on the board step by step so that the students can track the thinking process a little better. […] Yeah. Yes. For about five years I used ... Let me tell you a little bit about ... A molecular visualization program gives a fantastic view of biochemistry at a molecular level and I think it's an important thing for the students to be able to picture these molecules as they really exist, get a really nice picture of 'em, which we can't do on the blackboard. For about five years, I tried to introduce molecular visualization into my lectures, and I found out that I just didn't have enough time to get through the material and do this presentation as well. After about five years, I ended up withdrawing from that and pulling back. The idea there is, we show a picture of a sugar molecule as a hexagon ring and in the molecular visualization, you can see the sugar molecule as a solid, shaped a little bit like a hexagon, but with hydroxyl groups spread over the surface ready to hydrogen bond or react.

> There's a lot built into that picture that says a lot about the biochemistry, but maybe it was just too hard for me to get it across the students, it just didn't work. (Dr. Dalton, interview)

Dr. Dolly involved her students by having them solve problems on the board, but she got rid of that participation component, since her students were uncomfortable during these activities:

> In the beginning of class when I was making a lot of practical mistakes, I had a student come up to the board and work on the problems, and student complained once, like, "No, not comfortable at all." And feels like she's under pressure and all those things. And I thought about it, "Well, that's how I grew up, though." But I didn't. I understand that though, right? (Dr. Dolly, interview)

Dr. Mickey tried out POGIL as well as think-pair-share in his classroom, for example, but he did not see the direct benefit of using these methods to have his students learn more, so he went back to his lecturing:

> Oh. I'm a traditional lecture person, so the majority of my teaching style, as I'm sure that you saw on the videos, is lecture. I do group work as ... To me, that's lab work. Group work naturally lends itself to lab. I don't use anything like a POGIL system or anything of that nature. I'm a traditional lecture person. To me, that's efficient. It gets things done quickly and efficiently, and for students, it can be very difficult, because to listen consistently for an hour can be a lot of work, but yes. I'm a lecturer. […] As I learned about those techniques, I tried them out. I still use some of them, but I've never done anything like a flip a classroom, and I've never gone to a full POGIL and stayed with it. I've tried those things, or at least watched others try them, and seen the results. Yeah. I didn't make a decision somewhere along the line, "Well, I'm never going to lecture again and try these new things." I've tried to integrate those into my teaching. Some of those things have come and gone, and some of them have stayed, but yeah. I would say I've transitioned back more to full lecturing. (Dr. Mickey, interview)

Dr. Magnus was the only instructor in my entire cohort who said he did not significantly change his teaching style and was always lecturing.

Examples where instructors stated a drastic change from their previous style of teaching being more passive, to their current style of being more active, was mentioned by Dr. Berry, who pointed out what her previous teaching style looked like that:

> I still did lots of case studies. I did more case-based and small group problem kinds of stuff; so it'd be ten minutes of talking, 15 minutes of group work, ten minutes of talking, 15 minutes of group work and that's how my class flowed. (Dr. Berry, interview)

In order to bring her teaching style closer to her teaching philosophy, she joined a colleague in teaching her biochemistry class in a POGIL setting, where students spend more time in groups:

> Which actually goes back with that initial teaching philosophy of having them struggle first and then have them resolve by the end. (Dr. Berry, interview)

As was pointed out earlier in this chapter, she found her students to be more successful on her assessment with this more engaging teaching methodology than with her prior teaching style:

> I appreciate that it happens in small groups and with students struggling through materials, I think them talking is more effective than me talking. I try and listen to what they're saying and if I hear things that are wrong, trying to guide them towards the correct idea. (Dr. Berry, interview)

Dr. Bobbie went from a more drastic change of mainly teaching lectures to small group problem-solving:

> It has changed. When I started it was lecture, it was all write notes lecture kind of thing. The frustrating part about that is the learning; the outcomes of doing that are pathetic. If you want to improve true student learning that they can take with them, that they can take to another test, another class, another something you have to teach I think that you have to teach them how to think. You can’t just teach them content you have to teach them; problem solving skills, study skills all those things and the best way to do that is not through lecture. (Dr. Bobbie, interview)

Many small or large changes to incorporating a more student-focused lecture environment were implemented by instructors teaching biochemistry across the population investigated within the scope of this study. Changes from flipping classrooms completely (e.g., Dr. Donald), to halfway (e.g., Dr. Devora), to involving student in more group work (e.g., Dr. Derrick), and in-class discussions and discourse (e.g., Dr. Manju). Also, some instructors emphasized incorporating more structure to their worksheets or more active ways of approaching the material, for instance by using POGIL more in their classroom (e.g., Dr. Berry, Dr. Brigid, Dr. Maggie).

4.3.1.4 The Future of Biochemistry Teaching – Student-Centered Teaching Will Grow

The table below (Table 4.18) illustrates the results captured in my study, as I asked my participants how they viewed how the teaching of biochemistry will develop or change in the next decades, and originates from the code "future teaching of biochemistry (Table 3.5, Figure 3.8). Asking this question helped me to further understand their attitude towards the teaching methodologies they tended to use and their willingness to adapt new ways of teaching in the sciences. Many themes appeared in the data, of which multiple could be summarized into the category "student-centered teaching will grow". In this category, the main emphasis laid on engaging students in class and interacting with them personally, through different ways.

As an example of how to better interpret the table, Dr. Mickey's interview is analyzed here. He mentioned during the interview, that he envisions the ways in which biochemistry is taught will not change much in the future (see "x" in the column labeled with the theme "teaching will stay the same"). He valued student interactions, even if it was only through lecturing (see theme "personal interactions will stay"). He could envision using more technology in lecture and that the use of technology and different technological tools could change in the future (see check-mark at "technology in lecture").

Table 4.18 The future of teaching biochemistry

				Student-centered teaching will grow				
Type of institution	Participants	Teaching stays the same	Personalized teaching grows (emphasis on the individual)	Less personalized teaching will stay	Personal interactions will stay	Technology in lecture	More active learning in general	More online learning
Doctoral granting institutions	Dr. Derrick		x				x	
	Dr. Devora			x			x	x
	Dr. Duna	x						
	Dr. Dixie				x		x	
	Dr. Donald				x		x	
	Dr. Danner					x		x
	Dr. Dana						x	
	Dr. Dalton						x	
	Dr. Dolly						x	
	Dr. Donna						x	
Master granting institutions	Dr. Magnus	x			x			
	Dr. Manju	x				x		x
	Dr. Maggie					x		
	Dr. Mickey	x			x	x		
Bachelor granting institutions	Dr. Brigid					x	x	
	Dr. Berry						x	
	Dr. Bobbie				x		x	

A majority of my participants thought student-centered teaching methodologies will continue to be an integral part of future biochemistry classrooms in some way.

Instructors who valued human interactions during class time emphasized that, in the future, personal interactions will stay, meaning in person class-time will be still be valued. The importance of being in the room with students was voiced by multiple instructors, with many relying on eye contact with their students to judge how they are doing in class and how their students feel about the material. Dr. Magnus stressed the importance of individualized human activity in the classroom as follows:

> Human activity. There will never be two classes that are the same. There'll never be two teachers the same. […] That's just an inherent part of human interactions. That's also what keeps it fresh. People, a lot of times people ask you, "Doesn't it get boring teaching the same class every year?" I say, "I never have the same class twice. Always have different students." People then go, "Oh, I never thought of that." (Dr. Magnus, interview)

During her entire interview Dr. Dixie emphasized personnel contact during teaching as being the crucial key to conveying knowledge and the future of biochemistry teaching. Dr. Bobbie emphasized throughout her interview the importance of in person teaching experience as well, however she also made her worries being heard:

> […] it's about the fact that numbers of students are going to go up. There are numbers of students; the harder it is to implement alternative methodologies. I think alternative methodologies work best with small numbers or smaller numbers. I can do a truly individualized literature-based course as advanced biochem because I have 12 or less in the course. Can I do that with 23, not really. (Dr. Bobbie, interview)

Whereas she was a big supporter of active learning classrooms and did it against any odds she faced during her teaching career in terms of more challenging student feedback and teaching evaluations, she emphasized the struggle for her to feel the push towards bigger classes and the challenge to still enact her active style of teaching.

A smaller number of instructors argued that less personalized teaching would likely be the future of education, discussing the role of online learning. For example, Dr. Devora stated:

> There's a bigger push towards more butts in seats, bigger classes, "Let's do this at a cheaper way," and I think the students will suffer. There is no student who will not learn more effectively in a smaller group. I think I am an effective teacher, but there are also students in my class right now that would learn more effectively in a smaller group. I think we need to be careful about that. (Dr. Devora, interview)

Furthermore, she pointed out:

> I think it's because a lot of the way online teaching has gone is towards scaling things up massively, whereas the way my online section is, is towards providing accessibility to a group that wouldn't otherwise have it. We limit the size. There are only 50 in the online section this semester. We cut it off. It was like, "No more," because we've got to be able to engage, and it's harder to engage online students. I think the engagement, in the way that I teach, is key, […]. (Dr. Devora, interview)

As a student-centered instructor, she saw challenges in implementing online learning, since she translated her way of teaching into an online classroom and saw issues with that. For her, active engagement could still happen in an online environment, but then, class size would have to be limited in order to still be able to engage with all students and provide relevant activities, which is what she did for the online class she taught.

Dr. Manju also viewed online learning as a critical part of the future of biochemistry education, but had a more positive perspective:

> Even in the university now, they are cutting down the job subscriptions in house because they say it's online and everything. […] That is going to change a little bit, in the small colleges in the sense, teaching will still be a larger part, I mean in that person to person, will be much more the same as the online teaching. […] People are going to change more, and more towards the very same person will be still there, it may be more of an online courses. […] I think it's the online teaching is great, because you can learn a lot on your own. You can put them into discussions and ask for an answer there, so you can post a question to the professor anytime, and he can answer the questions however in the group discussion going on there. (Dr. Manju, interview)

He emphasized the growing number of online courses at colleges, and the adjustments for instructors to still teach in person as well as online. But he could also see positive effects from teaching online classes and he felt one was to be more "in contact" with his students.

Some instructors discussed the use of technology in the classroom in relation to student-centered approaches:

> I think the technology will improve to the point ... What I would love to see is cheap three-dimensional systems, particularly in biochemistry. You know, I can show things three-dimensionally through Jmol-type software, and when push comes to shoves, we can do what I call the poor man's 3D, where you do a cross-eyed stereo image. What I'd like to see and what I hope is that some sort of cheap virtual reality becomes available so that my class and I can literally walk through a molecule. I think that would be a real benefit, but the price and the equipment is going to have to be miniaturized, and the price is really going to have to come down for that to be useful on a class. […] Yeah. I think, you know, until we make that real leap into cheap virtual reality, I think that, yeah, I'll probably be doing the same things in 10 years that I'm doing now. (Dr. Mickey, interview)

The emphasis on teaching biochemistry with visualization technology in the classroom was also voiced by Dr. Maggie, who pointed out that textbooks are outdated and that we need to find a more "tech savvy" approach:

> They have to have stamina for reading those things, which is the textbook is beyond their stamina at the moment I think. You know? They don't feel like they understand it. It's hard to understand. The language is dense. It's technical, and so they have a hard time understanding it. And so what are resources out there? Like Wikipedia is a great example of an absolutely wonderful resource. In order to understand something, you can go to a Wikipedia site and get a fairly good understanding of some of the basics, but it's not ... You're going to be missing part. Go link to that. But I don't really understand what they mean by a nucleophilic attack. Let me go link to that. Let me go see what that's about. (Dr. Maggie, interview)

Dr. Danner pointed out another issue that was raised during the interview – the incorporation of students' phones into their classroom learning experiences to maintain modern students' attention and increase student involvement:

> Embrace technology, because you can't escape it. If there's a way you can put those things [points to phone] to a meaningful use in class, do it. Of course, stay up to

date with the topic, because it's a changing field. And I think, engaging students who are more and more glued to their electronic devices, I see that with my kids too, will be challenges that they'll have to meet. (Dr. Danner, interview)

One of the other trends observed was that instructors felt there would be more active learning incorporated in future course, as highlighted by the following exemplary quotes:

Just a more active class, more clicker problems and stuff like that in class, face to face. That's what's important. It's hard to put that into an online experience. And choose stuff that is significant to the students. (Dr. Donald, interview)

I think it's gonna be certainly more active learning. However, you define that, even if it's just more student participation because even though they don't like it and they claim they don't like it, if you ask them, "Would you be in an active learning class," most of them are probably gonna be like, "Oh no. What is that, that sounds weird. That sounds like you want me to do a lot." But then you get more out of it. It's more fun. (Dr. Dixie, interview)

But the she adds as a caveat:

I don't think we'll ever be done with just Power Point lectures. You can make them more interactive, but sometimes you just have to sit down or stand up there and tell people something. And there's not a way around that. So I think kind of the trash talking about lecture based courses, I think that's gonna ... I'm sort of new to all this. It seems really trendy to bash on those, but they do have a place. And they can be done well. So, to just totally write off kind of an essential component in teaching I think is maybe a little bit short sided. So I think they'll still be lectures. They might be more dynamic. (Dr. Dixie, interview)

With her more lecture centered teaching style, she adds the more content-oriented advancement in “actively” teaching biochemistry:

But I think we need to be more cognizant that all of these are tied together. And it makes more sense that way. It's not just your cell does glycolysis and then it stops. And then it decides, "I'm going to do the TCA cycle?" And then it starts the TCA cycle. It's like all of these things are worrying and going together at once. So I think that's gonna be more important, and I think we'll have cooler examples too. (Dr. Dixie, interview)

Dr. Brigid, who already enacted a rather active classroom, saw active teaching in biochemistry as progressing as follow:

> The resources are there. The teacher is there to help them figure out what resources are right, or what resources are useful. I think the way that I understand teaching in elementary and secondary schools is going now, I think we have to be able to adapt to that. I think getting away from teacher-centered learning ... And again, I don't know that it's all going to go away. I mean, I don't know, in graduate schools, are they going to go to this? I don't know. Graduate school, you have your lecture on Physical Chemistry. There's content that's delivered, and then you go off. Medical schools, there's some case-based learning, medical schools, but I've gotten feedback from my students who go to medical school, and they're like, "Yeah, they videotape the lectures, so I don't go to class, I just watch them when I want to." It's like, "Wow, that's very different." From my personal thing, I think we're probably going to be shifting away from that, but we'll see. (Dr. Brigid, interview)

Dr. Berry followed up her statement that active learning is crucial in the classroom:

> I think one of the biggest issues is the can of biochemistry keeps growing. Let's see if I can do the analogy. If I can see the books, I'll grab them fast. The book that I started with [inaudible 00:50:28] it was like 500 pages. It's now 1,000 pages. What we have to have in a class keeps growing and so then people get this content problem of oh my gosh, I have to teach all of metabolism. No, you don't. You don't have to teach all of metabolism. You have to teach students how to learn metabolism. I think that's a switch that needs to happen is convincing instructors that their role is not to teach them everything. It's not to fill up their head with a bunch of stuff, it's to teach them how to learn it so they can go learn it for themselves when it actually is useful to them. Because you retain what you use. If you're not going to use it, why teach it? (Dr. Berry, interview)

For Dr. Berry it was clear, that in order to teach more actively, less emphasis had to be given to every detail in biochemistry. More so, significant concepts had to be conveyed, the ability overall, to learn new concepts on their own.

It is encouraging to see, however, that, for some instructors, active learning is accepted as a natural movement that one has to follow and should follow:

> I suspect many of the science classes and biochemistry will be moving to much more active learning projects, just because that's the style. As more junior faculty come through, that will be the style that they start using. I think that's probably going to be a trend. (Dr. Dana, interview)

Dr. Derrick took it to an even higher extreme and pointed out that teaching in general will follow a trend towards personalization, to meet individual students' needs better and to improve their success through a personalized teaching approach. Through that statement, he voiced the need to understand students better and to get more knowledge about what makes them learn well:

> Of course where we want to go with this is drill down even further so that I have a drug that is specifically made for Franziska that will work on you. It might not work on anyone else, but it'll work on you, that's where we want to go in personalized medicine. I think we need to do more of that with teaching. […] Right? I mean I think it's pretty obvious, right? We have a whole classroom with kids and they're not all the same. They're all different and yet we're teaching them more or less the same and if there's some way. I don't have the answer, but if there's some way that we could get enough information about each of them beforehand that we could tailor teaching to help them most effectively, that would be great. I don't know what that answer is, but I think that's where we want to go. (Dr. Derrick, interview)

Only a handful of participants supported the thought that teaching would not change, but rather stay the way it was done already in their classrooms:

> I don't think it's going to change very much. It hasn't particularly changed over the last 75 years. I can't imagine the next 10 years are going to be that much different. The same information's going to be important. […] I see myself pretty much doing what I'm doing. Yeah, and maybe ... I can't see it changing too dramatically. (Dr. Duna, interview)

Dr. Duna voiced an idea many participants agreed upon, especially the ones with a more teacher-centered teaching approach. Dr. Mickey added in the same tone:

> I don't think lecturing will probably ever go away, again, because I think it's a very efficient method, and it's served well for thousands of years, so I don't think that'll go away. (Dr. Mickey, interview)

He further elaborated:

> Researcher: What do you see the field, the teaching of biochemistry, do you see it moving towards more, I mean, in ... like active learning, extreme active learning classrooms in terms of, like, using more POGIL, using more flip classroom, do you see that coming up more in the future?
>
> Dr. Mickey: Actually, I don't. You know, POGIL and similar things have been around since the '90s now, and if they were that good, everybody would have converted, myself included. I don't see a major shift in

> that. Again, I've been around long enough in teaching that teaching goes through cycles, and I saw POGIL roll out or similar systems roll out in the '90s and kind of went away in the 2000s, and now they're kind of coming back again. No, I don't see any major change from that, because I think if they were that good, things would have changed already. (Dr. Mickey, interview)

In the course of the interview, he emphasized the tremendous amount of material that has to be taught in biochemistry and the need to come up with a list of topics that should be taught in specific courses. This led him to see less of an opportunity to implement other methodologies than pure lecturing because there is simply no time for something else.

> I think one of the barriers that we're going to have in biochemistry and in all sciences is the amount of material that we're having to deal with. Again, when I started, one color textbooks, and they were small. Now, my biochemistry text, you know, it's two inches thick, and there's just no way that I can get through all that material. One of the things that we will have to figure out as a field, if you will, is to decide what do introductory students need to know and what can we leave to graduate level or job-specific training. I do that now. I mean, there's just no way that I can get through an entire biochemistry textbook in a year. It's just, I can't do it. Even with the best of students, I don't think I could do it, and so I already have to pick and choose what I think is important. Maybe that will become even more of an issue in the future. (Dr. Mickey, interview)

His view provided the voice representing the concerns any instructors brought up during their interviews (e.g., Dr. Donna, Dr. Berry, Dr. Dalton). The worry about focusing too much on content and therefore not being able to experiment somewhat in the classroom with activities and such was voiced throughout my entire pool of participants. I think the point Dr. Berry made prior to that is something that we as a community have to advance in teaching students how to learn and overcome the challenge of wanting to be taught everything in class.

Overall, most instructors agreed that the focus on student-centered teaching methodologies would increase in the future. However, doubts about the utility of changing the style of teaching and using more student-centered teaching methods and replacing lecturing were voiced, as previously discussed.

4.3.1.5 Professional Development of Biochemistry Instructors' Ways to Teach Biochemistry – Resources Used and Desired

This section describes instructors' views regarding resources that support the development of teaching and the incorporation of new methodologies in class. The interview questions that prompted this section were inspired through the concerns instructors voiced during the interview, where it was deemed important to provide insight regarding what instructors would find useful in order to make any changes to their teaching. Two main categories were extracted from the data, "resources used to gain knowledge in teaching", and "resources desired to have (medium most preferred)". Within these main categories, several themes emerged that provided more detail to resources used or needed to improve the teaching of biochemistry.

To elucidate the meaning of Table 4.19, Dr. Bobbie, for example, emphasized mainly resources she used to gain knowledge in teaching. Her responses could be categorized into the following themes: "professional development resources (e.g. workshops, conferences)", "reading up on educational research literature", and "peer interactions (observing others)". The absence of any "x" in any themes identified for the category "resources desired to have (medium most preferred)" indicates that Dr. Bobbie did not verbalize any resources she wanted to have available to improve her teaching.

This table was generated mainly from multiple original codes, such as "teaching role of importance", "professional development", "teaching methods – improvements", "teaching methods – creativity", and "teaching background", as seen in Figure 3.8. Many codes encompassed information on resources used and needed to develop professionally in teaching, therefore, multiple codes were used to extract this information (see description of codes, Table 3.5). In particular, many codes revealed specific challenges instructors faced that uncovered potential needs and resources in developing professionally in teaching.

Table 4.19 Professional development – diverse resources used/desired to be used

		Resources used to gain knowledge in teaching						Resources desired to have (Medium most preferred)		
Type of institution	Participants	Personal life experiences (e.g. reading books, experience in life, educational experiences)	Self-gained teaching experiences	Professional development resources (e.g. workshops, conferences)	Reading up on educational research literature	Peer interactions (observing others)	Student feedback (e.g. evaluations, out of class or in class feedback)	Teaching methods in class	Technical resources on teaching (support in technologies)	Teaching material
Doctoral granting institutions	Dr. Derrick	x	x	x				x		
	Dr. Devora			x		x		x		
	Dr. Duna		x	x		x		x		
	Dr. Dixie						x	x		
	Dr. Donald			x		x		x		
	Dr. Danner					x	x		x	
	Dr. Dana		x	x	x	x				
	Dr. Dalton		x					x		
	Dr. Dolly			x		x			x	x
	Dr. Donna			x		x				x
Master granting institutions	Dr. Magnus				x	x		x		
	Dr. Manju				x	x		x	x	x
	Dr. Maggie			x	x	x		x		
	Dr. Mickey		x	x		x	x	x		
Bachelor granting institutions	Dr. Brigid	x		x		x		x		x
	Dr. Berry			x	x	x		x		
	Dr. Bobbie			x	x	x				

Proficiency in Teaching through Interactions with Peers

Many instructors used multiple resources to gain knowledge about teaching. The most common resources involved utilizing colleagues and personal experiences.

> There's a communication, yes. Like I talk to people okay how they talk about different topics. And since I have in house experience with, so we always discuss about it, how to go about a different topic or something like that. […]. We are talking with a colleague because when we are starting this project at a different college, okay? […] I have a lot of resources, Dr. [X] has been very nice. He's always open, so that is a great thing for me. He's always an inspiration, to do something with it. So I think I can improve with decisions on ones that okay I still want to improve much more and be more effective than what I am right now. […] That's what I want to say, the colleagues are very helpful to inspire […]. (Dr. Manju, interview)

Dr. Magnus specifically referred to the material he was sharing with his colleagues, as also highlighted by others (Dr. Donna):

> Yeah, I mean at my [college], all the professors are always sharing materials. We trade resources, whether they be print or online. We borrow a lot from each other. Nothing is proprietary in our department. (Dr. Magnus, interview)

Furthermore, colleagues with an educational interest and background were mentioned as being helpful and enriching to trouble shoot teaching challenges:

> That was formative for me. I feel having chemical education, Ph.D people in my department has been really helpful. There have been times when I've been ... I can't get a concept across. I try this. I try that. It doesn't really work for me. Sometimes I can sit down with a colleague whose been trained in chemical education and they say, "Oh, well, there's this. There's that, so why don't you try this other thing?" That's a great idea. It's just a great way to get additional ideas and approaches that I really appreciate. (Dr. Maggie, interview)

Her department even instituted a peer evaluation system, where they had the opportunity of being observed and getting feedback at: "[...] We do get evaluated. Two people come and visit our class, and I go visit other people's classrooms. It's a beautiful thing. It's a wonderful thing."

Dr. Danner brought up an interesting aspect of alternative approaches to teaching when he talked about the difficulty of getting rich feedback from his colleagues who were asked to sit in his lecture and evaluate him:

> You learn it by doing it. Or, if you have trouble, you talk to colleagues and reach out, "Hey can you sit in my class and tell me what I'm doing right or doing wrong?" And I actually have done that a couple of times, that people said ... And here they even do that as part of your review. Like last year, somebody sat in one of my lectures and wrote a paragraph about it. But again, that is more an assessment of how you're doing. That doesn't really help […]. (Dr. Danner, interview)

On the other hand, he acknowledged, that he had difficulty identifying where help is needed. He sometimes could only say something did not work out, but identifying the problem was often challenging.

> I would have to see a clear need. For example, I felt I did a lousy job at teaching a certain class, and I have to change things, and I don't know how to do it. For example ... Depends on what I thought would be the underlying cause. If it's just lousy preparation, I know I just have to sit down a little bit longer before and get ready. If it's more conceptual or structural problems with your presentation and so forth, then I would probably ask for outside help. (Dr. Danner, interview)

Dr. Dolly emphasized how helpful it was for her to have a mentor when she started to teach biochemistry.

> Colleague, friend, mentor, it's one person, who is also professor in biochemistry. Up to this date I talk to her almost every day. When I first did start teaching ... Tell me to stop ... I sat in her class, so I learned how she taught. I asked her whether I could do this, she said, "Sure." And then we talk about it afterward, and she'd tell me what she did well that day, or what she did not do well that day. That was great. (Dr. Dolly, interview)

Dr. Bobbie stressed the fact that the on-campus exchange of knowledge was most rewarding for her, since it would relate to the world she taught in and was familiar with:

> I think more helpful are regular conversations with my colleagues who teach with a lot of different methodologies and we talk about outcomes with our students here. It's one thing to go to a big school where somebody is teaching one class each semester maybe once a year, it depends on the place right? It's a huge lecture hall of 500 versus having a class of five or 23 […]. It's not the same, so I learn a lot

> from my colleagues about what works and doesn't work with our students here. (Dr. Bobbie, interview)

Not only colleagues among the faculty were helpful sources of new ideas, students could also be an inspiring resource to make changes happen in one's own classroom:

> Researcher: How do you come across this creative moment of, "Oh, I can change this?" Is it with interactions with colleagues? Is it reading up on things?
>
> Dr. Dana: All of the above, yeah. Or sometimes, you know, a graduate student has a brilliant idea, and I'm like, "That's a great idea. Let's do that." (Dr. Dana, interview)

Dr. Brigid mentioned in her interview a supportive concluding remark where she stated:

> Right, and you know, in the Chemistry world, I think developing good teachers and developing, "It's okay to try new things," I think we have to make our younger colleagues understand that it's okay to try new things. (Dr. Brigid, interview)

Proficiency in Teaching through the Attendance of Professional Meetings

Many instructors, during the interview, also emphasized the importance of going to conferences or having the opportunity to utilize workshops that enriched their knowledge on teaching methodologies.

> We have a [center and institute for teaching], and they all have seminars and they'll invite authors who have just written a book in changing, reform of college education. I just go to those. Some of them have good points. Some of them aren't so good. Like the guy who wrote, I forget his name, he wrote Teaching Naked. He gave me the idea of having the exam wrapper. (Dr. Donald, interview)

In addition, he mentioned:

> Well, the American Society of Biochemistry and Molecular Biology had a flipped class one day workshop up at one of the colleges. It was along the coast. I did that, but it wasn't really intensive. It was pretty good. […]. This was a couple years ago, maybe two to three years ago. (Dr. Donald, interview)

Dr. Donna was an enthusiastic conference attendee and very interested in PD around teaching:

> So, whenever I'm at conferences I'm always thinking about my instruction. So ASBMB, I definitely go there for [inaudible 00:54:56] So for scholarship of teaching and learning. I definitely go, 'cause there's no research program to it, so I definitely go there to get better ideas for teaching. SABER is really the same thing, with better ideas for teaching. […] That's why I go to BCCE, BCCE is not a research conference in any way shape or form. […] I go there to improve my teaching. I think the last BCCE was the first time I went solely for research […]. But I go to the biennial to get cool new ideas for stuff to do in lecture or cool new ideas for me to implement in my classroom. (Dr. Donna, interview)

Dr. Brigid also expressed the importance of attending conferences to listen to colleagues as well as presenting at conferences as rewarding. Dr. Maggie highlighted the importance of workshops as well, however admitted, that you have to set the time aside to go to those. This was even true for instructors who taught at more teaching-oriented institutions such as master granting institutions:

> I do. I do. Yes. You know not as many as I should. We have a faculty teaching and learning center here on campus also that sponsors different workshops, et cetera for teaching in different ways. That's good. (Dr. Maggie, interview)

She also noted:

> I attended two additional POGIL workshops to hone my skill with this technique. At a POGIL workshop this summer, I presented our concept-rich on-line laboratory manual, and I participated in a “fish-bowl” experience, where other faculty evaluated my performance as I facilitated one of my POGIL activities. (Dr. Maggie, integrative statement for tenure promotion)

In her interview she added:

> My approach to active learning has been very much patterned after the POGIL approach that I went to a workshop ... I don't know how many years ago. Many years ago. (Dr. Maggie, interview)

Dr. Dolly also found it important to go to conferences from time to time, especially those that were hosted on campus as well as taking the opportunity to make use of teaching centers on campus. In the interview for example, she would mention examples such as:

> […] where people would develop a rubric to assessing the critical thinking skills among the students in their writing assignments. So I participated in those things,

> and I learned a lot because as biochemistry researcher, I'd never seen anybody doing anything like that. (Dr. Dolly, interview)

In contrast, Dr. Magnus mentioned that workshops or seminars on teaching were resources he used but did not find as helpful: “I have gone to those types of things, to some degree, but can't say that they dramatically altered my overall style.” (Dr. Magnus, interview). A similar position was taken by Dr. Bobbie, who found peer interactions on campus most helpful. For some instructors, it was though a future endeavor rather than a current endeavor to attend further PD opportunities. For instance, Dr. Duna said about attending workshops or PD opportunities on teaching:

> Yeah. Yeah. It's actually probably more useful now because I would be able to frame it on my own experience as opposed to just, "Here, do this." (Dr. Duna, interview)

Similarly, Dr. Dixie pointed out:

> I would be willing to take some. I've been to a few new faculty workshops when I first started. And it sounds bad, but there's sort of pie in the sky. They make you feel like you should all be doing flipped classrooms and completely innovative teaching and lecturing is dead. And then you actually come to do it, and you can't do all of it. You can't have a brand-new course that is a flipped classroom that you've redesigned from scratch with all the latest and greatest teaching innovations and run your research group. It's just not possible. I've not been to a workshop that's actually addressed that. […] There's a lot that comes in your first year if you want to do learning workshops. And I think a lot of it is you're just so overwhelmed that it's not the best time to be sending those out. If you sent them out to someone in third of fourth year like I am now, I kind of have a balance, I know what I'm doing course-wise. (Dr. Dixie, interview)

Proficiency in Teaching through Consultation of Educational Research Literature

Reading the educational research literature was another resource instructors mentioned. For example,

> Researcher: Oh, interesting. So, when do you implement flip classroom, do you know that already?

> Dr. Manju: No, I don't know yet because I'm working on it, how to ... I'm reading on it, but I haven't gotten too far on that one. (Dr. Manju, interview)

Dr. Maggie mentioned that she felt she needed to read more educational literature to polish her knowledge on teaching methodologies and opportunities. She especially consulted the literature when she came across a problem or when more data had to be gathered to have a better understanding about possible solutions.

Dr. Magnus mentioned that he would incorporate ways of improving students' learning based on education literature he came across:

> Then I actually have some citations from the education literature where they have found that writing your own notes with your own hand, people, it's been shown that people learn and remember more by doing that. (Dr. Magnus, interview)

It was interesting to see that Dr. Maggie also justified the use of active learning in her classroom by mentioning education research studies:

> It is well established that active learning maximizes student performance and retention. A recent metaanalysis of 225 studies, each which explored active learning vs. traditional lecturing in the science, technology, engineering and mathematics (STEM) fields, found students in courses centered on traditional lecturing were 1.5 times more likely to fail a course when compared to active learning-based courses, and student performance on exams increased on average 6% when active learning was used. (Dr. Maggie, integrative statement for tenure promotion)

Dr. Bobbie also brought up the importance for her to read relevant studies on teaching and learning.

Proficiency in Learning through Own Experiences

Factors that were discussed less often involved relying on one's own experiences during teaching and drawing from these experiences to further develop their teaching methodologies.

Researcher: But do you use any of these resources to gather more knowledge on student learning or ways of teaching and things like that?

Dr. Dalton: You know, I'd like to say yes, but in the time when I was going through learning how to teach, I wasn't aware of any, I don't know how much was back in those days, but I wasn't aware of any of that information. I look back at some of my early lectures and I have to laugh, because it was truly learning by doing. (Dr. Dalton, interview)

Dr. Dana simply relied on her intuition when she was trying out new methods in her classroom:

Researcher: You said you think that they learn better through active learning. Is it that you know that from some papers that you've read or from the feel you get in the classroom? And how does that ...

Dr. Dana: I did a little bit of reading on that, and the literature. It seems to be the consensus, but it's implemented in many different ways. So I experimented a bit in the classroom early on. (Dr. Dana, interview)

Only a few instructors noted that personal life experiences were resources they used to gain knowledge in teaching. Dr. Brigid emphasized the importance of peer group interaction that she learned during her baccalaureate education:

> Certainly, my peers in undergraduate, one of my roommates was also a Chemistry major. We […] worked on things together, and she brought understand to my work, I brought understanding to her work, and so that probably also did influence that. I think in our department we try to promote that, that it's really important to find this peer group that you can work with. Just looking at our students, we graduate 10 to 15 students each year in Chem and Biochem, and the students who are the most successful find that peer group to work with. Again, I try to translate that into the classroom, I think. (Dr. Brigid, interview)

Dr. Derrick cited a book he was reading that made him reflect on his teaching methodologies more:

> I don't know I mentioned to you this book that [X] sent to me and I remember reading. I haven't read it all yet. I haven't gotten to that, but it talked about a faculty member who for years would just digest the material for his students and realized that that wasn't necessarily an effective way to go. I certainly am guilty of that. (Dr. Derrick, interview)

Proficiency in Teaching through Instructional Support

Another part of the interview focused on what instructors would like to have, which would be useful for their personal development related to teaching. Participants were asked if an education researcher or instructional specialist at the university would be useful for supporting teaching. Many did not object the idea and found it worthwhile to try:

Researcher: Yep. When I asked you earlier if you would like to have an education researcher, or someone for example on hand to help you in the classroom. If you were to have that person for you know kind of for your disposal where you can say here's an idea. Especially for example, the fill in the blank, I would like to implement it. I do not have time to really come up with a fill in the blank because there is so much I have to do, research and teaching. If that person were to develop it for you and then work with you on developing instruments for your classroom, would that be something you would consider to be interesting?

Dr. Manju: Yeah, it would be interesting. It would be interesting […]. (Dr. Manju, interview)

Dr. Manju also highlighted the need to have additional help in his classroom to help facilitate teaching:

> So it is the tutor who will help in the class can lead the discussion, or something like that. Like the teaching assistant we have at universities who come and sit in the class with you. They don't grade the papers, but they also do the help the discussions, and other things, and dissolve the more difficulties the students may have. So [inaudible 01:18:41] tutor would be good to kind of start off the discussion and monitor them, when I've already taught them. And so it will be much easier because then students can relate to that person much more than approaching to the professor. It will be much easier to approach the tutor because the tutor is already sitting in the class as a student, that would be a great thing to do. (Dr. Manju, interview)

Dr. Dalton verbalized the need for support to implement technology more effectively:

> Yeah. In fact, I can see very easily that if somebody would sit in on the lectures and say, "You know, Dr. Dalton, you could use video clips here, and here, and here, and they're available or we could make 'em easily by doing this, and this, and this," that would be a tremendous help, because my thinking is that a more visual kind of approach would make an impact, I believe, on the students. If I had more years to

> go, definitely, I would be leaning toward how to incorporate more visual illustrations in my lectures, that kind of thing. (Dr. Dalton, interview)

The conversation with Dr. Dalton provided insight into the tremendous need for more instructional resources.

> Yes, in fact, that would be great to be able to look through a menu and say, "Well you know, this particular item looks really useful," or, "This one might work really well in my classroom," and then to be able to follow up on that would be great. […] Yeah. That's a good idea. That's a good idea. You know what would help, too, if there was the available resources for training so that you could say, "We have a professor, we'll give him half time this term just to train in this new technique." (Dr. Dalton, interview)

As one of the student-centered instructors, Dr. Donald had the opportunity through developing his flipped classroom to experience something similar to what I suggested to the participants, so he was open to my suggestion:

> It was helpful. What the [Teaching Center] does, when I started the course, they would come in the middle, midway, and ask me to leave for 15 minutes so that they could then query the students, "What's working? What's not working?" This was very helpful, because there you get the student perception, and this was before we had LA's. Then when we had LA's, getting students to say things that they wouldn't say to a professor, they would say to a learning assistant. And then we'd have our weekly learning assistant meeting, going over the course and what's coming up and how we did last week. They say, "They really didn't like that and this, this, this." So when I find those things out, I change them. I change them right away. (Dr. Donald, interview)

Dr. Maggie also emphasized her willingness to benefit from hands-on advice and help in her classroom to improve her teaching:

> Researcher: Just to play a little bit with potential new ways of teaching biochemistry, if someone in your department would be dedicated to help you figure that out and transform the classroom in a new setting, would that give you more of an open mind to try out that.
>
> Dr. Maggie: Sure. I would agree. Yes, to help. Yeah. Mm-hmm (affirmative). Of course. Yeah. (Dr. Maggie, interview)

Dr. Duna verbalized the hope that …

> Oh, absolutely. Yeah. I mean we always hoped that there would be much closer interaction between the […] Ed faculty and everybody else, with them trying to help us know how to teach, but everybody's busy so it never really happened. Yeah, no, that would be useful. I think. (Dr. Duna, interview)

Faculty with and without education background were pointed out as valuable resources:

> You know I've seen where faculty, like some of the ones who have had chem ed backgrounds, which that's been, as I say a real gift for us. They'll say, "Oh, you called ..." not me, of course, not me, but they'll tell a colleague, "Well, you called on this many males versus this many females." Like something that they didn't realize they were doing. I was like, "Ooh, that's cool. That he can look at this, not just what content and how you're teaching it, but how are you interacting with the students in what you're doing." (Dr. Maggie, interview)

Proficiency in Teaching through Observing Others

As seen throughout this section, most instructors would like to have more insight into teaching methodologies and how to implement them in their respective classrooms. Another way of bridging the gap between enacted practices and potential options was to observe other instructors teaching biochemistry. Many of the instructors found a suggestion that was brought up during the interviews, to be appealing and helpful.

> I would like to change a little bit of what do you call it, teaching style you may say, or teaching technique. I want to observe a couple of more guys, okay how they deal with it so that I can implement those changes. But time is not permitting me to go and attend other lectures so that I can have some different styles of something. What are the discussions they're having? It's not the practical, I mean his theory is good, okay we can all talk about it. But actually, seeing the student's reaction to the particular professor when he says okay this is my style of teaching it, so I can observe it greater. Observe it, then I can definitely improve my own teaching. (Dr. Manju, interview)

Dr. Maggie' peer evaluation system at her school encouraged her to visit other classrooms, to evaluate other instructors, which had a positive effect on her teaching methodologies.

> When you were asking what are the things that influence how you teach, some of those observations have been very formative for me as well. It's a gift that I'm able

> to go see how my colleagues do things. I learn about ... like when I go to do organic chemistry I'm like, "Oh, that's cool. I can tie that in with some of the biochem that I do knowing a little bit more about where they're coming from." Then some of this, like this idea of incorporating lecture and these little five-minute things. I first saw that model years ago by a colleague. I was like, "That's cool. I'm doing that. That's perfect." Like does where the note packet ... the skeletal notes helped being able to do that for this given stuff. […] It's been really helpful. It's been good. I think it's more useful being the observer almost. (Dr. Maggie, interview)

Dr. Magnus, who is at the same school as Dr. Maggie, also mentioned their peer evaluation system as a way to get inspiration from watching others teach, and then through that, creating his own new material:

> Yeah, certainly good examples. I mean being able to see it actually be done would be useful. On the other hand, given my tradition of, what's the word? We talked about how I like to create everything on my own. Just going in with other people's materials, just going in with my own pre-scheduled materials doesn't work. Going with somebody else's [inaudible 00:45:34] canned materials would probably not be something that I'm interested in. I would need to be able to take something and adapt it, create the resources myself to this. Probably using other people's materials would not be something that worked for me. I'd be looking more for the ideas and how I could implement them as opposed to having other people give me things to implement. […] Another thing is that in our department, every year we are required to observe and evaluate other professors. Visit their classes and give them feedback. That's not for their benefit but it's for the benefit of the observer so we see all these other professors and what they are doing. We certainly get lots of exposures and lots of good examples. (Dr. Magnus, interview)

Dr. Dolly found it most enjoyable to observe her mentor teach and learn through that. What helped her a lot was the possibility of discussing possible changes and asking questions regarding her mentor’s style of teaching and methodologies used right after class.

Dr. Brigid would also find it useful to watch other peoples’ teaching methods that she was wondering whether to try out, but time was always an issue:

> We talked about flipped classroom. I know one of my colleagues down in Business does it. Seeing what she does in class might do that, but I think I'd have to participate as a student. That'd be a lot of time. […] I think you can learn a lot from what your colleagues say. That's kind of nice feedback. (Dr. Brigid, interview)

Proficiency in Teaching through Technical Support

Only a few instructors voiced the need to have technical resources on teaching available, to incorporate technology more into their classrooms. Incorporating more educational technology was also considered a methodological change in teaching. Dr. Manju noted that, in order to implement a flipped classroom or to even get close to this environment, required overcoming several technical hurdles. Dr. Dolly also mentioned that if she needed help with teaching methodologies, she would like to have help with new technology to have everything run smoothly. Similarly, Dr. Danner said:

> Another thing where I might do that is the increasing trend to use technology in the classroom. Sometimes you just need to know a) how does it work, and more importantly, how do you put that to a use that make sense. Not just have clickers for the sake of being able to, "I use clickers!" Does it really help you or is it just a stupid little exercise, like you do because you think that looks cool on your CV or wherever you put it down. (Dr. Danner, interview)

Proficiency in Teaching through a Community of Biochemistry Instructors

Some instructors also emphasized the need for more readily available teaching materials in order to safe time on the implementation of student-centered activities. Dr. Donna stressed the fact the she was at a point in her career where she needed material to work with and implement in her classroom, to make time-efficient changes in her teaching:

> I was in a conferencing learning community but that was a huge waste of my time. So that's the issue is that most of the professional development provided to faculty are stuff that I teach teachers so it's not really helpful. At the point where I'm at, I need ideas or resources that I can take and implement it into my classroom. (Dr. Donna, interview)

She mentioned that the issue laid within the biochemistry community itself, where she feels needs are not met that interdisciplinary instructors like biochemistry teachers would need to be fulfilled:

> I think more PD for the biochemists. I don't feel like there's enough professional development. But I also feel like our societies need to back it more and as a [biochemistry researcher interested in teaching], I don't have a home. You would naturally think that it would be within the ASBMB but we don't have a home, so where do the biochemist, the bench researchers who want to do better at teaching go to improve their instruction? That doesn't exist yet. (Dr. Donna, interview)

She emphasized an important call for a closer community of instructors teaching biochemistry that could possibly provide valuable resources around teaching materials and methodologies to better succeed in the implementation of evidence-based knowledge on teaching and learning. Dr. Brigid stated, during her interview, that periodic meetings among biochemistry instructors were helpful to think about the teaching of biochemistry: “All the Biochemistry teachers sit down in a session and talk about what they're doing. Really interesting.” She was referring to a useful discussion she found happening at a conference. For her, a sense of community was coming up and that was helpful to get ideas and suggestion as well as defining the community of biochemistry educators better. She elaborated further: “I mean, if I could team up with a Biochemist at some other place, that would be awesome.”

Dr. Berry concluded:

> Because often biochemists are isolated where there's only one in a department. Finding somebody to say man, they still don't get it and I don't know what I should do, is a very valuable thing. As a field, figuring out ways to support those people, especially who are stuck in where they're the only biochemist or their institution isn't very supportive is important. (Dr. Berry, interview)

Results in this chapter showed a variety of resources instructors utilized to improve teaching, with peer interaction being the most common. Furthermore, PD opportunities were also used, but need improvement. The need for a better functioning community was discussed, which is necessary to help solve problems, provide teaching material, and support the implementation of teaching methodologies.

4.3.2 Summary of Main Results Addressing the Second Research Question

Results gained from the second research question showed that the more student-centered instructors were teaching—i.e., the more they involved their students in class -- the more likely they were to verbalize their teaching beliefs and perceptions in a more practical and less theoretical way. I found evidence that indicated that theory- versus practice-oriented ways of thinking about teaching and its implementation in biochemistry reflected in instructors in-class practices and obstacles they faced when instructing biochemistry.

Teaching methods seen in observations and discussed in interviews were different among the population of biochemistry instructors. Within my sample population I had participants who taught in a traditional style, with lecturing as their main focus. I also had participants who showed a range of levels of student-centered teaching, from short group work activities incorporated into their lectures to extensive in-class group work time with almost no lecture present. Overall, the majority of biochemistry instructors displayed efforts toward including more student involvement in class.

The trend of theory- versus practice-oriented ways of talking about teaching and its execution in the classroom was also visible in how instructors viewed active learning, and not only how practically or theoretically they approached their beliefs and perceptions in teaching biochemistry as highlighted in results summarized for the first research question.

More teacher-centered instructors interpreted active learning as being frequently executed through students' thinking through tasks and concepts while listening to lectures. Contrary to that observation, descriptions of active learning techniques that focused on involving students in in-class activities were frequently voiced among instructors with a more student-centered teaching focus.

Overall, almost all instructors, despite the level of student engagement they displayed in class, they felt that their classrooms provided an active learning environment. In essence, instructors' interpretation of active learning in their classrooms encompassed a broad range.

To gain more insight into the potential of students' involvement in class, results were also viewed through the lens of the ICAP (Interactive, Constructive, Active, and Passive) model. The ICAP model (Chi & Wiley, 2014) describes the possible modes of student engagement as either passive, active, constructive, or interactive -- in increasing amount of student-centered teaching from the passive to the interactive level of engagement. Student modes of engagement are described within this model from only listening to lectures (passive) to also being involved in in-class discussion and extensive group work opportunities (interactive).

When viewing the results of my observations of classroom methodologies used to teach biochemistry through the lens of the ICAP model, instructors were observed to provide potential platforms of student engagement primarily through supporting active and constructive student engagement. Many participants also demonstrated the potential to increase their modes of student engagement, through already displaying, to a small degree, more advanced student-centered methods in their classrooms.

When I looked at why instructors did not implement more student-centered teaching methodologies, such as group work activities, the predominant reason was that instructors lacked knowledge of the tools needed to succeed in advancing their teaching methodologies and/or did not have an understanding of how to implement the tools they had. Instructors also mentioned time as a significant issue, since they felt required to deliver extensive content in biochemistry classes and student-centered teaching took so much time. This particularly resonated with what teacher-centered instructors described, as mentioned in the results summary of the first research question.

To overcome these obstacles, instructors voiced interest for having more instructional support in their classes, having the opportunity to observe colleagues implementing EBIP, and being able to benefit from what is now a non-existent network of biochemistry educators to share material and knowledge on alternative teaching methodologies. Overall, instructors believed that biochemistry instruction will become more active in the future, and that learning more about EBIP would be a worthwhile pursuit.

4.4 Addressing the Third Research Question

Within the scope of this thesis, I recruited instructors from three different types of institutions: doctoral-, master-, and baccalaureate-granting institutions. We know that perceptions and beliefs vary from individuals to individuals (Richardson, 1996), but to what extent can trends be identified across different types of institutions? The following research question was used to address these interests:

> Do beliefs and styles of teaching biochemistry vary across different types of institutions?

This section is intended to provide a general idea of the commonalities observed within the pool of participants, to further discuss potential implications and future research in the following chapters. In addition, highlighted in each section are notable discussion points found on the departmental, course and experiential levels across the participants. Commonalities and differences found in this section are further discussed and related to one and another in the next chapter.

4.4.1 Detailed Views on Results Addressing the Third Research Question

4.4.1.1 Commonalities and Differences on Beliefs Centered around the Teaching of Biochemistry

Themes adhering to a utilitarian approach to teaching were seen to be present at all three types of institutions, as pointed out in Table 4.1. It is noteworthy to mention, that one theme especially, “science needs to be relevant”, came up at all institutions. Within this theme, instructors emphasized the importance of linking topics to students’ interests.

The belief centered around the theme “science is for everyone to understand and enjoy,” came up primarily among instructors teaching at doctoral granting institutions. Instructors voiced the belief that everyone should understand science and opportunities had to be established where everyone could enjoy the lecture.

4.4.1.2 Commonalities and Differences on Influences on Beliefs Centered around the Teaching of Biochemistry

As notable influences, many instructors mentioned important relationships with family members that shaped their belief system in teaching. This was mostly observed across instructors with a significant amount of teaching experience. Themes such as “learning by teaching” and “educational influence” were brought up across different levels of institutions as well.

Differences were seen regarding the theme “cultural influence”, where it mostly commonly came up among participants from doctoral institutions. However, “learning by learning” was only brought up, among the set of instructors investigated on the doctoral institutional level (Table 4.2). This last theme was mentioned among instructors with a significant interest in educational literature and/or research, who already executed student-centered teaching methods in their classes.

4.4.1.3 Commonalities and Differences on Interests Instructors Voiced on the Teaching of Biochemistry

Within the Table 4.3 commonalities were seen where the theme “teacher-centered” seemed to be balanced among all institutions within an institution. Everyone across colleges brought up the “love of teaching” as a strong factor in their interest of teaching.

Furthermore, common across doctoral and master-granting institutions were the interest to share fascination and to share knowledge. A commonality between master and baccalaureate-granting institutions was the interest in “effectiveness of teaching on learning”. This theme was raised by two women more interested in educational research with a significant experience in teaching biochemistry and an emphasis on student-centered teaching methods (Dr. Maggie, Dr. Bobbie). Common themes across doctoral and baccalaureate-granting institutions centered on “making a difference/having an impact” and “self-education”. The theme to “make a difference/have an impact” was mainly raised by instructors with an interest in educational research and/or literature. On the doctoral granting institutional level, two unique themes emerged, “motivation for own research”, as well as the theme “advancement in position”. “Advancement in position”, for example, was brought up by Dr. Dana.

4.4.1.4 Commonalities and Differences on Beliefs Centered around Teaching Goals

For instructors oriented towards a more student-centered teaching style, application of knowledge and conveying knowledge often went together (Table 4.4). This was true across all three types of institutions. Furthermore, “application of knowledge”, “convey knowledge”, as well as “development of skills” were themes that emerged within the population of participants I interviewed across all three institutions. Between the themes just mentioned, “development of skills” and “application of knowledge” often went hand-in hand across institutions.

Differences seen when looking closer at the doctoral and master-granting institutional level, were the theme “raise interest in biochemistry”, which came up uniquely at these two levels of institutions. Common across doctoral and baccalaureate granting institutions were the themes “boost confidence/be comfortable with topics” and “equip for future success”.

The themes “create models in students’ heads” was only apparent for one participant at the doctoral institutional level, with a more teacher-centered focus on teaching (Dr. Derrick). Two participants from master granting institutions emphasized the importance to “provide learning opportunities” to their students.

4.4.1.5 Commonalities and Differences on Success in Achieving Own Set Goals of Teaching

Within the Table 4.5, instructors across all institutions tended to feel successful in teaching and reaching their goals.

Although, a difference was seen between doctoral and baccalaureate granting institutions, participants from those institutions said that they “feel successful with room for improvement”. Relying on that one theme, one could argue that they were more self-reflective and critical about their teaching. All of them had in common that they were executing various degrees of student-centered teaching.

4.4.1.6 Commonalities and Differences on Teaching Goals and its Measure of Success

Instructors across all types of institutions measured student success by “student performance”, which essentially meant exam grades (see Table 4.6). “Student feedback”, was also a theme that was mentioned across institutions. Within that theme, “student feedback” referred to both instant in-class feedback as well as later feedback through student emails.

Common across only doctoral and master granting institutions were measures of success such as “intuition” and “class attendance”.

4.4.1.7 Commonalities and Differences on the Role of Biochemistry Instructors They See Taking Within Their Classrooms

“Facilitator of success” was a theme that came up among all participants at all different institutions (Table 4.7), where instructors highlighted the goal of supporting students in their class and equipping them with tools to be successful. Also, “motivator” and “communicator” were strongly emphasized themes among instructors across institutions, closely followed by guiding their students in class. That’s how most communicated instructor roles.

Instructors from doctoral and master granting institutions brought up the role of being the “challenger” within the classroom. Participants from doctoral and baccalaureate-granting institutions mentioned their role to be a “motivator” in particular, when teaching biochemistry. Common across master and baccalaureate granting institutions was the idea that instructors viewed their role as the “mentor.

4.4.1.8 Commonalities and Differences on the Students’ Roles Biochemistry Instructors Perceived They Should Fulfill

Participants at all institutions saw “learner”, “utilizer”, and “customer” as important roles participants felt students should take on (Table 4.8).

The only difference that emerged from that analysis was between doctoral and baccalaureate granting institutions, in which the role of “receiver” came up as a more common theme.

4.4.1.9 Commonalities and Differences on Teaching Methods Extracted from Instructors’ Interviews and Artifacts

Distinct differences were found on an institutional level with regard to Table 4.9. At the doctoral granting institutional level, teaching methodologies were diverse. From a rather teacher-centered to student-centered teaching style, both extremes were observed. Data collected gave the impression that there were plenty of faculty trying to incorporate student-centered teaching methodologies (e.g., Dr. Derrick, Dr. Dolly, Dr. Danner, Dr. Donna), but who still relied heavily on lecturing. At the masters granting institutional level, the pool of participants displayed a range of methodologies used in lecture settings to teach biochemistry. However, the majority still relied on lecturing as being their major teaching and learning channels for students. Again, attempts to incorporate more student-centered teaching was also apparent with this group of instructors (Dr. Manju). It is noteworthy to mention, that, even within the same institution, teaching methodologies varied largely among instructors (Dr. Maggie vs. Dr. Magnus). At the baccalaureate granting institutional level, strongly oriented student-centered teaching methodologies were identified among the participants. In general instructors with an interest in educational literature and research were more likely to implement student-centered teaching environments.

4.4.1.10 Commonalities and Differences on the Students' Roles Biochemistry Instructors Perceive They Should Fulfill

When looking at how instructors perceived active learning in their classrooms (Table 4.11, Table 4.12, Table 4.13), it could be seen that many instructors across multiple institutions and institutional types found their teaching to be active and engaging.

Most comments related to active learning that focused on students being active through thinking about mentioned concepts and what instructors explained in class were found to be present at the doctoral granting institutional level. Instructors also emphasized in their definition the importance of engaging their students with the material through activities.

At the master granting level, both more theory- and practice-oriented definitions of active learning were present. It was clear from their definition, that the majority of instructors that taught at baccalaureate granting institutions, were putting an emphasis on active learning being physically as well as mentally engaging.

4.4.1.11 Commonalities and Differences on Providing Potential Modes of Student Engagements in Their Classrooms Through the Lens of the ICAP Model

Multiple modes of student engagement were found across the different types of institutions investigated (Table 4.14, Figure 4.2). At the doctoral granting institutional level, instructors involved in this study tended to be represented in all categories of the ICAP framework, with even representatives executing constructive mode as well as interactive mode of engagement level in their classrooms. Instructors at master granting institutions had a multitude of modes of engagement for their students through their styles of teaching. Instructor at the baccalaureate granting institution were again, as categorized before, engaging their students overall through in-class activities. Also, one could conclude, that the more interested instructors were to consult education literature (mostly seen on the master- and baccalaureate granting institutions) or the more likely they were to execute education research, the more likely it was for them to reveal a more student-centered mode of engagement in their own classroom.

Instructors from all institutions showed a potential to move toward higher student engagement (Figure 4.3).

4.4.1.12 Commonalities and Differences on the Challenges Instructors Faced at Different Institutions when Teaching Biochemistry or Wanting to Make a Change to Their Style of Teaching

When analyzing challenges instructors faced with their current teaching methods, various obstacles were reported that were not unique to any institutions (Table 4.15); the challenges that were raised were applicable across all institutions.

When looking at the challenges raised when wanting to implement new teaching methodologies into their classrooms, some commonalities as well as differences were visible (Table 4.16). Instructors across all institutions discussed the concern of having students learn on their own through activities provided in the classroom. Since student-centered teaching was well-established in baccalaureate granting institutions, fewer concerns regarding involving students in the process of teaching and learning were raised at these institutions.

4.4.1.13 Commonalities and Differences on the Future of Teaching Biochemistry Across Institutions

It was encouraging to see that many instructors moved toward more student-centered engagement in their classes, across all different institutions (Table 4.18).

Furthermore, most views regarding the future of teaching biochemistry were shared among all three institutions investigated (Table 4.18).

However, two differences were apparent: (1) a majority of instructors at the masters granting institutional level supported the viewpoint on teaching not changing much and (2) changes to teaching would only occur by involving more technology within the existing classroom setup (brought up among instructors at the doctoral and master granting institutional level). Only instructors with a heavy emphasis on a teacher-centered approaches to teaching biochemistry brought discussed the future for biochemistry teaching as something that would not change.

4.4.1.14 Commonalities and Differences on Professional Development of Biochemistry Instructors' - Resources Used and Desired

It was interesting to see, that there were no preferred resources regarding PD across instructors working at different institutions. going to conferences or talking to peers (Table 4.19), for example, were common across all institutions. In particular, instructors with an education interest in their research or an interest in literature focused on education, who also emphasized their interest on student-centered methodologies in class, were likely subjects to enjoy and utilize more PD. Also, across all institutions, instructors desired to learn more teaching methods and be more equipped regarding how to implement these methods in their respective classrooms.

As a difference it was notable that the majority of instructors interviewed from master and baccalaureate granting institutions used educational literature to inform their teaching practices in comparison to instructors from doctoral granting institutions.

4.4.2 Summary of Main Results Addressing the Third Research Question

Results revealed more commonalities than differences among the instructors investigated within this study, across all institutions. Additionally, since my sample size for master-granting and baccalaureate-granting institutional levels were relatively small compared to the population I had among doctoral-granting institutions, no conclusion could be made that related results to institutional differences. Overall, on a doctoral-granting institutional level, I had instructors from teacher-centered to student-centered teaching interests. The same held true on the master-institutional level. All participants that agreed to take part in this study from baccalaureate institutions displayed student-centered teaching approaches and ways of thinking about teaching. If differences were observed, they related back to the different styles of teaching instructors displayed and how they thought about their teaching, rather than differences in institutional levels.

A common belief was that instructors taught for the greater good. Across all institutions, I was able to see a relation between the style of teaching instructors used. Instructors seemed to shape their teaching beliefs through educational influences including teachers they had in their past. Many instructors voiced their love of teaching biochemistry as motivating to them. Within this study, I identified this as a rather teacher-centered motivational factor. Teacher-centered instructors tended to view the application of knowledge and the delivery of content as two separate entities when teaching biochemistry. This was contrary to student-centered instructors, who viewed the delivery of content and its application as more unified when teaching biochemistry. Teacher-centered instructors did describe their classrooms as active; however, their definitions varied greatly. Teacher-centered instructors tended to describe student involvement through the process of listening to the instructor and thinking about what has just been explained. Student-centered instructors tended to emphasize students struggling with the material through in-class activities. Almost everyone in my population mentioned student feedback as one of the most beneficial resource to assess ones' own success. In terms of PD opportunities, what instructors across all institutions mainly had in common was that they did not know enough EBIP to implement methodological changes in their classrooms. Across institutions, the need was stated for more instructional support and other resources to implement changes in ways biochemistry could be taught.

CHAPTER 5. DISCUSSION

5.1 Connecting The Dots

I will relate the results from the first and second research questions by providing a brief summary of overall trends extracted from the data within this discussion chapter. As a reminder, I have listed my research questions again, below:

First research question:

> What are biochemistry instructors' perceptions and beliefs about teaching biochemistry at the college-university level?

Second research question:

> How do biochemistry instructors think they teach biochemistry? What guides the decisions they make on the methods they use to teach biochemistry?
>
> I will also discuss the overall differences and similarities among instructors

investigated within this study and the influence of other factors impacting beliefs, perceptions and actions within their classrooms, within the context of the third research question:

> Do beliefs and styles of teaching biochemistry vary across different types of institutions?

5.2 Uncovering a Variety of Teaching Approaches in Biochemistry Education – a Brief Summary

Teaching trends were identified within this study that were indications of the current state of biochemistry teaching at the college/university level. Overall, I identified five levels in which I categorized the participants depending on the level of student-centered teaching they displayed. The five levels are briefly summarized below:

- Not There Yet – a Primarily Teacher-Centered Approach.
- Advancing Toward Student-Centered Teaching – One Step at a Time.
- A Great Start – but Still Room for More Student Engagement.
- Almost There – Closer to Student-Centered Teaching.
- Student-Centered Teaching in Biochemistry – in all Shapes and Forms.

These categories originated from the data analysis presented in Chapter 4, Table 4.9, which offered an insight in how instructors teach biochemistry lectures. As stated previously, it is almost impossible to place instructors in only one category or another (Åkerlind, 2008; Prosser et al., 1994). During my data analysis, I therefore felt it was appropriate to place the instructors along a continuum, moving from teacher-centered to student-centered teaching. As previously defined, the term *teacher-centered* is used in this study as a *passive* student engagement as is *student-centered* teaching seen as providing a more *active* student engagement. I categorized the participants along this continuum, based on their tendency to use certain teaching methodologies and styles.

Not There Yet – a Primarily Teacher-Centered Approach

Dr. Mickey, Dr. Magnus and Dr. Dalton were grouped into this category. Their styles of teaching were similar to one another and had a strong emphasis on teacher-centered instruction, largely dominated by lecture. These instructors primarily lectured at their students while writing on the chalk board or white board. If, or when, they involved their students actively, it was usually on a theoretical level by posing questions to “make them think". Their ways of thinking about teaching were heavily theory-driven rather than practice-driven.

Advancing Toward Student-Centered Teaching – One Step At A Time

Dr. Danner, Dr. Derrick, Dr. Dolly, Dr. Dixie, Dr. Manju, and Dr. Duna relied heavily on lecture as the tool to convey knowledge, but they also implemented varying levels of student-centered teaching methodologies in their classrooms, such as fill-in-the blank notes, small group work, in-class discussion, or in front-of the-class demonstrations. Participants within this category showed more evidence of application-oriented approaches when thinking about ways of involving their students in class than participants in the previous category, although the emphasis was still placed on students practicing outside of class rather than in class.

A Great Start – but Still Room for More Student Engagement

Dr. Donna was a biochemistry instructor who was particularly interested in education research. Her teaching style was still dominated by a lecture-based instructional methodology. However, to a great extent, she tried to involve her students through asking questions continuously during her lecturing and holding them accountable for answers throughout the class period, which distinguished her from the participants in the first and second categories. She put a significant emphasis on using different tools in her classroom to transition it into a student-centered environment as much as possible. She used tools such as group quizzes, POGIL exercises, and in-class discussions. Due to her education background, she also stressed ways in which she would implement visuals in her classroom and noted that it was important to point out limitations and strengths these representations entailed. Her values were not yet consistent with the teaching style she implemented in her biochemistry classroom, something upon which I will elaborate later in this chapter.

Almost There – Closer to Student-Centered Teaching

This group of participants, which included Dr. Devora, Dr. Brigid, Dr. Dana, and Dr. Maggie, showed an emphasis on executing student-centered methodologies in their classrooms. Dr. Dana and Dr. Maggie had an emphasis on a constant conversation going on in their classrooms. Group work activities were of various lengths but had a significant emphasis on student involvement. Dr. Brigid, for example, had reduced the length of the "lecture" part of her day-to-day teaching and had her students constantly work in groups, instead. During the group work activities, her students worked on their own, with the instructor mainly overseeing their progress, instead of lecturing to them. POGIL activities were frequently utilized by this group of instructors. Dr. Devora achieved similar results by instituting a semi-flipped classroom. Instructors in this category still highlighted the need and usefulness of lectures, but also embraced more student-centered teaching methodologies overall, since they valued that the most. Their approaches to talking about their students' learning in their classrooms were not only of a theoretical nature anymore. They set a strong emphasis on the use of application questions being performed by students in class rather than only outside.

Student-Centered Teaching in Biochemistry – in All Shapes and Forms

Within this category, I included biochemistry educators such as Dr. Berry, Dr. Donald, and Dr. Bobbie, who implemented a predominantly student-centered classroom environment by utilizing different methodologies reported in the education literature. Dr.

Berry for example, taught her biochemistry class as a POGIL class, whereas Dr. Donald transitioned his classroom into a flipped classroom setup. The two methods were different in nature, but had the same intent: to enhance student learning by involving students actively in the learning process. Dr. Bobbie organized her classroom primarily around students solving problems within small groups. The only time when she would lecture was when she felt common misconceptions would have to be addressed to get everyone on the right track again. This "just-in-time" teaching approach allowed her to lecture at students briefly to set a common ground of understanding certain topics, before letting them explore and struggle with the material. These instructors' description of how teaching should occur in a biochemistry classroom was aligned with the practices they performed. All was action driven and application based.

The results summarized above are consistent with previous research (Martin et al., 2000). Their study explored the relationship between teaching conceptions and classroom practices among university science teachers. Educators oriented toward a teacher-centered approach tended to make use of a lecture-based style of teaching. Teachers who were more student-centered used whole-class discussions or student presentations throughout the class and therefore a larger emphasis on student learning was given. A similar trend was also noted by Bodner et al. (1997) as mentioned previously.

It was remarkable to see that, within the rather small number of participants in this study, a rather significant difference was seen in distribution of styles in teaching demonstrating a variety of ways to implement student-centered approaches. Although I am not able to claim that the participants displayed the full range of instructional approaches currently implemented in biochemistry classrooms, the distribution that was observed suggests that a broad range of teaching styles and their beliefs and perceptions were captured.

A recent study of the teaching of physics, chemistry and biology (Lund & Stains, 2015) found that physics classrooms provided a more student-centered teaching environment than chemistry classrooms. Biology classrooms were reported as being in the middle of this continuum, with an increasing amount of active learning engagement being used. Another recent study described the current state of STEM teaching among North Americas universities (Stains et al., 2018). That study confirmed the results reported by Lund and Stains (2015), that chemistry instructors still used mostly traditional instruction compared to biology, which, as a field, seemed to have migrated more towards student-centered teaching methodologies.

Within this dissertation it seemed that biochemistry, with its interdisciplinary nature, seemed to co-exist at multiple stages within this spectrum of teacher-centered versus student-centered teaching conceptions and actions, displaying a variety of teaching approaches and conceptions seen in chemistry and biology classrooms. The results of this study suggest that biochemistry seems to be following the trend of replacing its traditional lecture style with student-centered teaching approaches.

In the following section, I will elaborate further on the relationship I found between teaching methodologies used in classes and the ways instructors thought about the use of teacher- and student-centered approaches.

I used Kember’s (1997) approach to thinking about student involvement in class to assign the instructors to one of five categories based on the teaching styles they used. I found a continuum among the participants in this study of different levels of student involvement (Åkerlind, 2008; Prosser et al., 1994) that ranged between the two extremes of Kember's (1997) model of teacher-centered versus student-centered teaching conceptions. Teacher-centered approaches with an emphasis on conveying content through mainly lecturing, were listed in the following categories developed:

- Not There Yet – a Primarily Teacher-Centered Approach.
- Advancing Toward Student-Centered Teaching – One Step at a Time.

Student-centered teaching approaches that had a larger emphasis on conveying content through the facilitation of student learning were listed in the following categories created within this analysis:

- A Great Start – but Still Room for More Student Engagement.
- Almost There – Closer to Student-Centered Teaching.
- Student-Centered Teaching in Biochemistry – in all Shapes and Forms

5.3 Main Assertions from the Results Obtained

In the following section, I will discuss the data I gathered to support a series of assertations grouped according to the following topics:

- The Interconnectedness Between Beliefs and Perceptions About the Teaching of Biochemistry and Their Influences on Actions Taken Within the Classroom Setting.
- The Current Trend of Teaching in Biochemistry and Its Perspectives for the Future.
- Challenges Inherent in Current Styles of Teaching.

- Instructors Preferences and Needs to Further Develop Professionally in the Ways They Teach - Many Commonalities Shared.
- Thinking Big – Large Scale Influences on the Teaching of Biochemistry and Factors to Consider When Implementing Strategies of Change.

5.3.1 The Interconnectedness Between Beliefs and Perceptions about the Teaching of Biochemistry and their Influences on Actions Taken Within the Classroom Setting

Within this section, I will attempt to discuss the participants' beliefs and perceptions (from the first research question) with their methodological choices in class (from the second research question) and discuss similarities and differences between instructors' beliefs and their approaches to teaching observed in their classrooms.

5.3.1.1 **Assertion 1: Teaching Beliefs Often Centered around the Utilitarian Idea of Teaching for the Greater Good – the More Student-Centered Instructors Were, the More Practically-Oriented They Voiced Their Beliefs**

Overall, the instructors had a utilitarian approach to what they believed were the ways in which biochemistry should be taught, as shown in Table 4.1. Differences were noticed, however, in the way instructors voiced their beliefs. Instructors with a predominantly teacher-centered instructional approach in teaching biochemistry (Dr. Derrick, Dr. Duna, Dr. Dalton) commonly identified the theme "science is for everyone to understand and enjoy" as central to their belief system. This belief had a rather "talking-heavy" tone to it and was reflective of the instructors' overall approaches to communicating science through lecturing. Dr. Derrick voiced his approach of teaching for the greater good by saying:

> I have my philosophy of life. It's more or less utilitarianism, which has been expressed as the greatest amount of something called happiness of the greatest number of people, I think it is, but I would expand it to the greatest amount of

> whatever this happiness is for the world in general because I think affecting the world will affect the people who live here. We can't divorce ourselves from that. (Dr. Derrick, interview)

The belief "science needs to involve", through involving the students in the learning process, or making science fun, was mentioned by the majority of instructors who emphasized student-centered teaching approaches (Dr. Donald, Dr. Danner, Dr. Dana, Dr. Berry, Dr. Bobbie). That belief was accompanied by the notion of making students learn within their classrooms by having them take part in their learning (e.g. discussions, working in groups). Instructors with a more student-centered teaching approach were more likely to emphasize the practical aspect of the learning process over a theoretical approach, as mentioned previously. Dr. Berry, for example, stated:

> My thought on teaching biochemistry is I need to teach students how to learn biochemistry and what the fundamental guiding principles of biochemistry are, so they can go learn the new things that come out in the next 25 years, biochemistry I don't think we've arrived yet. […] I appreciate that it happens in small groups and with students struggling through materials, I think them talking is more effective than me talking. (Dr. Berry, interview)

The belief that "science needs to be relevant" was present throughout all different teaching styles, from more teacher-centered to more student-centered methodologies that were observed. This was particularly true for Dr. Duna, Dr. Dixie, Dr. Dalton, Dr. Donna, Dr. Manju, and Dr. Mickey.

The predominant themes were categorized under the umbrella of "a utilitarian approach", where instructors across all different styles of teaching emphasized the belief that everything in the classroom should be available for everyone, for the greater good. It was not surprising to find that individual differences among instructors' beliefs systems were based on their personal and individual interpretations of their own world (Bussis et al., 1976). However, it was even more interesting to identify the instructors' goal of "for the greater good," which was routed in individual life stories and resulted in various approaches to meet that belief within their classrooms.

5.3.1.2 Assertion 2: Teacher-Centered Biochemistry Instructors Shaped Their Beliefs on Teaching on the Basis of Experiences in Their Classrooms, Whereas the Majority Relied on Own Experiences Collected During Their Own Education

When looking at influences instructors identified around their beliefs on teaching biochemistry, the theme "learning by teaching" (Table 4.2) was most common among instructors who used a teacher-centered teaching style (Dr. Duna, Dr. Dixie, Dr. Danner, Dr. Dalton, Dr. Magnus, Dr. Manju). Within that theme, instructors highlighted the important influence of trying out teaching on their own as being an essential part in their advancement in teaching practices. Dr. Duna stated:

> No. It just ... It's very strange because you just get thrown into a room. Sink or each. You just kind of develop it as you go. It wasn't like oh I went in knowing what I was doing. I had no idea what I was doing. You go and you see what resonates and then if it works you keep doing it. If it doesn't, you stop doing it. You have to be flexible. You have to be willing to change. (Dr. Duna, interview)

When looking at Table 4.17, which describes teaching methods changes instructors had gone through in the past, Dr. Dalton was among the teacher-centered instructors (Dr. Dolly, Dr. Dalton, Dr. Mickey) who went back to a traditional lecture format after trying to implement a student-centered focus in his class. His trying out teaching on his own and not consulting others to receive help may have influenced his choices in going back to his traditional lecture style. "Learning by learning" was a theme that came up among participants who were more reflective about their teaching during the interview and utilized a more student-centered style of teaching (Dr. Devora, Dr. Donald, Dr. Donna). These instructors were also among those who implemented a more active classroom environment, ranging from semi-flipped classroom (Dr. Devora), to flipped classroom (Dr. Donald), to

Dr. Donna who focused on implementing group work, group quiz exercises, and class discussions.

Regardless of the teaching approach the instructors preferred, many mentioned the impact their own teachers had on them and how observing them and experiencing their styles of teaching changed the way they thought about teaching and their practices today (Dr. Derrick, Dr. Devora, Dr. Donald, Dr. Dana, Dr. Dolly, Dr. Donna, Dr. Magnus, Dr. Manju, Dr. Maggie, Dr. Mickey, Dr. Brigid, Dr. Berry).

These instructors also drew on their own learning experiences to develop their beliefs and subsequent teaching styles and were observed to continuously reflect on this as instructors of biochemistry. Dr. Derrick, for example, said that:

> Well, yeah. So, I was informed by my own experiences and they were very traditional. Professor X would get up and talk for an hour and then you'd go home, and you'd study for a couple of hours to figure out what they said. No, I think we all agree that wasn't a very good way to do it and I think when I arrived here, I thought it would be the same way and I quickly realized it's not like that at all. You really have to engage them and try and try and get them working with each other and talking to each other. (Dr. Derrick, interview)

Overall, similar influences identified in this study were also found within the context of research on preservice teachers' beliefs, as highlighted by Richardson (1996).

5.3.1.3 **Assertion 3: Instructors' Interest in Teaching Did Not Depend on Their Teaching Approaches**

I observed three groups that differed in their interest in teaching. The groups focused on their student's benefits (student-focused), their own benefits (teacher-focused), or sometimes both. The instructors were grouped as follows: instructors who were more student-focused in their interests to teach biochemistry (Dr. Duna, Dr. Dalton, Dr. Donna, Dr. Berry), instructors that were more teacher-focused (Dr. Devora, Dr. Dixie, Dr. Donald, Dr. Danner, Dr. Dana, Dr. Dolly, Dr. Magnus, Dr. Manju, Dr. Maggie, Dr. Brigid, Dr.

Bobbie) and instructors that were driven equally by both (Dr. Derrick, Dr. Mickey). Among instructors with a more teacher-centered teaching approach (e.g. Dr. Danner, Dr. Magnus, Dr. Manju, Dr. Dixie) (see Table 4.3), "self-education" came up (Dr. Derrick, Dr. Dixie, Dr. Danner). These instructors enjoyed the benefit of learning new material and advancing their knowledge continuously through preparing novel slides and getting new examples ready for class. Consider the following statement by Dr. Danner:

> The other thing is, since I do that every year, I like to change things around somewhat just for my personal benefit, so I don't get bored and learn something new. That's one of the things that I enjoy about teaching that you ... you're sort of educating yourself. You're learning things new again. You have to inform yourself about what's currently being done in that field. (Dr. Danner, interview)

This aligned well with the notion of traditionally-oriented instructors being more interested in teaching themselves about new methodologies by trying them out on their own in the classrooms (Dr. Dixie and Dr. Danner). Other examples (Dr. Derrick and Dr. Mickey) of teacher-centered instruction also mentioned interests motivated from the side of the students and the side of the instructor, equally.

Within a more lecture-focused setting, Dr. Dalton and Dr. Duna verbalized different student-focused motivations, for instance "sharing fascination" about biochemistry, which they mainly shared through lecturing. Dr. Duna elaborated on this motivation:

> I really just taught large enrollment undergrad classes my whole time, which I like because you get a big ... there's a big impact factor. I think that's important. That turned out to be important for me. You know, knowing that what I did actually affected somebody. […] Oh, yeah. Yeah. That's what's really important to me because nobody's going to care exactly what they learned from me, but that I made an impression on them on how to learn, that's more important to me. (Dr. Duna, interview)

Some instructors with a more student-centered teaching approach mentioned their interest in teaching to be more student-focused (Dr. Donna and Dr. Berry) than teacher-focused (as can be seen in Table 4.3) in terms of themes such as creating an “aha moment”, or to “make a difference/ have an impact” on students, and enjoying “mentoring” students. Other student-centered instructors cited teacher-focused factors to explain why they were both motivated to teach and to implement student-centered approaches in class (Dr. Devora, Dr. Donald, Dr. Dana, Dr. Dolly, Dr. Maggie). These factors had the commonality that their primary motivation was instructor-focused. Dr. Maggie elucidated this by discussing her “love of teaching”, which drives her interest in teaching biochemistry:

> I love teaching and I love biochemistry. How we work on the molecular level - that we don’t keel over on a regular basis needing a reboot - is fascinating to me. The molecular dance that allows us to think, move, and live is elegant, robust, and yet driven by random molecular motions and collisions. How cool is that. (Dr. Maggie, integrative statement for promotion to tenure)

The analysis of instructors’ interest in teaching revealed additional factors besides motivating students. These results resembled those reported in previous research in which college instructors from multiple disciplines with a student-centered approach showcased more interest in motivating students to reach their goal of facilitating learning and engage students in challenges (González, 2011).

5.3.1.4 Assertion 4: Teacher-Centered Instructors Were More Likely to View the Application and the Delivery of Biochemical Concepts as Two Separate Entities, Stressing Their Theory-Oriented Way of Thinking About Teaching

When analyzing instructors’ goals in teaching biochemistry**,** the theme “application of knowledge” (see Table 4.4) was emphasized by instructors with traditional and non-traditional teaching styles. However, the “application of knowledge” and the delivery of knowledge were seen as separate entities for the more traditionally-oriented instructors (Dr. Derrick, Dr. Dixie, Dr. Dalton, Dr. Manju, Dr. Mickey). This suggests that teacher-centered instructors were more likely than student-centered instructors to verbalize their teaching goals in a theoretical context. It seemed that knowledge was assumed to be applied through thinking through a presented problem rather than practicing them in class. This was usually done by the instructor through talking/lecturing in the classroom to also meet the shared belief that "science needs to be relevant" to the audience (e.g. Dr. Dixie, Dr. Dalton, Dr. Manju, Dr. Mickey). The following quote from Dr. Derrick stresses his more theory-oriented way of thinking about learning and his goal for his students to apply the knowledge on their own mostly, with only a few problems posed in class:

> Well, what I tell students when I meet with them, what I'm hoping for them to be able to do is to produce a model in their heads that they can refer in order to understand the story. […] So certainly, one goal is I want them to understand and appreciate the structure of biochemistry, how it does a very good job of explaining how energy is produced from the metabolism of nutrients, that sort of thing, on a content level, but in the process of doing this also, I'm hoping that they'll be challenged to think of problems, do some problem solving. […] Then once you know those things, with this model, that I hope that they acquire, I want them to be able to apply it to new situations because that's what they'll do. Whatever they do in life, they'll have to think outside the box and take their knowledge and their background to apply it to new situations. So that's part of it also and that's done partly by giving them problems to solve. There is some problem solving in that class outside of the exams. (Dr. Derrick, interview)

Student-centered instructors were more likely to talk about delivering the knowledge through practicing application in class. Here, Dr. Maggie gives the viewpoint of a more practice-oriented instructor:

> By actively engaging students in the course material, my goal is that they learn biochemistry concepts that are retained after the course is complete. In the group work, my goal is that they also learn important process skills, such as problem solving, critical thinking, and how to efficiently work with others in a technical team. (Dr. Maggie, integrative statement for promotion to tenure)

She further elaborated in the interview:

> I know this is somewhat of a spin of mine is that I'm much more interested in watching them active learn versus I need them to learn exactly this. I'm kind of like, "Well, they'll ..." I'm trying to as we say magic [inaudible 00:33:30] down to

> biochemistry. What will be revealed to them will be revealed to them in the process of doing it. (Dr. Maggie, interview)

This more practice-oriented way of thinking about teaching came up among the student-centered instructors, who expressed the importance of involving their students in the learning process and making learning fun in class (see the teaching belief's theme "science needs to involve") (Dr. Donald, Dr. Dana, Dr. Berry, Dr. Bobbie). A similar phenomenon was reported by González (2011) for college instructors from different disciplines. Overall, the development of different skills and the application of knowledge often went hand-in-hand for instructors with various levels of student involvement in their classrooms. For many instructors, it was also important to "increase interest in biochemistry", with a variety of teaching methods displayed.

5.3.1.5 Assertion 5: Biochemistry Instructors with a More Teacher-Centered Approach to Teaching Were More Theory-Focused When Verbalizing Their Ways of Implementing Active Learning Engagement

The notion of theory-oriented ways of thinking about learning and applying knowledge also came up for teacher-centered instructors when they talked about their beliefs about how active they viewed their classrooms to be. In general, instructors with a more teacher-centered approach (e.g. Dr. Dixie, Dr. Dalton, Dr. Dolly, Dr. Magnus, Dr. Mickey) talked in a more "thinking-focused" way of active learning engagement (see Table 4.12, and Table 4.13). Dr. Mickey, for example, viewed active learning through the lens of "watching" his students actively learn while he was lecturing in class:

> As I mentioned earlier, lecture, to listen, process, and to take notes, that is an active learning process, so I think what I do is active learning. It's just on what I would call the traditional side of active learning, and the new methods that are coming out, I'd, you know, I'd ... done a little bit of a disservice to themselves by not acknowledging that lecture is a form of active learning. (Dr. Mickey, interview)

To support this assertion, Dr. Magnus provided a view on how his traditional classroom was still providing an active learning environment:

> I try to engage them, if nothing else, by asking questions, even if they're rhetorical questions, meaning I don't necessarily expect them to answer at least hopefully that they are thinking about these things. […] I guess in that context, if the students are mentally engaged in what's going on then that's an act of learning, even if they're not necessarily physically engaged. I think a lot of people will define active learning environments are one where the students are actively asking the questions or involved in discussions. Lots of give and take. My class, certainly like I said, doesn't have as much event as others do. If I can have the students be thinking about these things in their own head, then perhaps it's active but in a different way. (Dr. Magnus, interview)

Most teacher-centered instructors categorized their classrooms as providing an active learning environment (Dr. Dr. Dixie, Dr. Dalton, Dr. Dolly, Dr. Manju and Dr. Mickey) or providing an active learning environment with limitations (Dr. Duna, Dr. Danner, Dr. Magnus) (see Table 4.13). Instructors who used more student-centered teaching methodologies expressed the importance of students' involvement in a more activity-driven way when talking about active learning engagement (e.g. Dr. Devora, Dr. Donna, Dr. Maggie, Dr. Brigid, Dr. Berry, Dr. Bobbie), as the following quotes illustrate:

> Active learning is where the students are given a task, and they have to come up with a reasonable result or answer on their own, maybe with some help from me […]. […] I think science is always a conversation, and if you can help the […] conversation, that's good. It's something that stimulates them to come up with an answer, and at the same time, promoting their understanding of the particular topic, so they have to be able to conceptualize what's going on. […] Yeah, this is mostly in group work. Active learning […] in group work, that is what's going on. (Dr. Brigid, interview)

> Active learning is when the students are busier than the instructor is. They are mentally engaged with the material and do actively doing […] things with it. Like about the small group work is it's really hard to fall asleep. In a lecture, even my own notes I can see my handwriting trailing off. I think active is very much them minds on, hands on thinking about it. (Dr. Berry, interview)

The more student-centered the instructors' classrooms were, the more critical they were about their ways of improving their teaching (as seen in Table 4.13). This additional layer of reflection was seldom seen among the more teacher-centered instructors, who mainly carried out their "active" engagement through talking at their students (e.g. Dr. Dolly, Dr. Magnus, Dr. Mickey, Dr. Dalton).

5.3.1.6 **Assertion 6: Instructors Implementing Student-Centered Learning Techniques Appeared Less Confident of Achieving Their Goals Than Those Using Teacher-Centered Methods in Their Classrooms**

When it came to the perception of achieving their set goals in their personal classroom environment, the more traditional, teacher-centered instructors seemed to be more confident in their success in the classroom than their colleagues who were applying a more student-centered teaching approach (Table 4.5). The student-centered instructors (Dr. Berry, Dr. Brigid, Dr. Donald, Dr. Maggie) were more critical about achieving their goals in their classrooms. Dr. Donald supported this assertation by raising the need of continuously improving one's teaching:

> Yeah, well nothing's perfect. It's always, there's an imperfection. After a class, I'll take one of the problems that wasn't working well for the students, and why was that? Kind of look at it and I can change it for the next time. (Dr. Donald, interview)

These instructors also seemed to value the importance of the "application of knowledge". This might be an indication of how critically they were thinking about making student-centered teaching work, for which they still needed significant amounts of support, regardless of their level of success implementing these methods.

5.3.1.7 Assertion 7: Most Instructors Used Student Feedback as One of Their Main Measures of Success in Achieving Their Goals, Whereas Teacher-Centered Instructors Were More Likely to Use Intuition as Another Important Measure of Success

As can be seen in Table 4.6, instructors with a teacher-centered teaching style seemed to be using various measures in reaching their goals in the classroom. Relating these results back to their perception of success in reaching their goals, most instructors who felt more successful in their teaching drew that conclusion from student feedback they received. Two contrary examples were noted in this study, however, that show how different teacher-centered instructors measure their success. Dr. Derrick, a teacher-centered instructor, noted that he did not feel successful in reaching his goals. He did not put an emphasis on measuring his success based of student feedback, but rather based it on “class attendance” and “student performance”. He expressed concern about students who did not attend his class and his students not performing well on the tests he would give. However, he was a teacher-centered instructor who raised the issue of his classroom not being much active as of right now. This was a unique view since many teacher-centered instructors were confident about their classrooms providing an active learning environment. Dr. Magnus, also a teacher-centered instructor, was confident that his classroom provided active student engagement and he was also confident that he reached his goals in class with his current style of teaching. He measured his success by student feedback.

When a student-teaching-centered focus was used, many instructors relied on “student performance”, “student feedback” and some on “class attendance” as their personal measures of success. Dr. Brigid stated:

> Some students tell me, "Oh, this is great. This class is great because now I see why I had to learn all that other stuff, why buffers were important, why I had to learn

> those organic mechanisms, because they all kind of come together at the end in Biochem and Advanced Biochem." (Dr. Brigid, interview)

More teacher-centered instructors also verbalized the need to base their success on their intuition in class through looking at their student while lecturing and “seeing” if they understood the material (Dr. Duna, Dr. Dixie, Dr. Manju, Dr. Mickey). These more traditionally oriented instructors emphasized that they felt successful when their teaching was based on their intuition. This result was aligned with their overall notion of conveying knowledge to the students by having them receive it from the instructor by listening, as previously discussed.

5.3.1.8 **Assertion 8: Both Theoretical and Practical Ways of Thinking About Teaching Reflected How Instructors Described Their Roles in Class**

When looking at their roles in their classrooms as shown in Table 4.7 on perceived teacher roles, instructors who described their roles as both communicator and motivator (e.g. Dr. Derrick, Dr. Duna, Dr. Dixie, Dr. Dalton, Dr. Dolly) were those who used a more teacher-centered teaching approach but also included some instructors with a student-centered teaching approach (e.g. Dr. Devora, Dr. Donald, Dr. Brigid). The emphasis for teacher-centered instructors rested more on the side of communicating the content through stories in a lecture setting, rather than practically applying the knowledge in class. The following quote by Dr. Duna emphasized that relationship as an example for teacher-centered instructors:

> You have to understand human nature to be a good teacher. You have to understand what motivates 18-year-olds. Right? 19-year-olds, 20-year-olds. That's kind of what I end up going back on. You got to put yourself in their shoes, not what you think is important. You got to frame it around what they think is important. That's where it gets trickier. […] If you tell them why you're doing something, they're much more motivated. Not just because I said so, but this is why I want you to learn. This is why I want you to do this. They're much more willing to follow along

> instead of do it because I said so. […] Okay. My job is to impart the information. […]. (Dr. Duna, interview)

Dr. Brigid, a student-centered instructor, talked about her roles in a more practically oriented way, to get her students to do activities both inside and outside of class:

> Okay, my role and responsibility is to help students understand the material and guide them through the material. I can't learn it for them. They have to have the responsibility of putting in the effort to learn it, and I do understand ... […] I think real learning and solidifying understanding has to happen outside the classroom, because there's a minimum amount of time in the classroom. I can facilitate it as much as possible, but inside the classroom, there's just not enough time […]. Again, and I think this goes back to my thoughts that you have to reinforce what you're learning all the time, and the exercises I give them in the classroom is a way for them to think about how they can think about questions that will reinforce their learning. […] Yes, I think by showing that I'm interested in understanding what they do and don't understand, and helping them become motivated to understand the material. I can help them, but it's not all me. It has to be some them. They have to have some of that internal motivation to do it. I think I can help influence them. (Dr. Brigid, interview)

The role of "challenger" (Dr. Dixie, Dr. Dolly, Dr. Magnus) was also identified among roles teachers fulfilled in the classrooms. When used by instructors whose focus was teacher-centered, "challenger" was primarily theory-based, where the students were challenged by what the instructors said and to think about certain ideas during lecture. Dr. Magnus elaborated on his role as a "challenger" in the classroom:

> [...] You're going to learn a lot more by taking the challenging exam than you would from the not challenging exam. I'm really doing my job if I write an exam that you've missed a lot of questions on." The students don't like that. (Dr. Magnus, interview)

The role of "facilitator of success" (Dr. Derrick, Dr. Dixie, Dr. Magnus) was brought up during the interviews among participants from all of the different categories of teaching styles. The ways in which instructors talked about being a facilitator in their classroom, however, was more through communicating the knowledge by lecturing for teacher-centered instructors. Instructors with a student-centered emphasis on teaching, displayed a more practice-oriented facilitation in class (e.g. Dr. Dana, Dr. Maggie, Dr. Brigid, Dr. Berry and Dr. Bobbie). In their classroom environment, students were asked to do activities, solve problems in groups, with the instructor providing help during class time. The focus on the role of being the facilitator was common for instructors who implemented a more active learning environment in their classrooms (e.g. Dr. Duna, Dr. Danner, Dr. Donna, Dr. Maggie, Dr. Bobbie). Instructors who focused on active learning engagement in their classes mentioned their role in class to be rather a "facilitator of success" than "communicator" (Dr. Dana, Dr. Donna, Dr. Berry and Dr. Bobbie).

5.3.1.9 **Assertion 9: Teacher-Centered and Student-Centered Instructors Valued Different Roles for Their Students During Class**

Utilizers of less student-centered instruction saw the role of their students (see Table 4.8) as the "learner" and "utilizer" (Dr. Dixie, Dr. Danner, Dr. Dalton, Dr. Magnus). They shared a common mindset of students getting information in class and learning it outside of the classroom. This was consistent with the way they presented information in the classroom setting. The one-way mode of instruction through lecturing equipped students with the necessary knowledge in class, but they were expected to primarily use the opportunities outside of class to learn the material (e.g. Dr. Magnus). That was consistent with the notion of instructors with a traditional, teacher-centered lecture style who thought students were responsible for their own learning. Dr. Danner and Dr. Manju were the participants who brought this up most frequently during their interviews. Most research literature revealed a larger emphasis on discussing active learning happening within a classroom setting as opposed to outside of the classroom. "Outsourcing" active learning from the classroom does not reflect evidence-based practices and recommendations on how active learning should be implemented to lead to successful student learning (Barkley, 2009). More “active” instructors were willing to talk about students trying out, failing, and their need to be willing to fail during in-class activities, with the instructor on the side to help and guide their students through problem they solve (e.g. Dr. Devora, Dr. Donna, Dr. Berry, Dr. Maggie, Dr. Bobbie), which is a common theme among college instructors in different disciplines (González, 2011). This more practical, less “theory-driven” approach to learning became more common for instructors who made more use of student-centered methodologies, and can be seen in the following statements from Dr. Donna and Dr. Bobbie:

> But the student's role is to be engaged. I try to provide the atmosphere and provide the resources for them to take and be engaged and to help facilitate those connections they've made. (Dr. Donna, interview)

> They need to be active learners, that they can’t learn without doing it themselves and that they need to be trying things even if they are the wrong things and making mistakes in order to learn. (Dr. Bobbie, interview)

Teacher-centered instructors primarily talked about students’ ways of learning in a more theory-oriented way. Dr. Dalton, for example said, that during his career he wanted his students to learn, and how he thought about teaching and why he started again to execute such detailed board work lectures. His talking through each step in his own words gave him the impression of making his students’ learning experiences more valuable and contributing their learning, instead of incorporating more activities in class, as he tried once during his career. As might be expected, the approach of talking to make students understand was common among instructors who had a lecture-focused classroom environment (e.g. Dr. Dixie, Dr. Dolly, Dr. Mickey).

Traditional instructors who were trying to incorporate student-centered methods usually experienced the need to “squeeze” in these activities (see Table 4.9). Dr. Derrick, for example, implemented short group work activities of two minutes each for his students to talk about a question he posed. This was probably not enough time to advance students' thinking and make it beneficial to them. It was well-intended, but rather "rushed." For instructors who made use of more student-centered teaching methodologies, activities became longer and there was a larger emphasis on letting students "do the talking".

5.3.2 The Current Trend of Teaching in Biochemistry and its Perspectives for the Future

This section will include assertions that came from the use of the ICAP framework.

5.3.2.1 **Assertion 10: Biochemistry is More Likely to be Taught Using Student-Centered Methods than in the Past**

I chose the ICAP framework developed by Chi and Wylie (2014) to enrich the insight I gained through the inductive analysis of interview data discussed in the first half of this chapter. The following discussion is based on results that originated from a holistic interpretation of instructors' teaching styles within their classrooms and considered all data sources obtained (observations, interviews, artifacts). Within the four categories of student mode of engagement in the ICAP framework, from "passive" to "interactive". I grouped the instructors within the following groups of potential student mode of engagement (see Figure 4.2):

- Passive mode of engagement.
    - This mode of engagement was not primarily identified in either the classrooms I observed or highlighted in the interviews, therefore, no instructors are listed.
- Active mode of student engagement.

    - Dr. Derrick, Dr. Dixie, Dr. Danner, Dr. Dalton, Dr. Dolly, Dr. Magnus, Dr. Manju, Dr. Mickey.
- Constructive mode of student engagement.
    - Dr. Duna, Dr. Dana, Dr. Donald, Dr. Donna, Dr. Maggie, Dr. Brigid.
- Interactive mode of student engagement.
    - Dr. Devora, Dr. Berry.

The ICAP framework was used to categorize differences between what happened in the participants'' classrooms in order to obtain a better insight on the interpretation of instructional approaches discussed within this study (see Table 4.14, Figure 4.2). Within the ICAP-generated categories I was able to confirm the trend that I saw in my analysis using the lens of teacher-centered versus student-centered approaches to teaching. Within the ICAP framework, teacher-centered approaches would be comparable to the passive mode or active modes of student engagement, whereas student-centered approaches would be most comparable to the constructive or interactive modes of student engagement.

The ICAP framework revealed a potential trend that suggested that the teaching of biochemistry was executed at differing levels of student activity, with the smallest engagement of students occurring in teacher-centered classrooms where the instructor posed questions while lecturing, and the largest level of engagement occurring through extensive group work opportunities where interactive student engagement was fostered (Figure 3.6). The ICAP framework views student mode of engagement through the lens of how active students are in the classroom. As stated throughout this dissertation, I interpreted students' level of engagement by looking at instructors' styles of teaching. The authors of the ICAP framework acknowledge that different teaching styles encourage certain student modes of engagement. Because the study design did not provide data on students' behavior in the classrooms, I have used carefully chosen language in this section to imply how the participants teaching styles could potentially provide a certain mode of engagement. The discussion of my results from the perspective of the ICAP model should be seen as nothing more than suggestions in categorizing ways of instruction in biochemistry classrooms.

Many instructors within my study showed signs of both active and constructive student engagement within their classrooms. Two out of seventeen instructors provided a platform for potentially instituting students' mode of interactive engagement (Dr. Berry and Dr. Devora, see Figure 4.2).

The ICAP framework gives suggestions for the benefits students experience when classrooms provide a certain mode of engagement, with the students potentially learning more effectively through reaching a higher mode of student engagement. For example, among the many instructors who provided an active mode of engagement in their classrooms, they probably only provided their students with a "shallow understanding" of concepts in class (Figure 3.6). As Chi and Wylie (2014) suggested within the active mode of engagement, students are not generating new knowledge, but rather rehearsing or repeating knowledge brought up during class. This is likely to be happening in classrooms were lecturing was still the dominant teaching style, which made me categorize instructors within the active student mode of engagement, who mainly displayed those methods of teaching.

When providing a constructive mode, Chi and Wylie (2014) suggested that students would be exposed to "deep understanding, potential for transfer". Instructors who were included in this mode used more teaching approaches to engage their students constructively, such as fill-in-the blank notes, for example.

Dr. Berry and Dr. Devora were categorized within the interactive student mode of engagement. With their extended use of in-class group work, long student group interactions and discussions, they were more likely to create a platform for an interactive mode of student engagement. The ICAP model suggests that within that mode, student would experience “deepest understanding, potential to innovative novel ideas”, through “dialoguing” (Figure 3.5).

In the context of this study, it was beneficial to use the ICAP framework to view my results since it gave suggestions on how students were engaged in the classrooms I looked at. The learning gains that were associated with each mode of student engagement within the ICAP model (Figure 3.6), were also the result of a literature analysis Chi and Wylie performed. In that analysis, they looked at what learning gains students achieved through the use of certain in-class activities and correlated these gains to a specific student mode of engagement they postulated. When interpreting my results through the lens of the ICAP model, I had to be cognizant of the fact that even though instructors were giving their students an opportunity with a certain task to engage in a certain level of student engagement, it did not have to mean that students fully engaged to the level expected of the task proposed.

The instructors I studied often showed signs of teaching methods that would encourage a higher level of student engagement (Figure 4.3). If instructors were to incorporate these methods more extensively, they could possibly reach a higher mode of student engagement.

From the perspective of the ICAP model, the instructors who provided an active mode of engagement showed signs of providing the basis for a constructive mode of engagement (see Figure 4.3Figure 4.3, Figure 3.5). Instructors (such as Dr. Dalton, Dr. Dixie, Dr. Manju, and Dr. Mickey) who encouraged students to take notes in their own words or incorporated short discussions more in class. Also, some instructors, such as Dr. Brigid, Dr. Bobbie, Dr. Dixie, Dr. Donald, and Dr. Donna showed signs of a higher mode of student engagement in their classrooms. These instructors more frequently provided a platform for constructive mode of engagement. However, through some use of discussions in class and longer group work activities, they showed the potential for more extensive dialoguing that would provide an interactive student mode of engagement according to the ICAP model.

5.3.2.2 Assertion 11: Most Instructors Agreed – the Teaching of Biochemistry Will Become More Student-Centered in the Future

To better understand instructors' beliefs about teaching biochemistry, I asked them about their views of where they think the teaching of biochemistry would go in the future. The majority of instructors believed that student-centered teaching would become more common in the future (refer to page 272 and thereafter), as mentioned by many instructors in this study (Dr. Derrick, Dr. Devora, Dr. Dixie, Dr. Donald, Dr. Dana, Dr. Dalton, Dr. Dolly, Dr. Donna, Dr. Brigid, Dr. Berry and Dr. Bobbie). Consider, for example, the following quote from Dr. Dixie:

> I think it's gonna be certainly more active learning. However, you define that, even if it's just more student participation because even though they don't like it and they claim they don't like it, if you ask them, "Would you be in an active learning class," most of them are probably gonna be like, "Oh no. What is that, that sounds weird. That sounds like you want me to do a lot." But then you get more out of it. It's more fun. (Dr. Dixie, interview)

These instructors also showed signs of having already increased the level of student engagement in their classroom by incorporating group work to a varying level in their classrooms (Dr. Derrick, Dr. Devora, Dr. Dixie, Dr. Donald, Dr. Dalton, Dr. Dolly, Dr. Donna, Dr. Brigid, Dr. Berry).

Instructors who believed that teaching was staying the way it traditionally had been, were those who were comfortable with the way they taught biochemistry (see Table 4.5, Table 4.13), usually with a larger emphasis on teacher-centered teaching (Dr. Duna, Dr. Magnus, Dr. Manju, Dr. Mickey). Dr. Duna states:

> I don't think it's going to change very much. It hasn't particularly changed over the last 75 years. I can't imagine the next 10 years are going to be that much different. The same information's going to be important. […] I see myself pretty much doing what I'm doing. Yeah, and maybe ... I can't see it changing too dramatically. (Dr. Duna, interview)

Instructors who had already incorporated teaching methods that would promote a higher mode of student engagement, were especially supportive of active learning being an integral part of future biochemistry teaching methodologies and styles, as would be expected. Dr. Brigid, who was among the instructors who incorporated activities that would promote a higher mode of student engagement, said:

> The resources are there. The teacher is there to help them figure out what resources are right, or what resources are useful. I think the way that I understand teaching in elementary and secondary schools is going now, I think we have to be able to adapt to that. I think getting away from teacher-centered learning ... […].

5.3.3 Challenges Inherent in Current Styles of Teaching

5.3.3.1 **Assertion 12: Many Instructors Do Not Have Either the Knowledge or the “Tool Box” Needed to Succeed in Moving Toward Evidence-Based Instructional Practices**

A multitude of challenges in the way biochemistry courses are now being taught were identified by instructors. I will discuss overall trends I saw that hindered instructors’ ability to improve their way they taught biochemistry. Most of these challenges centered around the main themes of missing knowledge about implementing active learning techniques and tools needed to implement evidence-based practices in one's own classrooms (Table 4.15, Table 4.16).

5.3.3.1.1 **Assertion 13: Some Participants Feared that Making Changes Could Lead to Failure**

Many instructors were anxious about failing at their teaching, which was demonstrated on many different levels. Dr. Brigid and Dr. Bobbie mentioned the fear of not receiving good student evaluations as a potential obstacle instructors might face during the implementation of student-centered teaching techniques. Dr. Brigid brought up an example of this:

> I tried to do some of this stuff, and the students didn't like it because it wasn't what other people were doing, and therefore I got bad student evaluations. (Dr. Brigid, interview)

Dr. Derrick was afraid of failing in his class through the lack of knowledge of ways to implement new teaching strategies. The fear of failing was also communicated as too big when making big future adjustments to their styles of teaching by Dr. Dixie, Dr. Danner and Dr. Derrick and Dr. Duna. Dr. Duna expressed these feelings by stating:

> Right now it's ... I mean I'll change it on the fly if it feels wrong, and I'll do it but it's working. I don't want to break it. Let's put it that way. (Dr. Duna, interview)

The phrase that many instructors seemed to hold on to was: "never touch a running system." However, most of the instructors who were afraid of failing were successful research scientists, where they frequently made adjustments to their "running system" – it just seemed to be more difficult to make changes in their teaching than in their research.

5.3.3.1.2 Assertion 14: Letting Go - Giving up the Position of the Knowledge Conveyer and Moving toward Being a Facilitator is a Mean of Supporting Active Learning

Some concerns about failing were emphasized more emphatically by some of instructors. For instance, Dr. Derrick, who strongly believed he was the key provider for understanding and learning in his classroom, was unsure about how much students would read on their own. He was concerned about how students would make up for the “loss” of material if he were to replace his lecture with longer group activities. Dr. Manju and Dr. Berry expressed similar concerns. Dr. Derrick and Dr. Manju both worried about letting students read essential material and coming prepared to class. Dr. Derrick voiced this concern, stating:

> […] I'm putting together a story based on a lot of different sources I feel, they don't have time to go to all these sources […] maybe the journey, having them go through the process a bit themselves will make it stick better. So that's a balance I haven't figured out. How much should they be doing themselves? (Dr. Derrick, interview)

5.3.3.1.3 Assertion 15: Many Instructors are Concerned about Missing the Tools to Implement Evidence-Based Practices

Instructors often lack basic knowledge on instructional practices (AAAS, 2012), which could lead to possible misconceptions and barriers that built up in regard to putting active learning into action.

Concerns about how to implement group work effectively were expressed by Dr. Derrick, Dr. Devora, Dr. Manju, Dr. Bobbie. During his interview, Dr. Derrick brought up these concerns:

> I think one of the challenges that I still have is the nature that all students have the ability to get support from each other because you might have some students who know each other already and they work together, but then there were some others who for whatever reason don't have that support group and they're at a disadvantage if they won't come to see me, which they usually don't. So unfortunately, from what I've heard, you really can't institute work groups. The students hate that if they said, "Oh, we'd have to work with X when we don't know this person," or whatever. So

> I don't know really the solution to that, but I think teaching comes from many places and from each other as well. So ways to increase that would be helpful I think. (Dr. Derrick, interview)

He further elaborated:

> […] I'm familiar with the idea there of having the students work on problem solving in the class where you're available to help them out. I just never in my own mind, I couldn't figure out how to get it to work. I still feel, maybe it's my traditional upbringing. I still feel that I should be there to provide the content or at least. (Dr. Derrick, interview)

Other instructors, such as Dr. Dana, noted that she did not know how to change existing activities to map them onto best practices. Teacher-centered instructors often said that lecture was the best method for instructors to convey knowledge (e.g. Dr. Dixie, Dr. Mickey), and Dr. Mickey went on to say: “'I’m a traditional lecture person. To me, that's efficient. It gets things done quickly and efficiently. (Dr. Mickey, interview)

Another concern that arose was knowing how to ask the right questions or pose the right tasks to have students engage in learning (e.g. Dr. Brigid, Dr. Berry, Dr. Maggie). Concerns about students not “buying in” properly was associated with instructors’ perception that their students were not prepared for active learning engagements and therefore might not engage in these activities (e.g. Dr. Devora, Dr. Donald, Dr. Mickey, Dr. Brigid). The following quote from Dr. Mickey showed that concern:

> To do POGIL right, the student has to do a lot of the work themselves, and I learned early on that a lot of first-generation students aren't quite ready for that yet, so that, yeah. That's why I moved away from that fairly quickly. (Dr. Mickey, interview)

Instructors noted that they were less likely to try out or pursue new methods of instruction if they heard about or experienced anything negative with new instructional methods they have not tried out yet themselves (Dr. Derrick, Dr. Dolly, Dr. Mickey). To illustrate this point, Dr. Mickey said:

> When I was at [XYZ] College, there was an organic faculty member who used something similar. It wasn't called POGIL. […] but kind of the same idea as the POGIL system. I was not involved in that class, […] and I had the fortunate ability to see her students before that and then after she tried that, for several years, both before and after, and there was no difference in the level of student […]. The students who came out of the POGIL-like system tended to be a little less prepared students who came out of her traditional lecture type. Yeah, a little less prepared. They didn't quite have the breadth of knowledge that the students in her traditional lecture format had. (Dr. Mickey, interview)

Dr. Duna, Dr. Danner, Dr. Dalton, Dr. Dolly and Dr. Manju verbalized the challenge of not knowing enough about certain techniques to pursue them further. Dr. Duna mentioned this challenge:

> I don't know how I would do group work in Biochemistry necessarily. I don't even know how that would work. Are they going to teach each other glycolysis? I have no idea how that would work. You know? […] (Dr. Duna, interview)

One technique that was mentioned quite often within this context was a flipped classroom setting. It seemed that the participants knew about flipped classrooms, even when they lacked knowledge of evidence-based practices (King et al., 2017; Muth, 2016).

Unique challenges were raised in this study that, to my knowledge, have not been reported in the literature. It was striking to see that instructors who used active learning in other chemistry courses found it challenging to implement these teaching methods in their biochemistry class, as mentioned by Dr. Donna:

> I think I do a better job in my gen chem class of doing more group instruction. […] So that's what I've been struggling this semester to try to figure out is how to help my students apply information and helping teach them that skill and I'm not there yet. […] I feel confident in my collection of what I can get rid of in gem chem and what I need to focus on in gen chem versus what I can cut and what I can focus on in biochem. (Dr. Donna, interview)

This lack of transferring skills between related disciplines was striking to me. Dr. Donna, for example, expressed beliefs that were strongly rooted in involving her students more in class and letting them struggle with the material on their own, but she continuously faced the issue of how to implement these beliefs in her biochemistry classroom. Dr. Dalton and Dr. Duna also mentioned that they thought biochemistry would be a less appropriate discipline in which to use active-learning methods compared to general chemistry, as Dr. Duna highlighted: “I mean in Gen Chem there's a lot of problems to solve. Right? I mean its concepts but within a discrete example they can solve.” (Dr. Duna, interview)

5.3.3.1.4 **Assertion 16: There are Hidden Obstacles to Increasing Student Engagement That Were Challenging for Instructors to Identify**

In addition to the challenges identified by the instructors themselves, there were also those that were partially hidden and not emphasized as a challenge. The use of analogies is one example of a “hidden” challenge or barrier to implementation of active learning. Dr Derrick was one of the instructors who voiced the need for analogies to teach biochemistry (see also Dr. Dana, Dr. Magnus, Dr. Maggie, see Table 4.9) but was relatively unconcerned about the problems that the use of analogies could introduce (Orgill, 2003; Orgill et al., 2015) and focused on their usefulness in the context of teaching biochemistry. He stated the importance of using analogies, but did not necessarily reflect on how carefully they have to be selected when used, so as to not confuse students:

> Students have always told me they appreciate the analogies I use. Some of them aren't entirely appropriate. They're not appropriate analogies, but I think it helps them to some degree and what we're doing here. […] But anyway, we can reduce a lot of what we talked about to a different analogies, whether it's the pumping of protons into the intermembrane space as analogous to pumping water into a dam so that energy can be used later. So, I think that's really effective means and I didn't invent any of this. They're books that have been written on using analogies. (Dr. Derrick, interview)

5.3.3.1.5 Assertion 17: Making Room for Active Engagement is the Predominant Obstacle Faced Among Instructors Along the Path to Evidence-Based Instructional Practices

A common challenge instructors faced was where to cut material that they wanted to tell their students about, in order to provide time for longer discussions or group work, as raised by Dr. Devora, Dr. Dixie, Dr. Danner, Dr. Dalton, Dr. Donna, Dr. Maggie, Dr. Manju, and Dr. Brigid. The lack of agreement about topics that should be taught at different levels of biochemistry courses (ABE, 2017, p. 6; Peterson & Carroll, 2015; Yarden et al., 2017) could possibly contribute to the problem with which the instructors struggled. It seemed as if this was a major obstacle the instructors would need to overcome to avoid reducing the quality of their teaching.

The delivery of content was also a predominant concern for instructors thinking about implementing new teaching methods (Dr. Dalton, Dr. Donna, Dr. Magnus, Dr. Manju, Dr. Maggie, Dr. Mickey, Dr. Brigid). Below is an excerpt from Dr. Manju's interview that illustrates his concern having time to increase student engagement during his class time:

> Dr. Manju: Because of the time constraints, you cannot have everything, plus you have to finish the course, all the things, within the given 16 weeks' time. So, it's tough, you can't have more discussions giving them just discussing the topic or asking them to give a presentation in that one. […] .
>
> Researcher: […] you mentioned earlier that you thought that these very brief and very short problem-solving questions that you basically have in your class that the reason they are so short is because you have to go through so much material, right?
>
> Dr. Manju: Yes, so much material. (Dr. Manju, interview)

It was interesting to note that this was still a challenge for instructors who were already further along in the process of implementation of student-centered practices as stated by Dr. Brigid:

> Application is great, and if I can incorporate it, we talk about certain diseases. Like a couple weeks ago, we were talking about phenylketonuria, and why does some of the population have this? How do they test for it? They're really interested in all that sort of things. I think I would like to work more on application stuff, but again, that takes a lot of time, and you have to sacrifice content then. (Dr. Brigid, interview)

However, other, more student-centered instructors, talked more positively about making room for activities by leaving out material (Dr. Devora, Dr. Berry), and selecting content to give students the opportunity to take a more active role in their learning, as it is advocated in many active learning strategies such as those associated with POGIL.

It is not surprising that the participants noted that implementing any novel teaching strategies takes time - time that could be invested in their research (Dr. Devora, Dr. Dana, Dr. Donald, Dr. Donna). This obstacle was raised primarily by faculty who had a strong research commitment. Dr. Donald, who taught his biochemistry lecture for decades in a traditional lecture format and had changed his class to a fully flipped learning classroom, said:

> My basic thought is, if your job is only teaching biochemistry, which is not the case in most universities, then something like what I'm doing could be done. But if you're still managing a couple of research grants, and you have way over half your time doing research, and you might not be doing the experiments, but you're getting all the stuff that your graduate students and post docs need, then this is hard to do because the flipped takes time. (Dr. Donald, interview)

However, the instructors who expressed this concern all had in common an interest in implementing student-centered teaching, differing primarily in the extent to which they wanted to implement it.

The recent literature has pointed out the usefulness of providing instructors with classrooms designed for implementing active learning, and accommodating student-centered teaching methods (Ramsay, Guo, & Purse, 2017). Dr. Danner voiced the problem of his class being too big to properly implement more active learning engagement, but others did not feel this was a problem, as Dr. Berry elaborated during her interview:

> I don't think that class size should limit what you do. I think you can do active learning. You have to tailor them and might need to develop different, like I might use the manager time keeper secretary roles more strictly in a bigger class but because they're small I can circulate more. […] I don't think class size - I think you can do it, it's just a matter of whether you're willing to figure out how to make it work for your population. We do shuffle groups on a pretty regular basis to try and even things out. (Dr. Berry, interview)

These concerns only came up sporadically, but they reflect the contents of recent publications (Stains et al., 2018).

Even though instructors all came to teaching with their own beliefs and perceptions, commonalities were still shared among concerns they had within this diverse population. Challenges identified within this study centered around personal beliefs and perceptions (Austin, 2011; Fairweather, 2008), and some challenges originated from previously existing beliefs systems. For instance, Dr. Magnus came from a belief system where he was the primary deliverer of content and expected his students to study outside of class, as mentioned previously in this chapter. The act of learning in class through involving students in activities was foreign to him. He mentioned that he already struggled enough involving his students to answer questions that he posed in class during lecture:

> They tend to be passive, so I consciously try to engage them, although, I will often ask a big question and get no response whatsoever. In which case, I could sit there for an hour waiting for someone to answer, which is not an effective use of time, so I just have to go on. I'm hoping that they're answering in their own head not giving an answer. […] Also, I think one thing that I probably do a lot of is making connections. […] I try to engage them, if nothing else, by asking questions, even if

> they're rhetorical questions, meaning I don't necessarily expect them to answer at least hopefully that they are thinking about these things. (Dr. Magnus, interview)

His value system and what he thought was the right way to teach did not align with the literature on evidence-based practices, which was an emerging commonality among instructors that still implemented a teacher-centered style of teaching. Instructors who implemented a more student-centered style of teaching saw the benefits of students struggling through the material on their own in class, but still faced challenges to put evidence-based practices into action.

5.3.4 Instructors Preferences and Needs to Further Develop Professionally in the Ways They Teach - Many Commonalities Shared

An analysis of the resources instructors used when obtaining knowledge about teaching methodologies revealed that there was no distinct pattern among the participants in this study in terms of the resources they preferred. The following themes were identified as instructors were interested in making changes in the way they teach or chose to gain proficiency in alternative teaching methods:

- Proficiency in teaching through interactions with peers.
  - Dr. Danner, Dr. Dana, Dr. Dolly, Dr. Magnus, Dr. Manju, Dr. Maggie, Dr. Brigid, Dr. Bobbie.
- Proficiency in teaching through attendance at professional meetings.
  - Dr. Donald, Dr. Dolly, Dr. Donna, Dr. Maggie, Dr. Brigid.
- Proficiency in teaching through consultation of educational research literature.
  - Dr. Manju, Dr. Maggie.
- Proficiency in teaching through own experiences.

- Dr. Dana, Dr. Dalton, Dr. Danner, Dr. Brigid, Dr. Derrick.

In most cases, multiple factors were identified by the participants, seldom relying on only one resource. Overall, there was a significant interest in improving their teaching and agreement of the benefit of using more student-centered teaching methodologies.

Relying on one's own experiences and beliefs was a strong factor in how instructors chose how to teach. It has been argued, however, that to effectively make changes, a PD system on teaching practices should be created (Henderson et al., 2011).

5.3.4.1 Assertion 18: On-Site Help, Peer Observations and Establishing a Strong Community to Share Resources Were Among the Main Factors Instructors' Valued as Ways to Provide the Support Needed.

During the interviews I asked the participants to identify the resources instructors would find useful as their teaching methods evolved. The strategies listed below summarize the main results I obtained.

- Many instructors found the idea helpful to gain "proficiency in teaching through instructional support." When I suggested that this might be someone within their department. Many responded this would be useful because it would save them time. Dr. Dalton, for one, said:

  > Yeah. In fact, I can see very easily that if somebody would sit in on the lectures and say, "You know, Dr. Dalton, you could use video clips here, and here, and here, and they're available or we could make 'em easily by doing this, and this, and this," that would be a tremendous help, because my thinking is that a more visual kind of approach would make an impact, I believe, on the students. If I had more years to go, definitely, I would be leaning toward how to incorporate more visual illustrations in my lectures, that kind of thing. (Dr. Dalton, interview)

  This is consistent with Yinger's (1980) study that showed that teachers involved in problem-solving experiences within their classrooms developed skills they could use in teaching their courses. The instructors in this study suggested it would be appealing to learn more about implementing alternative teaching styles by watching others teach. Some were already observing others but wanted to take greater advantage of this useful tool. Dr. Magnus stated: “Yeah, certainly good examples. I mean being able to see it actually be done would be useful.”

- Instructors who were open to discussing alternative teaching styles were in favor of having a supportive network of biochemistry instructors. This could not only save time but also to make one’s own teaching more flexible (Dr. Donna, Dr. Brigid, Dr. Berry). Dr. Berry pointed out:

> Because often biochemists are isolated where there's only one in a department. Finding somebody to say man, they still don't get it and I don't know what I should do, is a very valuable thing. As a field, figuring out ways to support those people, especially who are stuck in where they're the only biochemist or their institution isn't very supportive is important. (Dr. Berry, interview)

5.3.4.2 Factors to Consider When Supporting Faculty in their Development as Instructors

The point in the participants’ careers at which the study was done was a factor that influenced how they responded to the question of further developing their teaching proficiency. Their willingness to participate in PD activities early in their careers, when their research was being evaluated was an issue for several faculty (e.g. Dr. Dixie, Dr. Dana). Faculty who exhibited a rather teacher-centered teaching approach and focused on obstacles that made it challenging for them to change their styles of teaching, raised the issue of needing to be more informed in order to improve on their teaching (Dr. Duna, Dr. Dalton, Dr. Derrick). Within my study the need was often expressed to come back once stress had alleviated on the research side and the faculty had settled within their positions.

In addition, with more experience in teaching, faculty also raised the benefit of feeling readier for any further PD interventions (Dr. Dixie, Dr. Duna).

Calderhead (1996) pointed out that experienced teachers can build off of a skillset and practical knowledge they have accumulated over the years that equips them to deal with unforeseeable situations that arise within the course of teaching. The idea of getting faculty started early on PD has been advocated in PD, but research on beginning teachers (Simmons et al., 1990) suggests that teachers in the early years of their careers cannot benefit from PD because they are devoting their attention to merely "surviving." The chemical engineering community has a history of offering week-long PD programs every five years that all non-tenured faculty attend where issues of both research and teaching are discussed.

The participants noted that the timing of when it would be best to implement student-centered teaching methodologies was crucial. Dr. Donald, who worked at a doctoral granting institution, and Dr. Bobbie, who worked at a baccalaureate granting institution, both argued that implementing an active classroom was strongly career-dependent (Table 4.19). Both instructors raised the issue of time that had to be invested to implement a student-centered classroom and that it was hard to find time, besides doing research in parallel (Dr. Donald), and the teaching load that had to be fulfilled (Dr. Bobbie).

5.3.5 Thinking Big – Large Scale Influences on the Teaching of Biochemistry and Factors to Consider when Implementing Strategies of Change

Large-scale factors such as departmental structure, attitudes toward teaching, and support systems within a department can play a significant role in the implementation of changes in teaching (Figure 2.3, Stains et al., 2018). I identified evidence of large-scale influences that should be considered when developing or implementing change in instructional practices in teaching biochemistry. Most instructors, for example, shared the belief that what they do in the classroom should benefit everyone in their class. As stated previously, instructors from multiple institutions agreed that their beliefs about teaching biochemistry were primarily shaped by their own educational influences during their college education by the instructor they had, as well from their experiences while teaching on their own.

Even though the goals the instructors commented upon were centered around similar topics ("application of knowledge", "convey knowledge", as well as "development of skills") differences could also be found. Instructors with a teacher-centered approach were less likely to see their goals being as interconnected in the ways they could teach it in their classrooms. In contrast, more student-centered instructors voiced their goals as being more interconnected in the ways they could be taught. To give an example, teacher-centered instructors were more likely to value examples of students' applying knowledge they obtained in the biochemistry class *outside of the classroom*, whereas student-centered instructors utilized activities designed to incorporate the application of new knowledge *within the classroom setting.* The teacher-centered instructors still considered their classrooms to be active: Instructors across all institutions in this study found student feedback to be most relevant when reflecting on their own success in class. Since instructors using virtually every style of teaching encountered in this study seem to rely more on this aspects of their teaching, the results suggest the importance of efforts to introduce more critical student feedback mechanisms into biochemistry courses, to encourage more insight into students' learning gains and their perceptions of teaching styles/methods used in class. This would be consistent with research that suggests student evaluations increase positive feedback when more active learning methodologies are used in classrooms (Henderson, Khan, & Dancy, 2017).

Instructors across the different institutions had a common picture of what roles they should fulfill when being in the classrooms. Among the different styles of teaching, however, differences were visible where the more theory-oriented instructor was common among those who executed mainly teacher-centered teaching methods.

As noted in this chapter, there is some similarity in the challenges instructors face when changing their style of teaching to one that is more student-centered. Actions needed to meet those challenges were centered around equipping instructors with the necessary "tools" to improve their teaching as well as providing instructors with a support system that would help them to share their progress toward further implementation of evidence-based instructional practices.

As seen in this section, influences could be applied to all different institutions in a similar way, since many commonalities were shared and less differences were notable, that would have a significant influence on the alteration of suggested recommendations, as results from this study suggested.

CHAPTER 6. IMPLICATIONS AND FUTURE STUDIES

The following sections will highlight some of the implications that can be drawn from the results of this thesis that could provide the basis for the development of the teaching of biochemistry and the support structures needed to further increase the proficiency on evidence-based classroom methodologies.

6.1 Finding a Consensus on Teaching Biochemistry

Most of the participants in this study commented on the need for a source of support while deciding which content could be replaced by more active learning activities. Many of these individuals were especially concerned with the classic problem that has faced virtually every reform movement since the 1960's: Their belief that there was too much content that needed to be covered and not enough time for further student engagement in class. Some were also concerned by their belief that they had to find time to cover topics their students had not earned sufficiently well from previous classes that would provide the foundation upon which one build the knowledge they needed to cover in their class.

The need to find a consensus on what topics ought to be taught in which biochemistry courses was repeatedly emphasized during the interviews in this study among participants who were not likely to be familiar with the work of Tansey et al. (2013) on "foundational concepts and underlying theories for majors in 'biochemistry and molecular biology'." The existence of a consensus on what should be taught, and, at what level would help instructors decide what has to be covered and what contents could be skipped to build room for student-centered teaching. Although work is being done to address this problem, it has by no means attained the state of agreement the participants need. (ABE, 2017, p. 6; Niederhoffer et al. 2017; Peterson & Carroll, 2015; Yarden et al., 2017).

Another challenge that was frequently described focused the absence of a "toolbox" or "bag of tricks" into which the instructors could reach to find a way to implement changes in their classrooms. The following suggestions provide ways in which the community of biochemistry instructors could gain the necessary proficient knowledge to bring about changes in the way biochemistry is taught – at least from the perspectives of instructors involved in this study.

6.2 Establishing a Network of Instructors Who Teach Biochemistry

Some of the instructors in this study seemed to have struggled with finding resources they felt were needed to make significant changes in the way they taught their biochemistry courses. Considering the time constrains instructors face on a daily basis, the idea emerged during the course of the interviews that establishing a community of biochemistry instructors who could share material and alternative teaching methods could be discussed was deemed to be a potentially useful tool in biochemistry. A network of this nature might be built upon the model of the *Virtual Inorganic Pedagogical Electronic Resource* (VIPEr) project, which was designed to share resources about the teaching of inorganic chemistry (Benatan, et al., 2009).

6.3 Providing Opportunities to Learn About Evidence-Based Teaching Practices

Two ideas emerged from the interviews that could facilitate making changes in the way biochemistry is taught: (1) getting help through in-class support and (2) watching others teach.

As noted in the discussion chapter, the idea emerged during the interview to ask the instructors whether they would find it helpful to have access to what work on the epistemic development of chemistry graduate students (Bhattacharryya & Bodner, 2014) referred to as a “more knowledgeable other” who could help identify places in the curriculum where evidence-based practices, could be implemented to institute more student-centered teaching methods. As a group, the instructors found the idea to be very appealing. A source of help that was reported as already being utilized was input from teaching assistants interested in teaching biochemistry, who helped changing lecture sections they felt could be improved. A potential source of help that was recently discussed in the literature involved using ideas proposed by undergraduates taking the course (Filz & Gurung 2013; Haas, Heemstra, Medema, & Charkoudian, 2018).

A variety of sources of help in addition to “more knowledgeable others” have been described. Chi and Wylie (2014) noted that activities are rarely ranked or evaluated in terms of their level of active engagement. Mayer (2008) noted, however, that instructors can “encourage the learner to engage in making sense of the material.” Help from various sources can be used to overcome the problem of how instructors should choose from the wealth of proposed active learning activities (King, 1993; Van Dyke et al., 2017).

Among the list of items important for “teacher thinking,” Calderhead (1996) included the process of designing tasks that provide the basis upon which the instructor builds their teaching. Since the instructors in this study displayed concern about the process of designing activities that would correspond to student-centered teaching, the community of biochemistry instructors could encourage the development of both more and better support systems to bridge the gap between the instructors’ willingness to implement evidence-based teaching strategies and their ability to do so. This would be consistent with the work of Andresen et al. (1984) and Bussis et al. (1976), which highlighted the need to continuously involve teachers in processes such as self-exploration, reflection, and trial and error phases.

Another idea that came up in the participant interviews involved observing others teach as an opportunity to enlarge their body of knowledge about teaching practices and gain insights on how to make changes in the way they teach their classes. Many instructors who had experienced this approach to PD first utilized it because their department used a peer-review approach to evaluate the standard of teaching in the department.

Many biochemistry instructors who went through these opportunities expressed an interest in having this established on a larger scale. They noted the usefulness of observing others teach and seeing how, in concrete examples, teaching practices would look in someone else's biochemistry classroom setting. One of the implications of this study is the need to find ways to encourage more departments to institute peer-review of faculty, thereby establishing ways to "learn through observing others." Doing so would be consistent with the results of studies of systems of supporting instructors through peer observation (Richardson, 1996; Dancy, Henderson, & Turpen 2016). This could be supplemented by informal workshops that address the challenges the faculty share when teaching, as recommended by Dancy et al. (2016) who argued that informal learning engagement for faculty provide a significant source of communication and dissemination. This approach could be particularly useful for instructors who did not know how to go about making changes towards more evidence-based practices, as well as instructors who reached a plateau in the way they had shaped their teaching styles and did not know on their own what changes could be implemented. Unlike other chemistry content domains, this approach would benefit from reaching beyond the limits of a single department because biochemistry is often taught in more than one department.

It should be noted that a potential problem with peer review of teaching that came up in this study was the tendency for instructors to be discouraged by misleading information or not well executed teaching approaches in classrooms they had observed on their own. An emphasis might therefore be placed on having biochemists observe other biochemists so as not to overgeneralize factors that are applicable to certain STEM fields and not others (Lund & Stains, 2015). It should also be noted situational characteristics of individual instructors are crucial for the change in instructional choices (Henderson & Dancy, 2007), which means that we need to tailor PD approaches to the ones in need of them.

6.4 Reaching Out to Faculty When it is Most "Convenient" for Them – Implementing Change Effectively

Regardless of where the instructors in this study were in the process of implementing changes in their instruction, they all noted the existence of obstacles they would have to overcome to advance further. It was apparent among the participants involved in this study that student-centered instructors were more critical of how successful they felt they were at implementing their teaching goals in classes. The instructors who were still practicing more teacher-centered methodologies were among the ones who were most comfortable and confident in their teaching.

There have been attempts to develop models of how to implement effective PD strategies to overcome challenges and increase the implementation of quality instruction that positively affects student learning (Borrego & Henderson, 2014; Cascella & Jez 2017);

Pelletreau et al. 2018). No satisfying model has yet been established that would meet each instructors' needs and ensure effective changes. It has been suggested, however, that beliefs and actions are interrelated with one another (Richardson, 1996) and changes in PD are better accepted if beliefs are considered when designing PD opportunities to foster change toward evidence-based teaching practices (Bouwma-Gearhart, 2008). An approach that I support is to keep looking at individual groups, such as the community of biochemistry educators, and see what needs they have and how effective changes in teaching methodologies can be accomplished.

Research suggests that slow changes can make a difference and over time, these changes can accumulate and have a positive impact on the individual (Auerbach & Schussler, 2017). It is important to avoid overwhelming instructors with PD opportunities at the very beginning of their careers, nor should we wait too long. But starting on a small scale and introducing instructors with new methodologies through observing others, for example, and giving them the opportunity to consult specialists or be invited to seminars on teaching in their respective fields could encourage them to incorporate the process of continuously improving their teaching strategies in their classrooms. The overarching goal should be to bring active learning techniques into the biochemistry classrooms ("one step at a time" by Loertscher, 2009, p. 1; Palocaren et al., 2016).

This study revealed the importance of educational influences on their approach to teaching that instructors had experienced throughout their own education. This has been reported previously as being an important factor in establishing beliefs in general (Richardson, 1996). Personal experiences were among the most often-mentioned influences on beliefs on teaching biochemistry among the participants in this study.

Another factor that came up in this study was instructors' tendency to establish their values about how they teach through their experiences during their own teaching. This can make them possibly too "comfortable" at a level where less evidence-based teaching practices are implemented.

The interest in teaching, as a career, is a rather personal choice, as seen in this study. Categories were visible in the data from this study, however, that revealed factors that were important to college/university teachers that could be useful when designing PD programs, even though factors within each category varied.

6.5 Implications for Future Research

This exploratory study provided a rich description of a small population of instructors across multiple institutions. Although this dissertation revealed certain patterns in the instructors' responses to questions, it also opened the platform for pursuing multiple follow-up studies to investigate results in further detail or to scale up the scope of this research endeavor as described in the following paragraphs. In the future, I can see multiple research endeavors to be further pursued, which I will highlight in the next paragraphs.

It has been reported in the literature, that departmental factors play an important role in instructors' success in advancement (Henderson & Dancy, 2007; Stains et al. 2018). To uncover possible departmental differences or how other factors (e.g. difference in teaching experience) contribute to the choices of practices made in biochemistry classrooms, a large-scale survey could be considered to reach a broader population at different types of institution. Since this study was not able to reveal differences in teaching methodologies among different departments that teach biochemistry, a larger study might be able to confirm or refute past results from other research studies and reveal its applicability in biochemistry.

The variety of teaching approaches that were identified within the context of this study added to the body of existing knowledge on teaching approaches in STEM education (Stains et al., 2018). This suggests, however, that we should investigate a larger population of instructors teaching biochemistry and evaluate how teaching practices revealed within this study compare on the grand scheme of biochemistry teaching. According to Lund and Stains (2015), results on conceptions on the teaching of a certain STEM field should not be extrapolated to other STEM fields, since unique factors might be present and influencing a certain way of thinking and therefore influencing unique ways of teaching that subject, situated within its own microcosm. It therefore would be worthwhile to pursue a large-scale survey of instructional practices in biochemistry and the perceived challenges to a better understanding of the overall teaching practices in biochemistry education. This research endeavor could be enriched by following the trend of in-classroom analysis established and introduced by Lund and Stains (2015) through the use of the COPUS protocol. This analysis would enable the community of biochemistry instructors to compare, in a quantitative nature, the teaching of biochemistry with approaches to teaching in related fields, such as biology and chemistry, which have already been investigated in more depth.

The ICAP model offered an interesting perspective on the different levels of student engagement biochemistry classrooms potentially offered. In order to state with more certainty how students perceived the teaching methodologies used, it would be interesting to pursue a larger scale study of students' perceptions and beliefs of how biochemistry should be taught and what students would expect. This would allow us to distinguish between the enacted and intended mode of engagement raised as a concern by the creators of the ICAP framework when interpreting the results through that lens. It could also add to the body of knowledge on understanding why students are sometimes resistant to active learning methodologies (Finelli et al., 2018; Nguyen et al., 2017) in biochemistry classrooms and how that resistance can be overcome.

Future work could also build on the foundation of work that probes how classroom environments can make a difference in how instructors teach (Ramsay et al., 2017). Other researchers viewed critically the impact of classroom layouts on the teaching of biochemistry (Stains et al., 2018). This controversially discussed issue could be further investigated within the context of biochemistry, where I saw classroom environments play a role in the choices instructors made in how active or passive they voiced their teaching could be in class.

Further work could focus more closely on what makes biochemistry teacher teach the way they do. It could also investigate the interconnectedness between beliefs and action that has been the focus of research (Kim et al., 2012; Richardson, 1996). With this study, I intended to capture a broad range of views and practices centered on the teaching of biochemistry. The results and interpretation have to be seen in the context of the pool of participants I was able to recruit and investigate within the scope of this research endeavor. This study was never intended to criticize instructors' in-class practices, but rather to contribute to the understanding of how the teaching of biochemistry is being done and what factors and influences could be better used to introduce evidence-based teaching practices into biochemistry classrooms. It is on us, the education researchers, to help instructors achieve ensure a steady growth of the implementation of evidence-based teaching practices in classrooms, since students are the last to complain when less effective teaching strategies are implemented (Klionsky, 2017).

APPENDIX

IRB DOCUMENTATION

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	GEORGE BODNER WTHR 216G
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	03/10/2017
Committee Action:	**Determined Exempt, Category (2)**
IRB Action Date:	03/10/2017
IRB Protocol #:	1702018752
Study Title:	Beliefs and Perceptions About Teaching Biochemistry

The Institutional Review Board (IRB) has reviewed the above-referenced study application and has determined that it meets the criteria for exemption under 45 CFR 46.101(b).

Before making changes to the study procedures, please submit an Amendment to ensure that the regulatory status of the study has not changed. Changes in key research personnel should also be submitted to the IRB.

Please retain a copy of this letter for your regulatory records. We appreciate your commitment towards ensuring the ethical conduct of human subject research and wish you well with this study.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	GEORGE BODNER WTHR 216G
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	10/06/2017
Committee Action:	Amended Exemption Granted
Action Date:	10/06/2017
Protocol Number:	1702018752
Study Title:	Beliefs and Perceptions About Teaching Biochemistry

The Institutional Review Board (IRB) has reviewed the above-referenced amended project and has determined that it remains exempt. Before making changes to the study procedures, please submit an Amendment to ensure that the regulatory status of the study has not changed. Changes in key research personnel should also be submitted to the IRB through an amendment.

Please retain a copy of this letter for your regulatory records. We appreciate your commitment towards ensuring the ethical conduct of human subject research and wish you well with this study.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

RESEARCH PARTICIPANT INFORMATION SHEET (OBSERVATIONS)

Beliefs and perceptions about teaching biochemistry

Principle Investigator: Professor George M. Bodner

Co-Investigator: Franziska K. Lang

Chemistry Department

Purdue University

<u>What is the purpose of this study?</u>

Uncovering beliefs and perceptions about teaching biochemistry. I am asking you to participate in this research study to share with me insight on the way you teach biochemistry and communicate it to students during class time.

<u>What will I do if I choose to be in this study?</u>

If you choose to be in this study, I will be sitting in presumably 10 lectures the most with you and observing the classroom activities, specifically concentrating on the ways you teach biochemistry to your students, e.g which educational methods you are using in your classroom. The students will not be the focus of this study. You will go about your daily teaching as usual. I will in no way interrupt or participate in your lecture. The researcher is Franziska Lang, a Ph.D. candidate at Purdue University. Only you, the instructor, will be videotaped during the lectures in session. The recordings will only be available to the researcher, for later stages of analysis and coding.

<u>How long will I be in the study?</u>

A maximum of 10 lectures will be observed. I assume you will be part of the study for about 1 or two cycles of your course (1 or two semesters), depending on when observations can be taken, based on your convenience.

<u>What are the possible risks or discomforts?</u>

No more than minimal risk is associated with the study process. The participation is voluntarily. Observations will be non-judgmental and will only look at how the teaching of biochemistry is executed. The study’s aim is to capture the “status quo” of biochemistry teaching. The researcher will be discrete all the time and blend in with the audience as well as work with what you are comfortable with.

Are there any potential benefits?

There are no direct benefits. The indirect benefit we belief the study might yield to is gaining knowledge and insight in ways of thinking and understanding of the teaching of biochemistry.

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by Franziska Lang (aggregator) and George Bodner (principal investigator) and by departments at Purdue University responsible for regulatory and research oversight, as well as other IRB departments in other institutions if data is taken at a different institution such as Purdue University and IRB would have to be obtained from there. All personal information is strictly confidential, and no names will be disclosed. All video recordings will be transcribed, de-identified and coded in a timely manner. All data collected (e.g. video recordings, field notes, observations, and in-class material) will remain confidential. For transcription purposes, voices will be distorted and faces will be blurred. Immediately after data taking, codes will be applied to the resulting data to protect the identities of participants. A code key will be created and stored on a password-protected computer accessible only to the researchers listed on this protocol. All digital data will remain secured on the same password-protected computer only accessible to the protocol researchers. Any physical sources of data and signed consent forms will remain secured in a locked file cabinet, accessible only to the researchers. As soon as transcription has been completed, recordings will be destroyed. At that point, all identifiable research records will have been de-identified. All de-identified data will also be destroyed after completion of analysis at the end of the research project. The de-identification log-sheet will be kept in a locked cabinet/password protected PC where the analyzing researcher will not have access to. Any new information that develops during the project will be provided if that information may affect your willingness to continue participation in the project.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact Franziska Lang via email franziska@purdue.edu. If Franziska is not reachable, contact George Bodner via email gmbodner@purdue.edu.

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu)or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

RESEARCH PARTICIPANT INFORMATION SHEET (INTERVIEWS)

Beliefs and perceptions about teaching biochemistry

Principle Investigator: Professor George M. Bodner
Co-Investigator: Franziska K. Lang
Chemistry Department
Purdue University

What is the purpose of this study?

Uncovering beliefs and perceptions about teaching biochemistry. I am asking you to participate in this research study to share with me your perception and attitude on how biochemistry is taught.

What will I do if I choose to be in this study?

If you choose to be in this study, you will meet with a researcher for interview(s) about your beliefs and perception on the teaching of biochemistry. The researcher is Franziska Lang, a Ph.D. candidate at Purdue University. Your voice will be recorded during the interview. The recordings will only be available to the researcher, for later stages of analysis and coding.

How long will I be in the study?

A minimum of 1 interview will be conducted, however, the researcher may follow up with clarifying questions that require follow up interviews. Interviews will last ~1 hour. The interviews will be scheduled based on your convenience and willingness to participate in the study.

What are the possible risks or discomforts?

No more than minimal risk is associated with the study process. The interview participation is voluntarily. One potential risk is your expectation of privacy in case interviews are conducted online using a third-party provider such as Skype. For face-to-face interviews, this is not a risk. The researcher will ensure at any time that participants' expectation of privacy is maintained by removing identifiable information such as name, institution etc. from data records. Your identity will not be revealed. You as the participant can decide if the interviews are conducted in person or remotely.

Are there any potential benefits?

There are no direct benefits. The indirect benefit we belief the study might yield to is gaining knowledge and insight in ways of thinking and understanding of the teaching of biochemistry.

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by Franziska Lang (aggregator) and George Bodner (principal investigator) and by departments at Purdue University responsible for regulatory and research oversight, as well as other IRB departments in other institutions if data is taken at a different institution such as Purdue University and IRB would have to be obtained from there. All personal information is strictly confidential, and no names will be disclosed. All audio recordings will be transcribed, de-identified and coded in a timely manner. All data collected (e.g. audio recordings, transcriptions, field notes and interview notes) will remain confidential. For de-identification purposes, the voices in the audio recording will be distorted when transcribing the data. Codes will be applied to the resulting data to protect the identities of participants. A code key will be created and stored on a password-protected computer accessible only to the researchers listed on this protocol. All digital data will remain secured on the same password-protected computer only accessible to the protocol researchers. Any physical sources of data and signed consent forms will remain secured in a locked file cabinet, accessible only to the researchers. All identifiable data will be de-identified upon collection. All audio recordings will be destroyed right after transcription. All de-identified data will also be destroyed after completion of analysis and the end of the research project. The de-identification log-sheet will be kept in a locked cabinet/password protected PC where the analyzing researcher will not have access to. Any new information that develops during the project will be provided if that information may affect your willingness to continue participation in the project.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact Franziska Lang via email franziska@purdue.edu. If Franziska is not reachable, contact George Bodner via email gmbodner@purdue.edu.

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu)or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

REFERENCES

Åkerlind, G. S. (2004). A new dimension to understanding university teaching. *Teaching in Higher Education*, *9*(3), 363-375.

Åkerlind, G. S. (2008). A phenomenographic approach to developing academics' understanding of the nature of teaching and learning. *Teaching in Higher Education*, *13*(6), 633-644.

Alamoudi, A., Hassanien, M., Al Shawwa, L., Bima, A., Gad, H., & Tekian, A. (2018). Introducing TBL in clinical biochemistry: Perceptions of students and faculty. *MedEdPublish*, *7*.

Aldarmahi, A. A. (2016). The impact of problem based learning versus conventional education on students in the aspect of clinical reasoning and problem solving. *Education in Medicine Journal*, *8*(3), 1-10.

Allred, R., Zahilyn, D., Tai, H., Bretz, S. L., & Page, R. C. Using PyMOL to explore the effects of ph on noncovalent interactions between immunoglobulin g and protein A: A guided-inquiry biochemistry activity. *Biochemistry and Molecular Biology Education.*

American Association for the Advancement of Science (AAAS). (2011). *Vision and change in undergraduate biology education: A call to action.* Washington, DC: AAAS. Retrieved from Vision and Change: http://visionandchange.org/files/2011/03/Revised-Vision-and-Change-Final-Report.pdf

American Association for the Advancement of Science (AAAS). (2012). *Describing and measuring undergraduate STEM teaching practices*. Retrieved from http://ccliconference.org/files/2013/11/Measuring-STEM-Teaching-Practices.pdf

American Chemical Society (ACS). (2016). *What is biochemistry?* Retrieved from https://www.acs.org/content/acs/en/careers/college-to-career/areas-of-chemistry/biological-biochemistry.html

Anderson, T. R. (2007). Bridging the gap: Bridging the educational research-teaching practice gap. *Biochemistry and Molecular Biology Education*, *35*(6), 465–470.

Anderson, W. L., Mitchell, S. M., & Osgood, M. P. (2005). Comparison of student performance in cooperative learning and traditional lecture-based biochemistry classes. *Biochemistry and Molecular Biology Education*, *33*(6), 387-393.

Andresen, L., Barrett, E., Powell, J., & Wieneke, C. (1984). Planning and monitoring courses: University teachers reflect on their teaching. *Instructional Science*, *13*(4), 305-328.

Anfara, V. A., Jr., & Mertz, N. T. (Eds.). (2015). *Theoretical frameworks in qualitative research* (2nd ed.). Los Angeles, CA: Sage Publications.

Association of Biochemistry Educators (ABE). (2017). *Announcing the 6th international ABE conference*. Retrieved from http://www.abe.wildapricot.org/

Atkinson, P., & Silverman, D. (1997). Kundera's immortality: The interview society and the invention of the self. *Qualitative Inquiry*, *3*(3), 304-325.

Auerbach, A. J., & Schussler, E. (2017). A vision and change reform of introductory biology shifts faculty perceptions and use of active learning. *CBE-Life Sciences Education*, *16*(4), ar57.

Austin, A. E. (2011). Promoting evidence-based change in undergraduate science education. In *Fourth Committee Meeting on Status, Contributions, and Future Directions of Discipline-Based Education Research*. Retrieved from https://pdfs.semanticscholar.org/aeea/a99153a873884833eca5a67aa53a3039b32c.pdf

Bailey, C. P., Minderhout, V., & Loertscher, J. (2012). Learning transferable skills in large lecture halls: Implementing a POGIL approach in biochemistry. Biochemistry and Molecular Biology Education, 40(1), 1-7.

Barkley, E. F. (2009). Student engagement techniques: A handbook for college faculty. John Wiley & Sons.

Benatan, Dene, Stewart, Eppley, Watson, Geselbracht, Williams, Reisner, Jamieson, Johnson, JCE VIPEr: An Inorganic Teaching and Learning Community, *J. Chem. Educ*.,2009, 86(9), 766-767.

Bevan, S. J., Chan, C. W., & Tanner, J. A. (2014). Diverse assessment and active student engagement sustain deep learning: A comparative study of outcomes in two parallel introductory biochemistry courses. *Biochemistry and Molecular Biology Education*, *42*(6), 474-479.

Bhattacharyya, G. & Bodner, G. M. Culturing reality: How organic chemistry graduate students develop into practitioners, *Journal of Research in Science Teaching*, 2014, 51(6), 694-713.

Birt, L., Scott, S., Cavers, D., Campbell, C., & Walter, F. (2016). Member checking a tool to enhance trustworthiness or merely a nod to validation? *Qualitative Health Research, 26*(13), 1802-1811.

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, *63*(10), 873-878.

Bodner, G. M. (1992). Why changing the curriculum may not be enough. *Journal of Chemical Education*, *69*(3), 186-190.

Bodner, G. M., & MacIsaac, D. L. (1995). A critical examination of relevance in science education research, presented at the Annual Meeting of the National Association for Research in Science Teaching, San Francisco, April 22-25, 1995. San Francisco, CA: ERIC.

Bodner, G. M., Metz, P. A., & Tobin, K. (1997). Cooperative learning: An alternative to teaching at a medieval university. *Australian Science Teachers' Journal*, *43*(1), 23-28.

Bodner, G. (2004). Twenty years of learning: How to do research in chemical education. 2003 George C. Pimentel Award. *Journal of Chemical Education*, *81*(5), 618-625.

Bodner, G. M., & Orgill, M. (2007). *Theoretical frameworks for research in chemistry/science education*. Upper Saddle River, NJ: Prentice Hall.

Bodner, G. M., & Weaver, G. (2008). Introduction: Research and practice in chemical education in advanced courses. *Chemistry Education Research and Practice, 9*(2), 81-83.

Bogdan, R. C., & Bicklen, S. K. (1998). *Qualitative research for education: An introduction to theory and methods* (3rd ed.). Boston, MA: Allyn and Bacon.

Bonwell, C. C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom. 1991 ASHE-ERIC Higher Education Reports*. ERIC Clearinghouse on Higher Education, The George Washington University, One Dupont Circle, Suite 630, Washington, DC 20036-1183.

Borrego, M., & Henderson, C. (2014). Increasing the use of evidence-based teaching in STEM higher education: A comparison of eight change strategies. *Journal of Engineering Education, 103*(2), 220-252.

Bouwma-Gearhart, J. (2008). *Teaching professional development of science and engineering professors at a research-extensive university: Motivations, meaningfulness, obstacles, and effects* (Doctoral dissertation). Retrieved from ProQuest LLC. (UMI Number: 3327743)

Brickhouse, N., & Bodner, G. M. (1992). The beginning science teacher: Classroom narratives of convictions and constraints. *Journal of Research in Science Teaching, 29*(5), 471-485.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design.* Cambridge, MA: Harvard.

Bruck, L. B., Towns, M., & Bretz, S. L. (2010). Faculty perspectives of undergraduate chemistry laboratory: Goals and obstacles to success. *Journal of Chemical Education*, *87*(12), 1416 - 1424.

Bussis, A. M., Chittenden, E. A., & Amarel, M. (1976). *Beyond surface curriculum: An interview study of teachers' understandings*. Westview Press.

Calderhead, J. (1996). Teachers: Beliefs and knowledge. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 709–725). London, England: Prentice Hall International.

Carlgren, I., Handal, G., & Vaage, S. (1994). *Teachers' minds and actions: Research on teachers' thinking and practice*. Psychology Press.

Carlson, J. A. (2010). Avoiding traps in member checking. *The qualitative report*, *15*(5), 1102.

Cascella, B., & Jez, J. M. (2017). Beyond the Teaching Assistantship: CURE Leadership as a Training Platform for Future Faculty. *Journal of Chemical Education*, *95*(1), 3-6.

Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science*, 1(1), 73-105.

Chi, M. T., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist*, *49*(4), 219-243.

Cicuto, C. A. T., & Torres, B. B. (2016). Implementing an active learning environment to influence students' motivation in biochemistry. *Journal of Chemical Education*, *93*(6), 1020-1026.

Clandinin, D. J. (1986). Classroom practice: Teacher images in action. Falmer Press.

Clark, C. M., & Yinger, R. J. (1987). Teacher Planning. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 84-103). London: Cassell.

Cochran-Smith, M., & Lytle, S. L. (1990). Research on teaching and teacher research. *Educational Researcher*, *19*(2), 2–11.

Cochran-Smith, M., & Lytle, S. L. (Eds.). (1993). *Inside/outside: Teacher research and knowledge*. Teachers College Press.

Committee on Professional Training. (2015). Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs. Washington, DC: American Chemical Society.

Conway, C. J. (2014). Effects of guided inquiry versus lecture instruction on final grade distribution in a one-semester organic and biochemistry course. *Journal of Chemical Education*, *91*(4), 480-483.

Corbin, J. & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Cornett, J.W., Yeotis, C., & Terwilliger, L. (1990). Teacher personal practical theories and their influence upon teacher curricular and instructional actions: A case study of a secondary science teacher. *Science Education*, 74(5), 517-529.

Corno, L., & Mandinach, E. B. (1983). The role of cognitive engagement in classroom learning and motivation. *Educational Psychologist*, *18*(2), 88-108.

Cowden, C. D., & Santiago, M. F. (2016). Interdisciplinary explorations: Promoting critical thinking via problem-based learning in an advanced biochemistry class. *Journal of Chemical Education*, *93*(3), 464-469.

Creswell, J.W. (2009). Research design: Qualitative, quantitative and mixed methods approaches, 3rd ed., Thousand Oaks, CA: Sage Publications.

Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks, CA: Sage Publications.

Dancy, M., Henderson, C., & Turpen, C. (2016). How faculty learn about and implement research-based instructional strategies: The case of peer instruction. *Physical Review Physics Education Research*, *12*(1), 010110.

Dash, S., Kamath, U., Rao, G., Prakash, J., & Mishra, S. (2015). Audio–visual aid in teaching "fatty liver". *Biochemistry and Molecular Biology Education*, *44*(3), 241-245.

de Jong, O. (2000). Crossing the borders: chemical education research and teaching practice. *University Chemistry*, *4*(1), 31-34.

Denzin, N. K., & Lincoln, Y. S. (2011). *The SAGE handbook of qualitative research*. (4*th* ed.) Los Angeles: Sage Publications.

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education*, *76*(4), 543-547.

Eckel, P. D., & Kezar, A. J. (2003). *Taking the reins: Institutional transformation in higher education*. Greenwood Publishing Group.

Eisner, E. W. (1984). Can educational research inform educational practice? *The Phi Delta Kappan*, *65*(7), 447-452.

Fairweather, J. S. (2005). Beyond the rhetoric: Trends in the relative value of teaching and research in faculty salaries. *The Journal of Higher Education*, *76*(4), 401-422.

Fairweather, J. (2008). *Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education: A status report for the national academies national research council board of science education*. Washington, DC: The National Academies National Research Council Board of Science Education.

Fang, Z. (1996). A review of research on teacher beliefs and practices. *Educational Research*, *38*(1), 47-65.

Fernández-Santander, A. (2008). Cooperative learning combined with short periods of lecturing: A good alternative in teaching biochemistry. *Biochemistry and Molecular Biology Education*, *36*(1), 34–38.

Ferrarotti, F. (1981). On the autonomy of the biographical method. *Biography and society: The life history approach in the social sciences* (19-27). CA: Sage Publications.

Fisher, P. D., Fairweather, J. S., & Amey, M. (2001). Systemic reform in undergraduate engineering education: The role of collective responsibility. *Frontiers in Education Conference, 2001. 31st Annual* (Vol. 1, pp. T1A-1-T1A-6). IEEE.

Filz, T., & Gurung, R. A. (2013). Student perceptions of undergraduate teaching assistants. *Teaching of Psychology*, 40(1), 48-51.

Finelli, C. J., Nguyen, K., DeMonbrun, M., Borrego, M., Prince, M., Husman, J., ... & Waters, C. K. (2018). Reducing Student Resistance to Active Learning: Strategies for Instructors. *Journal of College Science Teaching*, *47*(5), 80-91.

Forbes-Lorman, R. M., Harris, M. A., Chang, W. S., Dent, E. W., Nordheim, E. V., & Franzen, M. A. (2016). Physical models have gender-specific effects on student understanding of protein structure–function relationships. *Biochemistry and Molecular Biology Education*, *44*(4), 326-335.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410-8415.

Gadamer, H. G. (1976). *Philosophical hermeneutics*. Berkley, CA: University of California Press.

Gadamer, H. G. (1996). *Reason in the age of science*. Cambridge: MIT Press.

Gadamer, H. G. (2000). *Truth and Method*. New York: Continuum.

Geelan, D. R., & Taylor, P. C. (2001). Writing our lived experience: Beyond the (pale) hermeneutic? *Electronic Journal of Science Education*, *5*(4). Retrieved from http://ejse.southwestern.edu/article/view/7663/5430

Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal*, *40*(3), 731-767.

Goeden, T. J., Kurtz, M. J., Quitadamo, I. J., & Thomas, C. (2015). Community-based inquiry in allied health biochemistry promotes equity by improving critical thinking for women and showing promise for increasing content gains for ethnic minority students. *Journal of Chemical Education*, *92*(5), 788-796.

Golland, J. H. (1998). A lesson plan model for the supervision of student teaching. *Education*, 118(3), 376-381.

González, C. (2011). Extending research on ‘conceptions of teaching’: commonalities and differences in recent investigations. *Teaching in Higher Education*, *16*(1), 65-80.

Goodyear, G. E., & Allchin, D. (1998). Statements of teaching philosophy. *To improve the Academy*, *17*(1), 103-121.

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication and Technology Journal*, *29*(2), 75–91.

Gunersel, A. B., & Fleming, S. (2014). Bio-organic reaction animations (BioORA): Student performance, student perceptions, and instructor feedback. *Biochemistry and Molecular Biology Education*, *42*(3), 190-202.

Haas, K. L., Heemstra, J. M., Medema, M. H., & Charkoudian, L. K. (2018). Collaborating with undergraduates to contribute to biochemistry community resources. *Biochemistry*, *57*(4), 383-389.

Hagenauer, G., & Volet, S. (2014). ‘I don’t think I could, you know, just teach without any emotion’: Exploring the nature and origin of university teachers’ emotions. *Research Papers in Education*, *29*(2), 240-262.

Hanna, P. (2012). Using internet technologies (such as skype) as a research medium: A research note. *Qualitative Research*, *12*(2), 239-242.

Hativa, N., & Goodyear, J. (Eds.). (2001). *Teacher thinking, beliefs and knowledge in higher education* (Vol. 28, No. 506). Springer Science & Business Media.

Henderson, C. R. (2002). *Faculty conceptions about the teaching and learning of problem solving in introductory calculus-based physics* (Doctoral dissertation). Retrieved from http://groups.physics.umn.edu/physed/People/Charles'%20Thesis/TOC-Title.pdf

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching*, 48(8), 952-984.

Henderson, C., & Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics-Physics Education Research*, *3*(2), 020102-1-020102-14.

Henderson, C., & Dancy, M. H. (2009). Impact of physics education research on the teaching of introductory quantitative physics in the United States. *Physical Review Special Topics-Physics Education Research*, *5*(2), 020107-1-020107-9.

Henderson, C., & Dancy, M. H. (2011, February). Increasing the impact and diffusion of STEM education innovations. *Invited paper for the National Academy of Engineering, Center for the Advancement of Engineering Education Forum, Impact and Diffusion of Transformative Engineering Education Innovations.* Retrieved from the msu webpage: http://create4stem.msu.edu/sites/default/files/discussions/attachments/HendersonandDancy10-20-2010.pdf

Henderson, C., Dancy, M., & Niewiadomska-Bugaj, M. (2012). Use of research-based instructional strategies in introductory physics: Where do faculty leave the innovation-decision process?. *Physical Review Special Topics-Physics Education Research*, *8*(2), 020104-1-020104-15.

Henderson, C., Khan, R., & Dancy, M. (2018). Will my student evaluations decrease if I adopt an active learning instructional strategy? Accepted in American Journal of Physics. Retrieved from https://drive.google.com/file/d/179ejdWZNrb6FsKZvtpBRSipDpeLdtIDh/view

Jansson, S., Söderström, H., Andersson, P. L., & Nording, M. L. (2015). Implementation of problem-based learning in environmental chemistry. *Journal of Chemical Education*, *92*(12), 2080-2086.

Kahveci, M., & Orgill, M. (Eds.). (2015). *Affective dimensions in chemistry education*. Berlin/Heidelberg, Germany: Springer Verlag.

Kember, D. (1997). A reconceptualisation of the research into university academics' conceptions of teaching. *Learning and Instruction*, *7*(3), 255-275.

Kember, D., & Gow, L. (1994). Orientations to teaching and their effect on the quality of student learning. *Journal of Higher Education*, *65*(I), 58-74.

Kenny, S. S., Alberts, B., Booth, W. C., Glaser, M., Glassick, C. E., Ikenberry, S. O., … Yang, C. N. (1999). *Reinventing undergraduate education: A blueprint for America’s research universities* (Vol. 2005). Retrieved from http://www.sunysb.edu/boyerreport

Kezar, A. J. (2008). *Rethinking leadership in a complex, multicultural, and global environment: New concepts and models for higher education*. Stylus Publishing, LLC.

King, A. (1993). From sage on the stage to guide on the side. *College Teaching*, *41*(1), 30-35.

King, A., Boysen-Osborn, M., Cooney, R., Mitzman, J., Misra, A., Williams, J., ... & Gottlieb, M. (2017). Curated collection for educators: Five key papers about the flipped classroom methodology. Cureus, 9(10).

Kirch, D. G., Mitchell, K., & Ast, C. (2013). The new 2015 MCAT: Testing competencies. *Jama*, 310(21), 2243-2244.

Klionsky, D. J. (2017). Education is the Only Business Where the Customer is Satisfied with Less of the Product. *Journal of microbiology & biology education*, *18*(2).

Klymkowsky, M. W., & Cooper, M. M. (2012). Now for the hard part: The path to coherent curricular design. *Biochemistry and Molecular Biology Education*, *40*(4), 271-272.

Knowles, J. G., & Holt-Reynolds, D. (1991). Shaping pedagogies through personal histories in preservice teacher education. *Teachers College Record*, *93*(1), 87-113.

Komives, S. R. (2010). Rethinking Leadership Practices in a Complex, Multicultural, and Global Environment: New Concepts and Models for Higher Education. *The Review of Higher Education*, *34*(1), 186-188.

Kuzel, A. J. (1992). Doing qualitative research, *sampling in qualitative inquiry* (pp. 31-44). Thousand Oaks, CA: Sage Publications.

Lang, F. K., & Bodner, G. M. (2017). *A review of biochemistry education research: Implications for university-level biochemistry instructors*. Manuscript in Preparation.

Laverty, S. M. (2003). Hermeneutic phenomenology and phenomenology: A comparison of historical and methodological considerations. *International Journal of Qualitative Methods*, *2*(3), 21-35.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage Publications.

Loertscher, J. (2009, December). *Bringing active learning to the biochemistry classroom one step at a time*. Retrieved from http://www.asbmb.org/asbmbtoday/asbmbtoday_article.aspx?id=4758

Loertscher, J., Villafañe, S. M., Lewis, J. E., & Minderhout, V. (2014). Probing and improving student's understanding of protein α-helix structure using targeted assessment and classroom interventions in collaboration with a faculty community of practice. *Biochemistry and Molecular Biology Education*, *42*(3), 213-223.

Lund, T. J., & Stains, M. (2015). The importance of context: An exploration of factors influencing the adoption of student-centered teaching among chemistry, biology, and physics faculty. *International Journal of STEM Education*, *2*(1), 13.

Mack, M. R. (2015). *A study of faculty approaches to teaching undergraduate physical chemistry courses* (Doctoral dissertation, Purdue University).

Mack, M. R., & Towns, M. H. (2016). Faculty beliefs about the purposes for teaching undergraduate physical chemistry courses. *Chemistry Education Research and Practice*, *17*(1), 80-99.

Martin, E., Prosser, M., Trigwell, K., Ramsden, P., & Benjamin, J. (2000). What university teachers teach and how they teach it. *Instructional Science*, *28*, 387–412.

McCoy, A. B., & Darbeau, R. W. (2013). Revision of the ACS guidelines for bachelor's degree programs. *Journal of Chemical Education*, 90(4), 398-400.

McKeachie, W. J., & Svinicki, M. D. (2014). *Teaching tips. Strategies, Research, and Theory for College and University Teachers* (14th ed.). Belmont CA: Wadsworth, Cengage Learning.

Menekse, M. (2012). *Interactive-constructive-active-passive: The relative effectiveness of differentiated activities on students' learning* (Doctoral dissertation, Arizona State University).

Menekse, M., Stump, G. S., Krause, S., & Chi, M. T. (2013). Differentiated overt learning activities for effective instruction in engineering classrooms. Journal of Engineering Education, 102(3), 346-374.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation.* San Francisco, CA: John Wiley & Sons, Inc.

Miles, N., & Soares da Costa, T. P. (2016). Acceptance of clickers in a large multimodal biochemistry class as determined by student evaluations of teaching: Are they just an annoying distraction for distance students?. *Biochemistry and Molecular Biology Education*, *44*(1), 99-108.

Minderhout, V., & Loertscher, J. (2007). Lecture-free biochemistry. *Biochemistry and Molecular Biology Education*, *35*(3), 172-180.

Moss, P. A. (1994). Can there be validity without reliability?. *Educational Researcher*, *23*(2), 5-12.

Munhall, P. (2008). Perception. In L. M. Given (Ed.), *The SAGE encyclopedia of qualitative research methods* (pp. 607-607). Thousand Oaks, CA: Sage Publications. doi: 10.4135/9781412963909.n314

Murray, K., & Macdonald, R. (1997). The disjunction between lecturers' conceptions of teaching and their claimed educational practice. *Higher Education*, *33*(3), 331-349.

Muth, G. W. (2016). Biochemistry and the Liberal Arts: Content and Communication in a Flipped Classroom. *The Flipped Classroom Volume 2: Results from Practice* (pp. 127-138). Washington, DC: Oxford University Press.

National Science Board. (2009). *Preparing our children: How research can better inform practice.* Retrieved from https://www.nsf.gov/pubs/1999/nsb9931/nsb9931-7.htm

National Research Council (NRC). (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. Washington, DC: The National Academies Press.

Nespor, J. (1987). The role of beliefs in the practice of teaching. *Journal of Curriculum Studies*, *19*(4), 317-328.

Nguyen, K., Husman, J., Borrego, M., Shekhar, P., Prince, M., Demonbrun, M., & Waters, C. (2017). Students' expectations, types of instruction, and instructor strategies predicting student response to active learning. *International Journal of Engineering Education*, *33*(1), 2-18.

Niederhoffer, E. C., Cline, S. D., Osheroff, N., Simmons, J. M., Diekman, A. B., Franklin, D. S., ... & Pearson, D. (2017). Teaching biochemistry and genetics to students of medicine, pharmacy, and dentistry. *Medical Science Educator*. doi: 10.1007/s40670-017-0441-1

Norton, L., Richardson, T. E., Hartley, J., Newstead, S., & Mayes, J. (2005). Teachers' beliefs and intentions concerning teaching in higher education. *Higher Education*, *50*(4), 537-571.

Olson, S., & Riordan, D. G. (2012). *Report to the president. engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics.* Retrieved from http://files.eric.ed.gov/fulltext/ED541511.pdf

Orgill, M. (2003). Playing with a double-edged sword: Analogies in biochemistry (Doctoral dissertation, Purdue University).

Orgill, M., Bussey, T. J., & Bodner, G. M. (2015). Biochemistry instructors' perceptions of analogies and their classroom use. *Chemistry Education Research and Practice*, *16*(4), 731-746.

Page, J. M. (2014). Childcare choices and voices: Using interpreted narratives and thematic meaning-making to analyse mothers' life histories. *International Journal of Qualitative Studies in Education*, *27*(7), 850-876.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*(3), 307-332.

Palocaren, J., Pillai, L. S., & Celine, T. M. (2016). Medical biochemistry: Is it time to change the teaching style. *The National Medical Journal of India*, *29*(4), 222–224.

Panasuk, R. M., & Todd, J. (2005). Effectiveness of lesson planning: Factor analysis. *Journal of Instructional Psychology*, 32(3).

Patton, M. Q. (2002). *Qualitative research & evaluation methods* (3rd ed.). Thousand Oaks: Sage Publications.

Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). Thousand Oaks, CA: Sage Publications.

Pelletreau, K. N., Knight, J. K., Lemons, P. P., McCourt, J. S., Merrill, J. E., Nehm, R. H., ... & Smith, M. K. (2018). A Faculty Professional Development Model That Improves Student Learning, Encourages Active-Learning Instructional Practices, and Works for Faculty at Multiple Institutions. *CBE—Life Sciences Education*, *17*(2), es5.

Peterson, C., & Carroll, M. (2015, October). *Biochemistry education. Training the next generation of biochemists and molecular biologists*. Retrieved from http://www.asbmb.org/asbmbtoday/201510/Meeting2016/Biochemistryeducation/?terms=biochemistry education

Peterson, P. L., Marx, R. W., & Clark, C. M. (1978). Teacher planning, teacher behavior, and student achievement. *American Educational Research Journal*, 15(3), 417-432.

Prakash, S. S., Muthuraman, N., & Anand, R. (2017). Short-duration podcasts as a supplementary learning tool: Perceptions of medical students and impact on assessment performance. *BMC Medical Education*, 17(1), 167.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223-231.

Prosser, M., Trigwell, K., & Taylor, P. (1994). A phenomenographic study of academics' conceptions of science learning and teaching. *Learning and Instruction*, *4*(3), 217-231.

Prosser, M., & Trigwell, K. (1999). *Understanding learning and teaching: The experience in higher education*. McGraw-Hill Education (UK).

Ramsay, C. M., Guo, X., & Pursel, B. K. (2017). Leveraging Faculty Reflective Practice to Understand Active Learning Spaces: Flashbacks and Re-Captures. *Journal of Learning Spaces*, *6*(3).

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. *Handbook of research on teacher education*, *2*, 102-119.

Richardson, D. C., Richardson, J. S., Sirochman, R., Weiner, S. W., Farwell, M., Putnam-Evans, C., ... & Bateman Jr, R. C. (2005). Assessment of molecular construction in undergraduate biochemistry. *Journal of Chemical Education*, 82(12), 1854.

Samuelowicz, K., & Bain, J. D. (1992). Conceptions of teaching held by academic teachers. *Higher Education*, *24*(1), 93-111.

Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. Educational Technology, 35(5), 31-38.

Schoenfeld-Tacher, R., Jones, L. L., & Persichitte, K. A. (2001). Differential effects of a multimedia goal-based scenario to teach introductory biochemistry—who benefits most?. *Journal of Science Education and Technology*, *10*(4), 305-317.

Schön, D. A. (1984). *The reflective practitioner: How professionals think in action* (Vol. 5126). New York: Basic books.

Schön, D. A. (1995). Knowing-in-action: The new scholarship requires a new epistemology. *Change: The Magazine of Higher Learning*, *27*(6), 27-34.

Schubert, W. H. (1991). Teacher lore: A basis for understanding praxis. *Stories lives tell: Narrative and dialogue in education*, 207-233.

Schuster, J. H., & Finkelstein, M. J. (2006). *The American faculty: The restructuring of academic work and careers*. Johns Hopkins University Press.

Seidman, I. (2013). *Interviewing as qualitative research: A guide for researchers in education and the social sciences*. New York, NY: Teachers college press.

Shane, J. W. (2007). Hermeneutics and the meaning of understanding. In G. M. Bodner & M. Orgill (Eds.), *Theoretical frameworks for research in chemistry/science education* (pp. 104 – 116). New Jersey: Prentice Hall.

Shavelson, R. J., & Stern, P. (1981). Research on teachers' pedagogical thoughts, judgments, decisions, and behavior. *Review of Educational Research*, *51*(4), 455-498.

Shaw, G. P., & Molnar, D. (2011). Non-native english language speakers benefit most from the use of lecture capture in medical school. *Biochemistry and Molecular Biology Education*, *39*(6), 416-420.

Simmons, P. E., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., ... & Brunkhorst, H. (1999). Beginning teachers: Beliefs and classroom actions. *Journal of Research in Science Teaching*, 36(8), 930-954.

Smith, M. K., Jones, F. H., Gilbert, S. L., & Wieman, C. E. (2013). The classroom observation protocol for undergraduate STEM (COPUS): A new instrument to characterize university STEM classroom practices. *CBE-Life Sciences Education*, *12*(4), 618-627.

Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., ... & Levis-Fitzgerald, M. (2018). Anatomy of STEM teaching in north american universities. *Science*, *359*(6383), 1468-1470.

Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and Teacher Education*, *17*(2), 213-226.

Strangis, D. E., Pringle, R. M., & Knopf, H. T. (2006). Road map or roadblock? Science lesson planning and preservice teachers. *Action in Teacher Education*, 28(1), 73-84.

Sunal, D. W., Hodges, J., Sunal, C. S., Whitaker, K. W., Freeman, L. M., Edwards, L., ... & Odell, M. (2001). Teaching science in higher education: Faculty professional development and barriers to change. *School Science and mathematics*, *101*(5), 246-257.

Tansey, J. T., Baird, T., Cox, M. M., Fox, K. M., Knight, J., Sears, D., & Bell, E. (2013). Foundational concepts and underlying theories for majors in "biochemistry and molecular biology". *Biochemistry and Molecular Biology Education*, *41*(5), 289-296).

Taylor, P. H. (1970). *How teachers plan their courses: Studies in curriculum planning*. New York: National Foundation for Educational Research in England and Wales.

Terrell, C. R., & Listenberger, L. L. (2017). Using molecular visualization to explore protein structure and function and enhance student facility with computational tools. *Biochemistry and Molecular Biology Education*, *45*(4), 318-328.

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, *27*(2), 237-246.

Towns, M. H. (2013). New guidelines for chemistry education research manuscripts and future directions of the field. *Journal of Chemical Education*, *90*, 1107–1108.

Trigwell, K., & Prosser, M. (1991). Improving the quality of student learning: The influence of learning context and student approaches to learning on learning outcomes. *Higher Education*, *22*(3), 251-266.

Tyler, R. W. (1950). *Basic principles of curriculum and instruction.* Chicago, USA: University of Chicago Press.

U.S. Department of Education. (2017). *Use of technology in teaching and learning.* Retrieved from https://www.ed.gov/oii-news/use-technology-teaching-and-learning

Van Dyke, A. R., Gatazka, D. H., & Hanania, M. M. (2017). Innovations in Undergraduate Chemical Biology Education. *ACS chemical biology*, *13*(1), 26-35.

Weaver, G., Burgess, W. D., Childress, A. L., & Slakey, L. (2015). *Transforming institutions. Undergraduate STEM education for the 21st century*. West Lafayette, Indiana: Purdue University Press.

Wenzel, T. J., McCoy, A. B., & Landis, C. R. (2015). An overview of the changes in the 2015 ACS guidelines for bachelor's degree programs. *Journal of Chemical Education*, 92(6), 965-968

Wieman, C., & Gilbert, S. (2015). Taking a scientific approach to science education, part I–research. *Microbe, 10*(4), 152-156.

Wieman, C., & Gilbert, S. (2015). Taking a scientific approach to science education, part II—changing teaching. *Microbe*, *10*(5), 203-207.

Wieman, C., Perkins, K., & Gilbert, S. (2010). Transforming science education at large research universities: A case study in progress. *Change: The Magazine of Higher Learning, 42*(2), 6-14.

Wilson, S. M., & Wineburg, S. (1991). *Using performance-based exercises to assess the knowledge of history teachers: A cross-case analysis*. Paper presented at the annual meeting of the American Educational Research Association, Chicago.

Wischow, E. D. (2008). *Development and analysis of lesson plans for nanoscience, engineering, and technology* (Doctoral dissertation, Purdue University).

Wolfson, A. J. (2010). *Biochemistry/molecular biology and liberal education: A report to the Teagle Foundation.* Retrieved from http://www.asbmb.org/uploadedFiles/ProfessionalDevelopment/Resources/Teagle%20Report(1).pdf

Yarden, A., Macaulay, J., & Akdogan, G. G. (2017, April 23). *New Horizons in biochemistry & molecular biology education*. Retrieved from http://www.weizmann.ac.il/conferences/NHBMB2017/

Yinger, R. J. (1980). A study of teacher planning. *The Elementary School Journal*, *80*(3), 107-127.

Zeichner, K. M. (1994). Research on teacher thinking and different views of reflective practice in teaching and teacher education. *Teachers' minds and actions: Research on teachers' thinking and practice* (9-27). Bristol, PA: The Falmer Press.

VITA

Franziska Klara Lang was born in Laupheim, Germany. She earned her Bachelor’s degree in Molecular and Cellular Biology at the Heidelberg University, Germany. After realizing that she was not only passionate about carrying out science herself, but also about teaching it, she pursued a degree equivalent to a Master’s in Science Education for Biology and Chemistry and stayed in the beautiful Heidelberg area, the land of romantic castles, mountains, and philosophers. In 2013, after having had the opportunity to finish up her Master’s degree at the Feinstein Institute for Medical Research on Long Island, NY, she moved to West Lafayette, IN and pursued her doctorate in Chemistry at Purdue University. She is not only successful as a researcher, but can also call herself a proud mum of two energetic twin boys. She established herself as an acknowledged instructor and passionate researcher at Purdue University and is eager to pursue an innovative and inspiring career within the Chemistry Department to further improve teaching and learning at the highest level. Boiler-up!

PUBLICATION

A Review of Biochemistry Education Research: Implications for University-Level Biochemistry Instructors

Franziska K. Lang and George M. Bodner[1]
Department of Chemistry
Purdue University
West Lafayette, IN 47907
Email: gmbodner@purdue.edu
Phone: (765) 494-5313

Introduction

The National Science Board (1999) has argued that educational research not only can but should be used to improve instruction. And yet, for at least 30 years, major figures within the field of educational research have argued that it may do so subtly, but not overtly (Eisner, 1984). One of the differences between traditional educational research and work being done more recently has been the growth in what is known as *discipline-based educational research* (DBER), such as chemistry (CER) or physics (PER) educational research. Another important difference has been the tendency in recent years to expand the context of educational research beyond the traditional focus on the K-12 classroom to address not only the challenges of teaching and learning at the college level, but, in particular, to extend this work to advanced-level courses such as upper-level undergraduate biochemistry courses (Bodner & Weaver, 2008). The reason to feel optimistic about the potential impact on instructional practices of research on teaching/learning in advanced undergraduate courses is that it does not search for universal truths that might apply to STEM education, in general, but on the particular classroom environment in which instructors find themselves on a daily basis. In order to achieve its potential impact on instructional practices, however, it is necessary to bring the results of biochemistry education research to the attention of the practicing biochemist who teaches these courses.

Our work began with a search of the literature on all phases of biochemistry education across the multiple disciplines in which biochemistry is taught. From this sample of more than 1600 references, we examined the papers that reported the results of biochemistry education research (BCER)[2], with a special focus on upper-level biochemistry courses in either "lecture" or "laboratory" settings. Because biochemistry is an interdisciplinary field, encompassing many traditional research areas and serving as the foundation for emerging fields of research, our literature search looked beyond typical

---

[1] Author to whom correspondence should be sent, Department of Chemistry, Purdue University, 560 Oval Dr., West Lafayette, IN 47907-2084. Email address: gmbodner@purdue.edu.

[2] Biochemistry education research will be abbreviated as *BCER* to differentiate it from biology education research, *BER*.

biochemistry courses and included courses that integrate biochemistry within curriculum areas such as health sciences, medicinal chemistry, chemical biology, and molecular biology, as well as courses that combine biochemistry with other topics in chemistry, such as general chemistry and/or organic chemistry. This provided a holistic approach that served as a basis upon which progress in biochemistry education could be built.

The framework for this study was grounded theory (Corbin & Strauss, 1990; Stauss & Corbin, 1990, 1994), which is a commonly used approach for analysis of qualitative data that can be thought of as the opposite of the hypothesis-testing approach often used in biochemistry research. Instead of designing an experiment in which an idea or concept is tested, grounded theory uses the analysis of observations to generate concepts, ideas, categories, and/or patterns in the data that can serve as the basis upon which a theory that might then undergo experimental testing. Qualitative research based on a grounded theory foundation is often based on an explicit research question. E.g., how do chemistry majors enrolled in the sophomore-level organic chemistry course make sense of the "curved arrow" formalism used by practicing organic chemists? (Ferguson & Bodner, 2008).

Qualitative analysis software (NVivo, 2017) was used to establish categories based on repeatedly reviewing the data and these categories were enriched using grounded theory techniques known as "open-coding" (Strauss & Corbin, 1990) and "memoing" techniques (Corbin & Strauss, 1990).

"Open coding" is a methodological tool used to organize the data from a grounded theory study. It describes the stage of the study during which raw research data are systematically analyzed to create a limited number of descriptive themes, ideas, and/or categories into which similar examples from the qualitative data set can be sorted.

Memoing has been described by Glaser (1998) as follows: "Memos are the theorizing write-up of ideas about substantive codes and their theoretically coded relationships as they emerge during coding, collecting and analyzing data, and during memoing." Corbin and Strauss (1990) have argued that: "If a researcher omits the memoing and moves directly from coding to writing, a great deal of conceptual detail is lost or left undeveloped." "Memos" are important tools to both keep track of and refine ideas that develop when the researcher compares similar incidents that arise in the course of data analysis and develops connections between concepts that appear in the theory that evolves from grounded theory approaches. Through memos, the researcher develops and keeps track of concepts that arise from the data analysis and in the form of tables, diagrams or figures that both help make the evolving ideas grow and provides a context for comparing these ideas.

The following themes or codes arose from the grounded theory analysis of the biochemistry education research literature: i) classroom and laboratory practices for teaching biochemistry; ii) identification of particular concepts or topics in biochemistry for which students exhibited learning difficulties; and iii) assessment tools and techniques that are appropriate for use in biochemistry. This analysis also revealed patterns in the biochemistry education research literature. The studies published so far have been predominantly situated within the lecture setting, with a focus on identifying learning difficulties and suggestions for improved teaching. At the time of this analysis, no research has been reported that would reveal difficulties with learning in the laboratory setting (I found 1 paper in the meantime that did that – I mentioned it in the difficulties section). The absence of research studies on learning in the biochemistry laboratory is analogous to what would be found in both the chemistry and physics education research literature. Within the context of topics in biochemistry, the analysis of the biochemistry education research literature suggests that there is a particularly rich pool of references centering on structure and function, which has been recognized as an ASBMB Foundational Concept (Tansey, et al. 2013). It might be useful to think of these Foundational Concepts as examples of what have been termed “threshold concepts,” upon which a conceptual understanding of biochemistry is built. Meyer and Land (2006) have argued that “a threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something” (p.3).

Currently, no reviews have been published that examine the literature on biochemistry education research. Our review may prove useful to instructors teaching biochemistry by providing links to the BCER literature on a particular topic or mode of instruction. It may also be useful to the biochemistry education research community because it indicates an uneven distribution of topics about which research has been done. By communicating the current state of the biochemistry education research, it might provide a foundation upon which a search for possible research topics could be built.

To place our results in perspective, we will elaborate on fundamental gaps in the literature as well as directions for new research in line with the recommendations of the National Research Council's Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research (National Research Council, 2012).

Methodology

This study was built upon a framework analogous to that which has been used by Bain et al. (2014), to review educational research in the areas of thermodynamics and, more recently, kinetics. Research studies included in this review included peer-reviewed journal articles and dissertations/theses conducted within the context of college- or university-level courses, concentrating on undergraduate education. Courses were included that were intended for interdisciplinary populations or as well as those that focused on the needs of students enrolled in a particular discipline. To be included, however, courses had to incorporate biochemistry as a significant portion of the curriculum.

The studies included in the analysis were carried out during, before, or after a biochemistry lecture or laboratory, and involved qualitative, quantitative, or mixed methods approaches. These studies primarily examined student understanding, different approaches to instruction, and the validation of measurement instruments for assessment.

While looking for literature that could (or should) be included within the category of “biochemistry education research,” it became apparent that there were research studies that lacked explicit theoretical and/or methodological frameworks or did not define an explicit set of research questions that guided the investigations. In order to be included in this review, studies had to meet the following selection criteria: (1) a clearly defined topic of investigation, (2) an explicitly stated methodology, and (3) clearly presented results.

Literature search

The Initial literature search was conducted using SciFinder (CAS, 2017) as a collective research article data base that has more than 100 million substances and related literature in its registry. Key terms such as “Biochem Education Review”, “Biochem Education” and similar combinations were applied to broaden the scope of the search to avoid missing relevant literature that used alternative terms to those used in the definition of “biochemistry” on sites such as the American Chemical Society’s college-to-career site (ACS, 2016). To further broaden the scope of the literature search, three other search engines were used: Education Resources Information Center (ERIC), Web of Science, and Google Scholar. A total of 1607 references were located using various search terms, which were then narrowed down using the selection criteria described in the previous section. The selection of papers for inclusion in this review was then cross-verified by four graduate students pursuing their Ph.D. in biochemistry education. “Papers that were found to be of relevance were obtained. Each papers’ list of reference were looked at and included in the search for obtaining all relevant references for this review.” Given the extensive nature on biochemistry education literature, we do assume we have not captured all, however do think we have captured a representable sample size to derive the common themes seen in the areas of biochemistry education we considered reviewing, as outlined above.

Methodological framework

The titles for the majority of the articles initially extracted from the different search engines were entered into NVivo 11 Pro (NVivo, 2017) and then analyzed using the word frequency tool as a step toward creating categories and subcategories for use in this analysis. Based upon the word frequency map and careful, systematic examination of the headings it was possible to take a first step toward grouping papers that discussed similar topics and/or took place in similar settings. The dominant categories into which the papers could be sorted were *teaching*, *learning*, and *assessment* (Figure 1). Qualitative analysis of the contents of the papers revealed that each of the major categories could be divided into the subcategories of *lecture* and *laboratory*. These subcategories could be further divided into content-specific topics such as *inquiry* or *mechanism*. This three-tier organization will serve as the outline for this review, with each topic placed in the context of lecture or laboratory and either teaching, learning, or assessment. One of the results of this phase of the analysis was the recognition of the complexity of biochemistry, particularly with respect to its multifaceted nature and its foundational role in a variety of interdisciplinary curricula such as molecular biology and medical education.

NVivo was then used to create hierarchical query charts, and matrix coding queries that helped to cope with the amount of literature and to get an overview of the frequency with which a particular code could be found in the biochemistry education research literature.

Open-coding involved repeated reading of the titles and abstracts of all references to determine whether the categories and/or subcategories needed to be adjusted. During this process, acquiring memos was used to keep track of thoughts and compare them with the already established analysis through NVivo.

The ASBMB Foundational Concepts

In an analysis of students' beliefs about the nature of engineering, we found that the ABET criteria provided a useful framework for both the analysis and reporting of the results of qualitative interviews (Karatas, Bodner & Unal, 2015). In this study, the ASBMB Foundational Concepts (Mattos, et al. 2013; Tansey et al. 2013; Wright, et al. 2013) served as a scaffold to categorize the topics focused on and difficulties investigated that arose from the body of literature chosen for this review. This framework categorizes concepts prevalent in teaching biochemistry and molecular biology into a hierarchy system. Each reference was critically viewed through the lens of the ASBMB foundational concepts, although it was not always clear in which categories to place topics. Some papers were associated with the closest ASBMB categories, whereas for others we noted that the paper could not be matched to this framework. Consider the topic of "metabolism," for example, which is related to several ASBMB categories for which the foundational concepts framework was not appropriate. Since the framework was primarily used to confirm the existence of certain major categories, this was not viewed as a problem.

Defining biochemistry

Throughout the analysis of the literature, the first step to a working definition of the term "biochemistry" was based on the following description from the ACS website: "… the study of the structure, composition, and chemical reactions of substances in living systems. Biochemistry emerged as a separate discipline when scientists combined biology with organic, inorganic, and physical chemistry and began to study how living things obtain energy from food, the chemical basis of heredity, what fundamental changes occur in disease, and related issues. Biochemistry includes the sciences of molecular biology, immunochemistry, and neurochemistry, as well as bioinorganic, bioorganic, and biophysical chemistry" (ACS, 2016). Because of the interdisciplinary nature of biochemistry, relevant research papers from disciplines other than biochemistry that involved teaching biochemistry as a component, were also considered. The Biochemical Society (2016) reflects the interdisciplinary nature of the field as follows: "Biochemistry covers a range of scientific disciplines, including genetics, microbiology, forensics, plant science and medicine."

Biochemistry education research literature

An overview of trends in the BCER literature

While examining the biochemistry education research literature, we looked for patterns in research articles that fit various categories. We first looked at the three primary categories: course content (regardless of whether it was covered in lecture of in a lab course, lecture, and laboratory environments. Most papers concentrate on the course content without any particular focus on either lecture or laboratory components of the course. About one-third of the papers focused in particular on the lecture, whereas almost one-fourth emphasized laboratory instruction.

The majority of the studies that met the sampling categories for this literature review were done in the United States, although others were carried out in other countries, with a small proportion involved populations of mixed nationalities having been carried out in more than one country. Most studies used quantitatively-oriented methodology, a small proportion used primarily qualitative research methods and roughly the same proportion were based on mixed-methods approaches.

Roughly half of the papers focused on the educational context of proteins. The others were based on context of metabolic pathways, nucleic acids, or various other topics. Some papers examined more than one topic, others were not based on any specific biochemistry topic.

Teaching biochemistry

The instructional environment used to teach biochemistry varies from institution to institution, or between one course and another at the same institution. Some courses contain both lecture and laboratory components, others involve only lecture or only a laboratory component. Thus, it was not surprising to find that some of the research literature does not specify whether the study was done in lecture or laboratory, whereas other studies were done exclusively in either lecture or lab. Because of inherent differences between lecture and lab-based courses, we will separate these two environments in reporting the results of our analysis as best as possible, based on information provided in the research articles selected in this review.

The use of technology in biochemistry classrooms

The U.S. Department of Education begins a discussion of the use of technology in teaching and learning by noting:

> Technology ushers in fundamental structural changes that can be integral to achieving significant improvements in productivity. Used to support both teaching and learning, technology infuses classrooms with digital learning tools, such as computers and hand held devices; expands course offerings, experiences, and learning materials; supports learning 24 hours a day, 7 days a week; builds 21st century skills; increases student engagement and motivation; and accelerates learning. Technology also has the power to transform teaching by ushering in a new model of connected teaching … [that] … links teachers to their students and to professional content, resources, and systems to help them improve their own instruction and personalize learning.

Without commenting on the strengths versus weaknesses of various approaches to integrating technology into the biochemistry classroom, we noted studies of the use of videos, clickers and games in both classroom-based and online settings, but only within the context of the biochemistry lecture, not the lab.

Dash et al. (2015) investigated the efficacy of a video about “fatty liver, designed and used as a model topic with clinical relevance”. The video was played to Bachelor of Medicine and Bachelor of Surgery (MBBS) students right after they received a lecture on the same topic to enhance cognitive processing skills as well as learning in a medical class setting. The students responded positively toward the utilization of the video in class when a technique known as a retrospective pre-test (Lamb, 2005) was used, which asks participants after a class or workshop to reflect on what they knew before and then after they were exposed to the material covered. This study concluded that well-designed multimedia tools can be helpful if used wisely. Moreover, cognitive processing and working memory capacity can be advanced by using multimedia tools.

Schoenfeld-Tacher et al. (2001) studied cognitive abilities and learning outcomes from the use of multimedia in a biochemistry course using a goal-based scenario program. Demographic variables included “… gender, ethnicity, prior science coursework in college and high school, final score in current chemistry course, and prior experience with computers,” whereas the cognitive variable concentrated on “… logical thinking ability, spatial ability, and disembedding ability.” The only factor that correlated with learning outcomes was logical thinking.

Shaw & Molnar (2011) noted that use of lecture-capture technology in podiatric medical education resulted in significantly higher student test scores on biochemistry content material. Interestingly, non-native English speakers benefitted significantly more from this technique than native speakers.

Miles and Soares da Costa (2015) investigated the usefulness of clickers on student engagement and performance in classroom-based and distance education lecture settings. Both cohorts viewed the use of clickers as fun and beneficial. In fact, students expressed the opinion that clickers were under-used during lecture.

Shi, Knight, Chun, Guild, and Martin (2017) realized the benefit of multiple different assessments within one course period, to remediate students’ misconceptions. In their study, they used pre-class assessment questions to see where students understanding stands in regard to molecular movements. With that knowledge, they created in-class clicker questions to shape students furthermore and continuous understanding towards more sound answers. At the end of the that unit, they tested their students’ knowledge by confronting them with exam questions that reiterated concepts on molecular movements they were exposed to during the pre-class assessment as well as the clicker questions. In their study, they did use two-tier clicker questions, containing a multiple-choice section as well as a reasoning free response section. Students revealed a drastic improvement in conceptual understanding of the topic tested. Shi, Knight, Chun, Guild, and Martin (2017) suggest that bringing in clicker questions in a way to remediate misconceptions detected through a pre-class assessment does tremendously help to correct students’ unsound ideas about topics centered around molecular movement, presumably also other scientific concepts.

Vanderlelie (2013) suggests that incorporating an additional multimedia-based group project does help students to understand metabolic pathways in biochemistry. The group assessment consisted of designing a 5-minute creative multimedia presentation centered around the topic metabolism. The groups consisted of about 5 students each. In addition to the suggested learning benefit, students found the task to be ‘fun’ as well and beneficial to them.

Gunersel and Fleming (2014) used a mixed-methods approach to study the effectiveness of bio-organic reaction animations in four biochemistry classes at different institutions. They noted improved student performance relative to traditional instructional methods in three of the four classes.

In general, research on the use of technology in biochemistry courses suggests:

- Using a video in class can improve working memory capacity and cognitive processing (Dash, et al. 2015)
- When lectures were videotaped and provided to students online, student test scores improved significantly, with a more significant benefit for non-native English speakers (Shaw & Molnar, 2011)
- Within the context of multimedia instruction, logical thinking was the only factor related to learning outcomes (Schoenfeld-Tacher, et al. 2001)
- The use of clickers in distant and non-distant learning is fun and beneficial to students and from the students’ perspective, could be used more in classes or online (Miles and Soares da Costa, 2015)
- The use of reaction animations can lead to improved student performance (Gunersel & Fleming, 2014).

Terrell and Listenberger (2017) used molecular visualization to investigate its effects on student facilitation with computational tools as well how suitable it is to explore protein structure and function. With this multiweek, inquiry based molecular visualization project for a Biochemistry I course, they seeked to explore a virtual approach to help students understand multiple levels of protein structure analysis. The topics that were investigated were centered around cyclooxygenase (COX) enzymes. With the use of a mixed methods approach, using a pre- and postsurvey, they were able to demonstrate student gains in knowledge about COX enzymes as well as a boost in their confidence using online databases as well as computational tools in their biochemistry course. Again, this approach shows that even with virtual support of visualizing the unseen concepts biochemistry is built upon, student do benefit from incorporating technological methodologies like molecular visualization tools in the classroom.

Prakash et al. (2017) investigated the usefulness of podcasts in classrooms, with a particular focus in learning biochemistry for medical students. Their podcasts were addressing two topics (centered around fat soluble vitamins and also heme metabolism and disorders of hemoglobin) in a biochemistry lecture and each under three minutes long. Results reveal that students find these short podcasts useful and convenient to use. Interestingly enough, the overall mean scores when looking at students’ grades did not improve when students used the short podcasts, however, through pairwise comparison they were able to reveal improved scores for students who used the short podcasts for both topics. Overall, students conceived short podcast useful as supplementary tools in learning topics in biochemistry, especially using them to review material and prepare for assessments.

The use of technology in biochemistry laboratory teaching

The use of phones in teaching is slowly but surely becoming more interesting through the development of strategies how they can be integrated. Van Dyke and Smith-Carpenter (2017) developed a so called digital laboratory note (DLN) to be used in upper-division undergraduate biochemistry laboratory courses. This technology (e.g. using the Cloud) enabled students to bring their own phones to class. Through this 'own-device' accessibility, students reported in a post-semester survey that the collaboration among peers and also instructor was greatly enhanced. Their survey also showed that 70% of the students would want to keep working with DLN instead of using a traditional paper notebook. The authors also point out that in a world of digitalization, using devices such as phones will help in the future to prepare the students better to move on with the notion of digitalization in all sectors of healthcare and industry in particular.

Learner-centered approaches to teaching in biochemistry classrooms

Anderson (2007) began a very useful stream of papers on the issue of bridging the gap between the results of educational research and teaching practice by noting:

> There is a large body of educational research results available in the science education literature that could be usefully applied for the improvement of teaching practice in biochemistry and molecular biology. Unfortunately, for a great variety of reasons, such applications are relatively limited in our discipline. In this first paper in the series, "Bridging the Gap", I describe some of the barriers that are hampering the bridging of this gap and suggest some possible strategies that colleagues might wish to try in order to promote the wider use of this excellent educational resource.

The search for learner-centered techniques for teaching is not new, it has been over 30 years since our group tried to describe a new approach to thinking about teaching and learning based on the constructivist theory of knowledge [Bodner, 1986] and 25 years since we advocated new approaches to teaching by arguing that the problems students encounter when they enroll in our courses cannot be solved by yet another round of the seemingly endless process of just changing what we teach, without worrying about how we teach it (Bodner, 1992).

A series of biochemistry education research papers have appeared, primarily in the last 10 years, on new approaches to teaching the content associated with biochemistry courses. There has been a particular emphasis in this work on the use and effectiveness of interactive teaching approaches as well as an emphasis on introductory courses, with special attention to the general topic of structure and function.

Bevan et al. (2014) compared an interactive teaching approach versus a didactic, lecture-based course approach in terms of both surface-level and deep learning in different classroom settings. They concluded that the traditional lecture setup encourages students to adopt a surface-learning approach, whereas if biochemistry taught in a more engaging way that utilizes different forms of assessment, it resulted in deeper levels of student learning. The benefit of interactive environments was also studied by Conway (2014) who compared students' performance on exam grades and final course grades taught by lecture, lecture/guided inquiry, and guided inquiry course formats. She concluded that students' performance using guided inquiry instruction using POGIL materials or even partially guided inquiry approaches was significantly better than students taught by traditional lecture techniques.

Goeden et al. (2015) examined the effect on the teaching/learning of biochemistry of using an inquiry-based community approach that used case study activities that addressed "authentic community needs" and found statistically significant improvements in students' critical thinking. This approach was particularly beneficial for the women and for students who did not self-identify as "Caucasian."

Kulak, Newton, and Sharm (2017) studied the success of using case-based learning (CBL) on knowledge retention of key concepts in biochemistry. CBL desires to increase knowledge retention and interest to deeper learning. In their study, they looked at a CBL course as well as a non-CBL course and compared the knowledge retention in both of those courses centered around the topic of metabolism. By using a quantitative approach, the Revised Two-Factor Study Process Questionnaire, which is a retention test, was administered to detect differences in learning retention. They were able to see a significantly better result on the retention test in the CBL class than compared to the control group. Also, they were able to report "[…] a positive correlation between a deep learning approach and higher retention scores." Their results should encourage instructors to make more use of the CBL technique, to improve student learning in biochemistry.

Case-based learning has also been proven to be thought of being useful by students. Students do support the assumption that it enhances group discussion and interpersonal skills (Naveed, Bhatti, & Malik (2017)).

Not only do many new teaching methods approach learning from a group-work perspective, we know today that enhancing group work activity does show a positive effect on student learning. Stockwell, Stockwell and Jiang (2017) investigated, in a randomized controlled trial, the benefit of small group work versus individual work. In their assessments, they had both groups answer recall questions as well as predict questions. They found out, that both groups performed similarly answering the recall questions, but the individuals working together in groups performed significantly better than their colleagues who did work on their own. These results encourage to incorporate more active learning engagements of students into nowadays biochemistry lecture.

Loertscher et al. (2014) studied a community of practice [Wegner, 2000] that consisted of faculty working together to design active-learning classroom activities to improve student learning of concepts of protein structure. They found that student understanding of these concepts was improved by the use of these POGIL-oriented activities.

Fernández-Santander (2008) studied cooperative learning sessions designed to emphasize teamwork, responsibility, as well as communication skills. During the cooperative learning sessions, students worked together in groups. These sessions were followed by short periods of lecturing, as need, to clarify misunderstood concepts. The students found this approach to be more satisfying than the traditional lecture because they felt more involved in the learning experience.

Anderson et al. (2005) investigated a learning environment that involved cooperative learning, problem-based learning, and inquiry-based learning. They noted improvements in student performance in terms of specific content knowledge and problem-solving skills as well as students' opinions of the course when these techniques were implemented in an introductory biochemistry class.

Cowden and Santiago (2016) studied the effect of implementing a problem-based learning (PBL) approach (White, 2002). The problem-based learning activity centered on a literature search, which was facilitated by including a librarian in the instructional team. They noted that the PBL approach had the potential to improve students' research skills and multidisciplinary thinking.

Bobby et al. (2006) probed the effect of incorporating cooperative learning beyond the traditional classroom environment. They work focused on the effect on students' retention of knowledge/understanding when the students worked together to study and discuss short-answer questions (SAQs) that the students created as homework and then discussed with their peers. The formulation and discussion of SAQs lead to a significant positive change in students' performance on exams for all groups in the study, regardless of whether they were low, medium or high achievers. High achievers benefitted more from formulating SAQs than from taking part in the discussion, whereas low and medium achievers benefitted more from small group discussions than high achievers in general. After 15 days, all groups showed improved retention. The study by Offerdahl and Montplaisir (2014) that will be discussed in another section has also shown the benefit of student-generated questions.

The call for making our classrooms more interactive is heard all over the world. Yan, Ma, Zhu, and Zhang (2017) implemented a Hybrid-PBL curriculum, that combined problem-based learning (PBL) with traditional lectures. Examination scores as well as students' perceptions on the use of this new style of teaching was assessed between treatment and control group (no PBL received). Their student cohorts were medical international students. Their results show that this population was agreeing that the Hybrid-PBL style was a good addition to the traditional lecture style courses have been taught in so far. Their study also revealed, that with the change of teaching style, students gained more biochemical knowledge and an improved understanding of biochemical topics.

Cicuto and Torres (2016) looked at the effect of an active learning environment on students' motivation. Their approach involved using study periods that involved group work supervised by teachers and teaching assistants and discussion groups that involved discussions of solutions with peers designed to reach consensus as a substitute for their lecture classes. This learning environment led to students' valuing achievement (working harder to "learn") over performance (trying to get "good" grades).

Zuidema and Herndon (2016) tried a new approach to teaching that involved using the *Poisoner's Handbook* to introduce the origin of forensic chemistry and the use of toxins to students. The effect of this approach was investigated through student feedback, which suggested that this was a "… tangible starting point for several different conversations throughout the course". Their survey revealed that using the book to introduce a biochemical topic was good "… to spark interest in the forensic and medicinal chemistry of poisons".

Orgill and Bodner (2004, 2005, 2007, 2015) studied the range of experiences students have with analogies in a biochemical context. They found that both students and their instructors use analogies in many different ways to enhance understanding, visualize new material, recall information, and also as motivation in their class. Instructor and student use and intention of analogies, however, did not necessarily correlate with one another. While both students and their instructors respond favorably to the use of analogies in biochemistry, this work emphasized the importance of making sure that the limitations of these analogies are adequately explained. They also found that not understanding an analogy until students started to study for an exam was a very common theme in classrooms.

Forbes-Lorman et al. (2016) probed the impact of the use of hand-held physical models on students' three-dimensional mental models of the structure of biomolecules and their ability to logically predict structure-function relationships. They found a significant improvement on quiz scores for females, whereas no effect was detected for males. Females also showed an awareness of the benefit of the use of physical models in the form of self-reported learning gains within the context of protein structure-function relationships.

Cooper and Oliver-Hoyo (2017) investigated the improvement of understanding the relationship between structure and property. Within their study, they designed four unique 3D physical models to focus on student understanding of electrostatics as well as noncovalent interactions and how those properties are linked to macromolecular structure. Their models target specifically the areas of "protein secondary structure, protein tertiary structure, membrane protein solubility, and DNA structure." Through physical manipulation of these models, they found that understanding of complex protein structures can be improved. In addition, by using the Behavioral Observation of Students in Schools (BOSS) protocol, they were also able to monitor students' behavior when interacting with the newly created devices. Their created models were able to let the student work alone and figure out protein structure properties mostly on their own with minimal help from their instructor. The models helped the students to connect the rather abstract concepts with the reality going on in macromolecular structures such as proteins and DNA. This paper, again, highlights the fact that introducing students actively to abstract concepts with hands-on approaches increases understanding of abstract macromolecular properties.

Gerczei (2016) studied students' change in perception of science when using a mini-conference approach during a biochemistry lecture course. Students in class worked in groups on research topics to present in a format that was closed aligned with the structure of a conference poster session. Retaining the spirit of conference format, students' grades were determined by peer evaluations and not by the instructor. In this study, the authors were able to distinguish between non-STEM and STEM majors. For non-STEM majors, there was a significant positive benefit from the mini-conference as well as significant improvement in their view of the nature of science, but there was no change in the students' interest becoming a STEM major. STEM majors, who started out with a more positive attitude about science coming into the project, enjoyed the task and acknowledged the value of the peer evaluation process.

Mallick and Ahsan (2017) tested if students were more engaged and learned more in traditional lecture if an additional learning task was completed before lecture was attended. In their study, they gave one cohort of students a laboratory report to work on before lecture and one cohort attended lecture with no given task prior. Mallick and his colleague were able to show that having completed the active learning task of interpreting laboratory reports before attending lecture helped them greatly to learn the material better as well as increased their confidence in answering question. Their assessment entailed short answer questions as well as multiple-choice questions. The test was administered after lectures were completed.

Games in classroom settings can be helpful for students' learning topics, especially when memorization is the key to intake the new information. Ooi and Sanger (2009) looked at how they could teach biochemical pathways through the implementation of a game during lecture. Their goal was to use the game approach to keep students' interest up and lead them through the process of learning new metabolic pathways easier. The game was designed for pairs of students. Each partner had a metabolic pathway taped to their back and by asking each other, each partner had to figure out which pathways was taped to his or her back. Only yes and no questions were allowed. The effectiveness of this hands-on game was tested by a pre- and post-test setup. The tests investigated students' ability to answer questions centered around 10 biochemical pathways that were the focus of this learning unit. The 10 biochemical pathways included: glycolysis, gluconeogenesis, aerobic respiration, anaerobic respiration, citric acid cycle, electron transport chain coupled to ATP synthesis, cori cycle, glucosealanine cycle, pentose phosphate pathway, glycogenesis, and glycogenolysis. After playing the game for two hours, students took the post-test assessment. This study was run over several years and a total of 172 students were involved. The results indicated, that students gained knowledge in the areas tested and reiterated during the game. Students showed a significant improvement in performance on the post-test after playing the game. Ooi and Sanger (2009) believe that the difference in performance before and after playing the game was due to students' active engagement when playing the game and learning the pathways.

The study by Schoenfeld-Tacher et al. (2001) discussed previously also probed the effect of games. This study used a goal-based scenario (GBS) game that dealt with a crime investigation centered on the topic of DNA. As noted previously, they observed a relationship between learning outcomes and logical thinking ability.

De Fátima Wardenski at al. (2012) looked at blended learning that combines text-based asynchronous technology with traditional face-to-face instruction. Students found blended learning to be motivating and believed it helped them learn the material. The students also expressed interest in using blending learning as a tool for communication with fellow students in the biochemistry class.

Anderson and Grayson (1994) studied an alternative teaching approach to promote understanding over memorization, focusing in this trial on the topic of carbohydrate metabolism to "… reduce the necessity for excessive rote learning". They identified specific course goals, designed problems centered on these goals, and encouraged students to reflect on their progress. In the course of this study they identified difficulties associated with carbohydrate metabolism to further improve their alternative teaching approach further. The success of their revised course tasks was measured by improved scores of students throughout the class period.

Both extremes – Online and inverted biochemistry teaching settings for laboratories and classrooms – what we have investigated so far:

Through all transition from traditional to flipped classroom settings and fully online classes, research so far has shown that students do enjoy instructor contact and do learn most effectively through student-centered approaches. In the spirit of our globalized world and including also students from further away or students who's schedule does not allow to participate in a course, online courses have proven to be an option, however, not the best one possibly out there so far to teach biochemistry. Ahern (2017) introduced an approach to compare online and in-class biochemistry lectures with each other. He assessed online versus in-class sessions through test performances as well as students' satisfaction. His results could not reveal any significant advantage of the online biochemistry course over the in-class course. This being said, he emphasized the fact that his study did suggest that students receive comparable quality teaching through the online setting, which results in reasonable learning outcomes and positive satisfactory scores on the course evaluations. He highlights the fact that in his next steps he will include inquiry-based learning approaches in both forms of biochemistry teaching, to have a more student-centered approach and enhance student learning more effectively.

Clark and Edwards (2017) designed a virtual laboratory around the topic protein purification. Their intention was to find a solution to incorporate more laboratory time into lecture and expose students with different media to the same topics. Students were given a defined time period to work on an online protein purification task. Students could show in the final exam, that key concepts such as pH and charge of proteins when being purified were able to be linked and prompts were answered correctly by 2/3rd of the student population being tested. Their test results are consistent with attitudinal survey data, that showed that students were feeling confident about these key concepts. In order to make further claims about the usefulness of this exercise, further learning gains have to be investigated that this task may offer, as well as results should be compared to a control group to see the task's effectiveness.

Kühl, Toberer, Keis, Tolks, Fischer, and Kühl (2017) designed an inverted classroom (IC), another description for a flipped classroom, as method for a competency-based biochemistry course for medical students. Their intentions were to increase the relevance for biochemical topics for those students, who often find biochemistry not directly related and relevant for their future on-the-job-use. Questionnaires to capture their satisfaction and exams to give insights into their learning gains were administered. A control group, receiving the same materials but not in an inverted classroom setting (no material was handed out prior to be investigated in the self-learning phase) was included. Their results reveal, that students in the IC group were more motivated than students in the control group, as well as were recognizing the relevance of the topics taught. In addition, exam performance improved and learning of the biochemical material was enhanced. The authors also based this success on the fact that students in the IC group did much more enjoy the course than the control group did.

Muth (2016) reported on his experience with teaching a liberal arts biochemistry course for years the traditional way and then for several years in a flipped classroom setting. In his paper he shared that the level of difficulty of questions asked in the flipped classroom setting was higher than in his traditional way of lecturing prior. In addition, his students reported beneficial gains in terms of problem solving skills, communication skills, as well as learning how to work in groups. He felt that besides all the work that he had to put in to make the flipped classroom transition, it was worth it.

In the context of looking at how active our biochemistry classrooms have become over the past years, we also need to consider in which classroom environments our biochemistry faculty are able to teach their lectures in, especially, if they have active learning classrooms (ALCs) available to them. Ramsay, Guo, and Pursel (2017) were able to show "[…] that in ALCs, faculty are easily able to design "activity strings," multiple active learning activities knitted together within the same instructional period. Further, over time, activity strings become regular occurrences, manifesting as "instructional routines"."

Laboratory practices

Biochemistry education research that has focused on the laboratory setting exhibits patterns that are similar to those seen in studies of lecture-based instruction. Both research streams have concentrated primarily upon the topic of structure and function, with particular emphasis on proteins and, to a lesser extent, DNA. In much the same manner as the work done on teaching and learning in the lecture, only a few studies of laboratory-based instruction did not focus on one particular aspect of the content material of a biochemistry class (Coleman, Lam, & Soowal, 2015; Pogačnik & Cigić, 2006; Streu, et al., 2016). Nevertheless, new branches of research appeared in this domain that investigated alternative approaches to biochemistry laboratory including early research-like experiences for students and inquiry/discovery based activities.

Murthy et al. (2014) developed an inquiry-based approach to the laboratory course that emphasized "… active student participation, evaluation of data, and critical thinking …" The first part of the course introduced students to open-ended experiments involving common biochemistry/molecular biology techniques, while the second part focused on an original research project. Students did not focus only on their own results but also incorporated results from students in their laboratory group. Student self-assessment of learning gains through (SALG) were used to study the effect of this intervention and the authors noted improvement in hypothesis development, project design, and critical thinking.

Cook et al. (2015) also implemented inquiry-based learning activities to engage students more in the learning process with the goal of boosting students' confidence in trouble-shooting in a laboratory setting. Students were taught tools and skills needed to use PCR techniques, but then did experiments of their own. Using a pre-test/post-test design, they found significant improvements in both students' perceptions of their knowledge acquisition and their confidence in trouble-shooting and solving problems in the laboratory.

Gray et al. (2015) provides an example of both inquiry-based approach and bringing research into the classroom laboratory environment with the goal of improving students' content knowledge and their self-confidence. Their laboratory curriculum used a combination of experiment and computation to examine the function of a protein based on its three-dimensional structure. The first half of their two-semester laboratory sequence focused on teaching biochemical techniques that were then used in the second semester to perform individual research experiments. The goal was to model the challenges researchers face, including working alone, working in groups, data analysis, and communication of results both orally and in writing. Their study examined the effectiveness of their new course material in terms of student performance- and content-gain, in a self-assessment environment using a pre-/post-course survey (SALG). They found a positive effect on the understanding of biochemical concepts, laboratory/research skills, and attitude/enthusiasm for biochemical research. They also noted increases in scientific confidence, biochemical knowledge, and the ability to work in groups. Pre- and post-course concept inventory tests showed student learning gains and gains in retention of scientific content with this curriculum design.

Silva and Galembeck (2017) also contributed with a mixed-method study to support the use of inquiry-based laboratory sessions in teaching undergraduates. In their laboratory design, students gradually "took" over the experiment, from at the beginning following step-by-step instructions, to at the end designing and carrying out the experiment all by themselves. Through this approach, by collecting student in-laboratory assignments and investigating their laboratory report grades over time, they were able to report increasing student skills related to autonomy and ownership.

Knutson (2010) also developed a year-long laboratory curriculum which centered on similar topics and had a similar structural layout than in the study described above by Gray et al. (2015). Their laboratory design also followed the independent researcher approach in guiding students in establishing a set of skills and pursuing a research project on proteins by themselves, gaining scientific skills along the way such as laboratory skills, taking ownership, making choices for their experiments. Their formative assessment revealed gains in laboratory skills and critical thinking. The curriculum design was perceived very positively by the student population tested.

Lewis, Seal, Lorts, and Stewart (2017) designed a circular dichroism (CD) laboratory experiment to enhance students background in biochemical spectroscopy techniques, that is often lacking in pre-existing experiments addressing this concept. Their pre- and posttest results show significant knowledge gain in the use of DC technology and the administration in a biochemical context when using this laboratory experiment. Of course, once can only for sure tell if this (Lewis, Seal, Lorts, and Stewart (2017) experiment is better over the more traditional, previously existing experiment, if pre- and posttest are also administered in that course and a control group is established, to cross-validate results among different experiments. This statement is true for many research studies that have used a pre-and posttest to claim usage of their developed experimental protocol over others.

Meyer (2015) created a laboratory task that integrated the use of 3D printing of protein models and molecular graphics software to better visualize the topic of protein leucine zippers. What differentiates this work from the many projects whose goal is to improve students' learning and/or motivation was Meyer's pre-test/post-test experimental design to study the effect of the curriculum reform, which demonstrated not only positive feedback about the new laboratory activity but evidence that students reported improve skills at imagining 3D structures of proteins on a molecular level and that they also felt more comfortable talking about topics such as 3D structures and protein folding. Roberts et al. (2005) also noted the benefits of using physical models to improve students' ability to visualize 3D structures on the molecular scale.

Pennington et al. (2014) focused on improving students' understanding of the 20 amino acids and the identification of the one-letter abbreviation using a game similar to "Hangman." By approaching the topic of amino acids in a more versatile way with significant student involvement and active engagement, they were able to report an immense improvement in memorizing amino acid structures and identifying them and a positive student attitude toward the game. They noted that their "game" can be used in a variety of settings in the biochemistry curriculum. It is suitable to "kill time" during incubation periods or as a reminder throughout a biochemistry course. The authors report students had a positive attitude towards the game.

Roche Allred, Tai, Lowery Bretz, and Page (2017) designed a biochemistry laboratory experiment using PyMOL to investigate pH effects on noncovalent interactions in proteins, specifically immunoglobulin G and Protein A. Their activity indicated that students' overall performance in respect to their ability to highlight and label successfully noncovalent interactions improved. However, in parallel they uncovered students' difficulties with analyzing the influences of varying pH/pKa conditions on noncovalent interactions. Students found the task as valuable and challenging at the same time. The material they designed includes a molecular visualization video, noncovalent interactions video as well as prelaboratory questions. Their novel task intends to teach pH/pKa along with the concept of proteins. Both topics are usually taught disconnectedly.

Hall and Vardar-Ulu (2014) developed a laboratory activity that focused on guiding students' learning with an instructor-created template. The goal of their study was to give students the opportunity to "… focus on quality observations, careful data collection and thought processes surrounding the chemistry involved". Frequent feedback on students' work in a collaborative environment was one of the key features of their laboratory innovations. Their laboratory session was divided into four stages: pre-lab work, an in-lab discussion, in-lab work, and a post-lab assignment. One of the ways they incorporated technology into the course involved providing students with the opportunity to record their laboratory notes in an E-Notebook during the lab session. A survey of the students indicated a higher level of satisfaction with the introductory biochemistry course that was also reflected in a statistically significant improvement in the quality of the students' work.

Attention has been paid in recent years to the idea of incorporating authentic research experiences into the undergraduate lab (Weaver, Russel & Wink, 2008). Being involved in authentic research in the introductory course has been viewed positively by both STEM and non-STEM majors. Horowitz et al. (2014) studied the effect of providing students in undergraduate biochemistry course with an authentic research experience by asking students to start with the electron density map from a crystal structure and some indication of the N-terminal amino acid, to determine the original sequence of amino acids. They noted that more than half of the class were able to recover the original structure, sometimes getting better structures than those that had been published. The students were not able to identify many of the finer details of the structure with respect to hydrogen bonding and hydrophobicity.

Streu et al. (2016) investigated a biochemistry laboratory activity that involved having students synthesize an organic compound and then test its biological activity. The laboratory environment modeled a research-based experience for students. The lab was done by students working in groups and concluded with a formal written laboratory report. The goal was to discover the optimal procedure for the experimental steps, which meant that the outcomes of the experiments were not pre-determined. This left students with an unsure feeling of the "success" of their work, but more closely replicated an authentic research-based experience. Survey results suggested student gains in "… understanding of the concepts of Michaelis−Menten kinetics, understanding of the experiments and calculations required to determine the kinetic parameters of an enzyme, and confidence in performing experiments with an unknown outcome."

Wei et al. (2015) focused on enhancing students' exposure to research-like experiences by centering their laboratory around lysozyme and its inhibitors. Using PyMol as a 3D visualization tool, the students could improve their understanding of the actual binding interactions. In order to characterize concepts not understood by most students before the start of the experiments, an online Background Knowledge Probe was administered along with a pre-test/post-test Readiness Assessment Tool, which is a technique used at various levels from the classroom to the governments in OECD countries to probe how prepared the students (or the organization, country, etc.) is to make major changes (RATs).Students with no prior knowledge in isothermal titration calorimetry (ITC) do benefit from the developed laboratory experiment. Through the RAT assessment, students' ability to make reasonable arguments was measured. Mostly students were able to reason in a scientific way about concepts tested.

Boyd-Kimball and Miller (2017) redesigned a biochemistry laboratory which was previously outlined as a cookbook more towards a true-research-like experience for students, by integrating team-taught and project-based components, with more freedom for students to design their own experiments as well as troubleshoot their experiments themselves. In their guided-inquiry-based study, through a pre- and postsurvey, they found out that students' confidence, in regard to process skills required for self-directed research, was again raised through this approach. With their study, they want to inevitably encourage fellow instructors to incorporate more active laboratory experiments into their classroom, promoting guided-inquiry teaching.

Cook, Hannon, Southard, and Majumdar (2017) contribute supportively to the claim that more research-like laboratory experiments, compared to pure cookbook experiments, do positively reflect on students' learning attitude towards "doing" science. In their study, they presented a new laboratory experiment, using small laccase (SLAC) from *Streptomyces coelicolor*, to combine concepts from biochemistry and molecular biology. Their pre- and post- student assessment has resulted in an overall increase in enthusiasm students show towards acting out such an experimental procedure on the topics of modern protein chemistry, as well as in learning the material.

Miao and Thomas (2017) looked at students' performance when using a more research-like experiment, by including primary literature in their laboratory experiment. Through the administration of a pre- and posttest over three years, they were able to see a significant improvement in student learning related to laboratory topics taught.

Lipchock, Ginther, Douglas, Bird, and Loria (2017) designed a Cure -based 10-week laboratory, centered around mutagenesis and the impact on enzyme functionality. Their intention was to offer an alternative way of teaching laboratories in biochemistry, to come again closer to a research-like experience to prepare students better for their endeavors beyond a classroom, may it entail becoming a scientist or an informed citizen. Their study verified that with their developed CURE-based laboratory tool, students performed significantly better on questions related to protein structure and dynamical aspects. This conclusion was drawn by examining students' exam performance on specific questions related to the topics investigated. In addition, through an anonymous survey at the beginning and end of the course, students showed statistically significant changes in their knowledge about e.g. the relationship between structure and function in enzymes, protein motion in enzyme function, as well as increased confidence in analyzing and interpreting data resulting from biochemical experiments. In addition, through the use of a pre- and post- content assessment, the authors wanted to seek clarity if this newly developed tool, which revealed this could also help students apply and transfer their knowledge to a new system. They were able to proof, that students improved statistically significant on applying their newly gained knowledge successfully in a new context.

Cookmeyer et al. (2017) do support the movement from cookbook to research-like experience laboratory tasks as well. Through presenting their newly designed protein-protein interactions, team-based biochemistry course (a CURE practice), they again, follow also the trend of more hands-on student involvement in research-like experiences.

Van Dyke, Gatazka, and Hanania (2017) stress the point in how necessary it is, for scientists working at the interface of biology and chemistry, to integrate their research into their teaching, to "become holistic teacher-scholars." With the implementation of course-based undergraduate research experiences (CUREs), an innovative method was established to offer additional ways of student-centered learning. The five defining characteristics of CUREs are: "significance, scientific practices, discovery, collaboration and iteration."

To sum-up, course-based undergraduate research experiences (CUREs) are impacting undergraduate students' biochemistry experiences and helping to approach pedagogical goals. They are now widely used and added to the pool of useful tools to teach biochemistry to undergraduate students. Another move has set in place where so called community resources "CoRe" projects can be used to increase student-generated contributions to a pool of digital community resources. Haas, Heemstram, Medema, and Charkoudian (2017) have elaborated on the advantages of these CoRe, that represent a class of CUREs, being less resource-intensive than laboratory-based CUREs as well as having the benefit of allowing the students "[…] to create rapid and publicly viewable contributions to society." Within their publication, they list available CUREs at the intersection of chemistry and biology as well as discuss two CoRe projects that can be implemented: "bioinformatics annotations and development of educational tools". With their publication, they hope to encourage the use of CUREs as well as CoRe projects and contribute to a positive impact on the future of teaching biochemistry.

Learning biochemistry – skills and knowledge

Starting in the 1960s, Ausubel (1963, 1978) developed a theory of learning based on the assumption that the single most important factor influencing learning is what the learner already knows. According to his theory, meaningful learning within the context of school-based instruction occurs when an individual relates new knowledge to relevant concepts they already know. Learning biochemistry is therefore dependent on students being able to link the material they encounter in biochemistry courses to prior coursework in either the lecture or laboratory settings (e.g., Sears et al., 2007). Many terms can be found in the literature to describe incorrect concepts or ideas students might hold, including preconceptions, alternative conceptions, naïve conceptions, misconceptions, and so forth (Bodner, 1986). Although there are significant philosophical differences that underlay the use of one of these terms versus another, many of these alternative descriptors will appear in the following discussion of biochemistry education research that focused on learning difficulties. Anderson and Grayson (1994) provided a useful perspective from which to view incorrect ideas or concepts student construct when they noted that we can help students remediate incorrect ideas if we can catch incorrect knowledge or conceptual misunderstanding soon after it is constructed.

References in the previous sections used BCER techniques to probe the impact of a project whose primary goal was curriculum change/reform. The literature in this section, is different because the primary focus is biochemistry education research on the learning process, itself. It is interesting to note that all of the research done so far has focused on material from biochemistry lectures and/or the textbook; no research has been reported, so far, that examines learning difficulties associated with the biochemistry laboratory even when studies were done in courses that included both lecture and lab.

Orgill and Sutherland (2008) focused their study on students' conceptions and misconceptions of buffers and buffer problems. As might be expected from the perspective of Ausubel's theory of meaningful learning, they found that students with experience from analytical chemistry had less difficulty solving buffer problems than students who had not taken classes of this nature. They noted the following patterns in students' thinking about buffers in general.

- Students have a macroscopic view of buffers and talk about buffers as if they contained a single substance, i.e., the "buffer."
- They had almost no conception of what is needed to make a buffer; that it cannot consist of any base and any acid.
- Students have difficulty with the concept of weak versus strong acids and bases within the context of buffers.
- They had difficulty understanding how buffers resist changes in pH; buffers were viewed as static systems that stay neutral (e.g., at pH 7)
- Students lack a mental model of buffers.

They also noted the following difficulties with buffer problems.

- Students approach buffer problems as pure mathematics problems, ignoring the chemical species involved.
- The students had difficulties with the following terms associated with buffer problems: *protonated*, *deprotonated*, *zwitterion*, *salt*, *anionic*, *buffer concentration*, and *concentration ratio*.
- They became confused with the way chemical formulas are written for the contents of a buffer and found it difficult to identify the conjugated acid/base pair within a buffer system.

Loertscher et al. (2014) built a nationwide pre-test/post-test study to examine students understanding of the basic knowledge of protein structure and found students had "robust" incorrect ideas about the location of amino acid side chains in the protein a-helix structure. While testing and then utilizing an assessment instrument, Villafañe et al. (2011) identified the following incorrect statements students were bringing up in a variety of topics related to both the structure and the energetics associated with protein function.

- Bond energy: Bond formation requires energy
- Alpha helix: The side chains of the amino acid residues are inside the α helix
- London dispersion forces: A dipole is not involved in the interaction between non-polar molecules
- Hydrogen bonding: All hydrogens are capable of hydrogen bonding

- Free energy: The free energy change for a process indicates whether the process releases heat

The authors noted no change from pre-test to post-test for the α-helix misconception; it remained consistent throughout the course. In a subsequent study, Villafañe et al. (2015) reported incorrect ideas students have that they observed while developing an assessment tool to measure understanding of protein structure and enzyme inhibition.

Schonborn et al. (2002) investigated difficulties associated with textbook diagrams used for immunoglobulin G (IgG). They identified multiple categories and subcategories of difficulties that arose during their study, but focused on three main categories into which difficulties could be grouped:

- Process-type: Misinterpretation of the diagram that led to a misunderstanding of the mechanism represented.
- Structural-type: Trouble reading the diagram and therefore problems with identifying structural features of the antibody-antigen unit represented
- DNA-related difficulties: Students misinterpreted the structure as related to the structure of DNA.

They argued that these problems could be used to raise awareness of the use and introduction of textbook diagrams in biochemistry classrooms and suggested that instructors should explicitly help students interpret these diagrams.

Bretz and Linenberger (2012) developed an assessment, the Enzyme-Substrate Interaction Concept Inventory (ESICI) that helped them identify misconceptions about enzyme-substrate interactions that could be summarized in terms of the following categories:

- The role of shape and charge of amino acids and binding criteria/specificity of amino acids in the binding pocket of enzyme
- The enzyme-substrate interaction and places where the substrate interacted with the enzyme
- The strength of bonds between substrate and enzyme and the process of binding of substrate to enzyme
- Enzyme inhibitions (types and interactions of inhibitors with enzyme and substrate)
- Effect of binding on conformation, the role of the nature of substrates on the enzyme-substrate interaction, and the characteristics of enzymes.

Bretz and Linenberger (2012) noted that "… 85% of students held at least one misconception in three or more of the five categories of misconceptions", whereas "only 3 of 707 students correctly answered all 15 items on the ESICI …"

In a subsequent study, Linenberger and Bretz (2014) focused on one specific misconception they identified using the ESICI: "… students' understanding of shape and charge in the context of enzyme-substrate interactions" in order to get a better understanding of the inherent difficulty detected. They noted that students disregarded stereochemistry when looking at enzyme-substrate interactions. The students considered the "complementary between enzyme and substrate," but focused only on charge and hydrogen bonding. Linenberger and Bretz noted that students utilized representations that were discussed and shown in lecture as "conceptual anchors." This is consistent with the observation by Bretz and Linenberger (2012), who saw a discrepancy in how students talked about representations and interpreted them depending on how they were talked about and introduced in class. They suggested instructors talk in detail about how to interpret the representations – noting both their limitations and strengths – that they introduce in order to improve student understanding of these representations.

Linenberger and Bretz (2015) investigated, through the use of clinical interviews and a national administration of their developed Enzyme-Substrate Interactions Concept Inventory, misconception centered around the biochemical concept enzyme-substrate interactions. They revealed several misconceptions centered around the concept they investigated, e.g.: "1) the active site is the only place of interaction; 2) the allosteric site is not a binding site on the enzyme; 3) the specificity pocket is not a binding site on the enzyme; and 4) differentiation between the roles of the active site and specificity pocket."

Anderson et al. (1999) identified reasoning and conceptual difficulties in an introductory biochemistry class within the context of glycolysis and oxidative phosphorylation. The following difficulties were identified in this study:

- Understanding how metabolic pathways function, the essential role of enzymes in advancing biochemical reactions, and difficulties with "localized reasoning" needed to understand the global effects of enzymes within a metabolic pathway.
- Understanding the meaning of such constants as the equilibrium constant, the maximum rate of enzyme activity and its related variables, the mass action ratio, and actual enzyme activity, which were all identified as a source of confusion for students. Students also misinterpreted the effect of inhibition on these variables.
- Reasoning about quantities and their values, e.g., students confused the differences between the value of a function compared with the change in the function
- Conceptions of the meaning of the term *spontaneous* in biochemistry, confusing the meaning of the word in an everyday life context and the scientific context.

The study of students' conceptions of glycolysis and oxidative phosphorylation occurred after the students had been exposed to the basic background knowledge surrounding thermodynamics and enzyme kinetics and how they play into understanding metabolic pathways. The background against which students' misconceptions were identified was a consensus of correct responses developed by experts -- including teaching assistants -- associated with the course.

In an earlier study, Anderson and Grayson (1994) uncovered three more difficulties associated with metab9olic pathways:

- Enzyme inhibition influencing metabolic pathways: Students did not see a problem in pathways continuing to function after inhibitor was added and substrate was removed from enzymatic reactions
- Understanding of the second law of thermodynamics: Difficulties spanned from concept of thermodynamics to concentration and steady-state kinetics, as well as reversibility
- Bioenergetics of pathways: Difficulties with thermodynamics – misleading conceptions about calculations

Oliveira et al. (2003) looked at questions regarding metabolism and its associated ATP production. They asked questions such as: What happens to the overall ATP production in an individual fed a low carbohydrate diet? And: What happens to the overall ATP production in an individual undergoing prolonged (many days of) fasting? Only a small portion of the 304 students in the sample population could answer these questions correctly. Oliveira et al. (2003) found that a significant number of students were not aware of how metabolisms work in certain common live situations, such as dieting or fasting. Misconceptions revealed in this study included statements such as: "... glucose is the only fuel available for ATP production by the cells". This was one of the predominant answers students gave and was therefore considered a misconception. Another interesting misconception identified in this study was the belief that only lipids are responsible for possible weight loss.

Through the use of surveys and interviews, Wolfson et al. (2014) investigated students understanding about free energy and flow in biological and chemical reactions and metabolic pathways. The most prevalent confusion they were able to identify were the following:

- Confusion about the difference between standard-state ($\Delta_r G^{\circ'}$) and actual ($\Delta_r G^{'}$) free energies.
- The role of enzymes related to confusion about $\Delta_r G^{'}$ and $\Delta_r G^{\circ'}$.
- The relationship of free energy change to flux through pathways within the context of concentrations relevant for biochemical processes, equilibrium, and irreversible metabolic pathways.

Wolfson et al. (2014) found a variety of student beliefs and sub-categories of the primary incorrect related to the ideas stated above. For example, students had trouble grasping what spontaneous biological reactions entail and what happens when bonds were broken and formed. They noted that the transfer of core concepts such as energy and the role of enzymes as catalysts from introductory physics and chemistry to biochemistry courses is essential but often does not happen.

McPartland and Segel (1986) administered a take-home quiz that brought the difficulties in the following main categories to light:

- The difference between equilibrium constants and equilibrium concentration can be confused when asked as part of a quiz or exam question.
- Free energy changes such as the $\Delta_r G'$ *in vivo* and $\Delta_r G^{\circ'}$ at standard state were mentioned incorrectly when put into a biochemical context.
- The concept of coupled reactions

Some difficulties, especially incorrect ideas tied to free energy changes, were also found in the study by Wolfson et al. (2014). McPartland and Segel (1986) noted, however, that most difficulties arose predominantly when scientific terms were used in a biochemical context. Students were able to define equilibrium constants and free energy, in general, but were not able to use those terms in a context where application and transfer to biochemistry was required.

Misconceptions are not the only "difficulties" it is worthy reporting about. Students taking biochemistry do also reveal a lack on skills in problem-solving. Within Sensibaugh's et al. (2017) study, the Individual Problem Solving Assessment (IPSA) tool was administered in biochemistry courses. This tool tests for "[…] student performance in scientific problem solving […] and […] probing the qualitative nature of unsatisfactory solutions." Within their study, which was embedded in the context of the constructivist framework of learning, they found graduates to being only successful in "[…] evaluating given experimental data to state results and reflecting on performance after the solution to the problem was provided." In addition, they found that the challenge most students shared was to design scientific experiments to rationally align with a hypothesis.

Trends in assessments used in biochemistry education research

Nathaniel Gage has been recognized as one of the foremost figures in the field of educational psychology of his time. Some have gone so far as to identify him as "the father of the field of research on teaching" (Berliner, 2004). Evidence to support this assertion can be found by noting that he conceived of and then edited the first *Handbook of Research on Teaching* (Gage, 1963). It is therefore interesting to note that he felt compelled to write a review on what he called "The Paradigm Wars" (Gage, 1989), the period during which there was a pitched battle between advocates of quantitative research and proponents of qualitative research methods. If there is any doubt that this "war" carried over to the field of BCER, we could cite a review of a paper published in this journal that argued that our work was not "research," but "journalism." Fortunately, evidence to suggest that the debate might have "cooled" to becoming nothing more than a border skirmish might be found in the growing popularity of what is called "mixed methods" discipline-based educational research, which does what the combatants from the 70's and 80's argued could not be done; using both quantitative and qualitative techniques in a single study.

Within the context of biochemistry education research, we noted that two-thirds of the papers published so far used a quantitatively-oriented methodology. Qualitative and mixed methods approaches were used considerably less often. As might be expected, studies that focused on assessment were particularly likely to be carried out using quantitative or mixed methods approaches.

It is easy to understand the inherent assumption of a significant amount of discipline-based educational research across the many fields of STEM majors that the development of tools for diagnosing students' thinking is a key step toward an understanding of how students struggle with the course material with which we present them. From just-in-time assessment to long-term assessment tools, biochemistry education does offer more and more tools to investigate students' knowledge. Through implementation of their survey, Francisco, Bonafe, Ailton, Bispo, and Bispo de Jesus (2017) saw that through the use of the polygonal model, misconceptions were being detected that students held, such as misconceptions related to stereochemistry and some centered around organic groups. This tool might allow just-in-time revealing of unsound conceptions, to prevent manifestation of those. Furthermore, student reported, the model was easy to use, and they chose it over the traditional Fischer projection. Since the polygonal model was tested to represent metabolic structures, it is suggested that it can also be used in teaching metabolic structures.

Anderson, Mitchell and Osgood (2008) reported about the use of interactive online Problem-Based Learning (PBS) case discussions in large biochemistry class settings. They presented a novel way of tracking groups' and individual students' use of PBL methods. Their methods intended to give faculty a tool to intercede in students' development in that area and track their progress. Students first worked on online cases by themselves and were then assigned to online discussion groups in order to solve the given puzzle as a group. Using grading rubrics, they were able to track students' use of scientific reasoning and measure also their contribution and performance. This tool also revealed itself as user-friendly, especially for large classes.

Monitoring problem-solving skills and giving feedback to students on how their progress is within a course is essential to continuously provide the right guidance from the instructor's side as well as providing insights on students how well they are "on track", as found by Mitchell, Anderson, Sensibaugh, and Osgood (2011). With their developed tool, they hope to have created an assessment tool (IPSA= Individual Problem-Solving Assessment) that is attractive for use in large bioscience classes, for formative and summative assessments of the student population in class.

Xu, Lewis, Loertscher, Minderhout, and Tienson (2017) also confirmed the use of multiple-choice assessments for bigger science classes. By looking at multiple sessions of the same biochemistry course, they were able to see an improvement in students' understanding due to the impact on instructional changes made when teaching several sessions of the course. Interventions such as "[…] including targeted changes in lecture content, specially designed clicker questions […]" were included. The instrument, pre- and post-test targeted the following concepts: "(hydrogen bonding, bond energy, pKa, equilibrium, free energy, alpha-helical structure, protein function)", which was originally developed by Villafane and collegues. Multiple-choice questions are a helpful tool to give instant feedback through formative assessment, to make informed decision on how teaching can more effectively improve student earning within the same semester a course is being taught.

Villafañe et al. (2011), for example, developed an instrument to assess student understanding in biochemistry with a focus on the foundational concepts they encounter before they are exposed to biochemistry coursework. As so many papers developing assessment tools for use with biochemistry content materials have pointed out, biochemistry is an interdisciplinary topic that integrates conceptual knowledge from many other fields, particularly the general and organic chemistry courses and a variety of biology courses. The multiple-choice instrument developed by Villafañe et al. (2011) focuses on five concepts from general chemistry: bond energy, free energy, London dispersion forces, pH/pKa, and hydrogen bonding and three concepts from biology: the α- helix, amino acids, and protein function that were chosen because they were considered prerequisite concepts for biochemistry courses. Within the context of this work, it might be useful to consider whether these prerequisite concepts can be considered “threshold concepts” upon which the understanding of biochemistry not only can, but must be built (Meyer & Land, 2006), as cited earlier.

Students’ ability to reason on a lower-level in Bloom’s taxonomy is much likelier than using their reasoning abilities to achieve upper-level reasoning skills in Bloom’s taxonomy – this is what Villafane, Heyen, Lewis, Loertscher, Minderhout and Murray (2015) were able to identify with their assessment tool. The instrument they developed centered around the topic “protein structure and enzyme inhibition”, situated in the novel context of saturable binding. This instrument was tested across multiple institutions. The authors hope that by utilizing this assessment tool will give instructors further insights on how difficulties in understanding can hinder knowledge application centered around the topics protein structure and binding. On a further note, within their study methodology, they made use of a community of biochemistry educators to design the instrument in an iterative process. They suggest that this method, that they found particularly helpful, could help future education researcher to develop other assessment tools which could enrich the body of literature to keep improving students’’ understanding.

Miller and Kim (2017) showed, that an assessment of intermolecular forces, hydrogen bonding, allowed the investigation of representational competence in student responses. This was achieved by their novel use of coupling a “multiple-select format assessment item”, with open-ended responses. In their findings, they see heuristic usage contributing to students’ unsound responses. Overall, they found that the reason for students to continuously struggle with hydrogen bonding could be their poor representational competence to interpret hydrogen bonding representations.

Villafañe et al. (2015) went on to design and test an assessment instrument to reveal students’ conceptual understanding about protein structure and enzyme inhibition within the context of saturable binding. This assessment tool was mapped onto Bloom’s taxonomy of educational objectives created in the 1950s to categorize the levels of reasoning skills needed to answer a question. It is not surprising that this assessment tool suggested that students had trouble with tasks at higher levels of Blooms taxonomy, but not with those that map onto lower levels.

Offerdahl and Montplaisir (2014) developed a formative assessment tool using student-generated reading questions (SGRQs). Their working definition of formative assessment was described as “… any activity that yields evidence of student thinking which feeds back to instructors and students and is subsequently used to adjust instruction and/or learning activities.” The use of SGRQs can help elucidate students’ thought-process about topics as well as connections they make between topics being discussed. In this study, students were encouraged to purse their SGRQs in a way that would let their instructors know what the students felt they need to know more about in order to achieve a deep conceptual understanding of the topic. Their data suggest that SGRQs are a powerful tool to get at students’ thinking. This study also revealed a significant variety of depth in students’ conceptual understanding.

Physics, as the first platform of using concept inventories to assess student knowledge, is by far not the only scientific field where concept inventories are used anymore. Other disciplines such as biology, chemistry and also biochemistry are making a greater use of this assessment tool (Costa et al. (2008)). As noted previously, Bretz and Linenberger (2012) developed a concept inventory designed to test students' understanding of enzyme-substrate interactions that can be used as an assessment tool to probe students' conceptions and/or misconceptions about this topic.

Dos Santos and Galembeck (2015) developed an assessment tool to differentiate between different students' visualization skills within the context of visual representations of metabolic pathways. The test is based on six main visualization skills they identified as key skills needed for understanding metabolic map diagrams. The metabolic pathways visualization skill test (MPVST) not only identifies the visualization skills developed by biochemistry students, it also re-iterates the importance of instructors devoting class time to "explaining visual representations to their students." This work targets a weak point in biochemistry education research whereby we assume that students equip themselves with the necessary skills needed to master a biochemistry class, whereas, in reality, they need more guidance than we assume

Rowland et al. (2011) noted the same challenge in biochemistry courses as Offerdahl and Montplaisir (2014), ensuring that students are able to connect topics taught in biochemistry with other courses that might be prerequisites. They focused on finding new ways to present biochemistry content in terms of "big ideas," to emphasize the interconnectivity of biochemistry with other subjects. They used a survey to identify ideas, terms and concepts that are particularly important in biochemistry, such as: information transfer and storage, thermodynamics and energy, structure/function of biomolecules, regulation, and organization in living systems, and experimental approaches (or disciplinary practice). They then designed a proposed structure for a teaching-module framework for use in an introductory biochemistry course that was based upon these core concepts. They noted that they succeeded in stimulating students to think more deeply and improved students' ability to construct links to the material in other courses.

Following the interest of investigating biochemical literacy, Schönborn and Anderson published 2009 a paper on the development on creating more insight in students' understanding of biochemical representations used in teaching. Through previously creating a novel interview design approach, the "three-phase single interview technique" (3P-SIT), Schönborn and Anderson explored their participants understanding of antibody-antigen interaction. By analyzing their qualitative data gathered, they were able to verify their proposed model of "[…] factors affecting students' ability to interpret external representations (ERs) in biochemistry." With their methodological approach, they were able to validate their model, which consists of seven factors: "[…] conceptual (C), reasoning (R), representation mode (M), reasoning-mode (R-M), reasoning conceptual, (R-C), conceptual-mode (C-M), and conceptual-reasoning-mode (C-R-M) factors." With their model, they hope to add to the understanding of how biochemical ERs can be interpreted and how ERs in the field of biochemistry education can be modified and created.

Linenberger and Bretz (2012) reported on the use of the 3P-SIT methodology to generate cognitive dissonance in students' statements during interviews on enzyme-substrate interactions. Within their study, they were able to report on the 3P-SIT technique to be successful in creating cognitive dissonance between multiple representations when used in interviews. This technique, they claimed, could provide important insight on misconceptions of students, since it probes deeply and effectively for their understanding. Especially in biochemistry, a field that utilizes many representations, could benefit from a technique like that – as a tool to evaluate visual literacy, to move the field of biochemistry forward, toward better and more informed use of visuals in the future.

Not only is it important to identify effective ways of teaching biochemistry to enhance conceptual knowledge gain, it is also imperative to examine the use of instructional tools, such as external representations (ERs), that are used with the goal of promoting learning that often are found not to do so. In her work, Milner (2014) developed a scale to investigate students' attitudes towards biochemical images. She emphasized students' willingness and their ability to use images to support their learning. She also investigated three differences between learners that might have an impact on learning outcomes: students' attitude towards images, their visual cognitive skills, and their learning approach. The results of her study suggested that students the use of images in a biochemical context and they consider their use useful. Her participants acknowledged, though, that the use of verbal explanations was more significant than images alone. Furthermore, this assessment tool revealed that "... there was no relationship between learning outcomes and the students' self-reported attitude toward images or visual cognitive skills," whereas "... learning outcomes were significantly correlated with the students' self-reported approach to learning."

Towns et al. (2012) created a framework for use with external representations that was built upon a combination of Johnstone's representation of the three domains of chemistry (atomic/molecular, macroscopic, and symbolic, see Johnstone, 1991), Ainsworth's functional taxonomy of multiple ERs (Ainsworth, 1999, 2006),and a Taxonomy of Biochemistry External Representations (TOBER) to describe ERs used in the context of biochemistry in order to better understand the strengths and weaknesses of ERs and to determine what knowledge they can convey to students.

In an extensive series of papers, Anderson and colleges elaborate on how to improve biochemical literacy to enhance student understanding of biochemical phenomena. Schönborn & Anderson (2010) offered a guideline on what to check in biochemistry ERs to see if they are clearly understandable and to reduce obstacles that could prevent students from having access to understanding the biochemical concept represented. In addition, they gave suggestion in what assessment questions could be used accompanying biochemical representations, in this case protein representations. Relying on eight visualization skills that are discussed in the article, suggestions were highlighted.

Mnguni, Schönborn and Anderson (2016) investigated visualization skills that students need to successfully process ERs with biochemistry content. Their study revealed 24 cognitive skills, visualization skills respectively. They achieved that through using a modified Bloom's taxonomy. Subsequently, probes were developed based on their previous findings to develop a test instrument. Using the Rasch model, they were able to score and process students' responses. With their approach, they were able to

"[…] rate the degree of difficulty of each visualization skill on a linear scale […]", as well as being able to create a person-item map which measures individual level of visual literacy. With their approach, they were able to rank the visualization skills found according to students' level of difficulty as well as to estimate an individual level of visual literacy per student investigated. This tool bears great potential to accompany many studies that try to improve the understanding of the interpretation of biochemical representations, to further enhance student understanding and remediate difficulties associated with and related to biochemistry literacy.

Great efforts have been made in cataloging well defined learning goals and objectives centered around visual literacy in biosciences, to which biochemistry belongs. It is known that instructors in biosciences do use representations of various kinds to teach, visual literacy does not seem to be taught along with exposing students to different visuals. The authors here present a biomolecular visualization framework which can be used to improve visual literacy by developing effective visual literacy assessments. Dries and colleagues (2017) stressed the fact that novices, amateurs as well as experts make use of a different set of skills when dealing with visuals of any kind. Visuals do have to meet the skill set of the ones being taught, otherwise they are overwhelming and enhance unsound understanding. Furthermore, new and more challenging visuals need to be introduced to a student population carefully, as well as in parallel, skill sets need to be taught to teach how to read and use the visuals presented. In many ways, instructors are not aware of these discrepancies and differences among learners and tools to teach, therefore this framework does give an additional toolbox to draw from when teaching concepts in biosciences, where visuals are essential in making the unseen seen.

Arneson and Offerdahl, based on Bloom's taxonomy, designed the Visualization Blooming Tool (VBT). With this tool, they want to facilitate and help instructors to better design instructions and assessment that specifically target scientific visual literacy, with a special focus on undergraduate education. Their intentions are to bring practice and assessment together and have them as similar strong counterparts, so that learning can occur through using visuals more effectively, in their words: "Using the VBT to craft visual-based assessment items at each cognitive level would provide instructors with a way to assess student mastery of visual learning skills, identify the areas that students find most challenging, and adapt their instructional practices to enhance focus on those aspects of scientific visual literacy".

Students' attitudes/motivation and self-confidence in biochemistry

Various studies measured changes in student attitudes, motivation and/or self-confidence that occurred as a result of changes made in course content, how the course was taught, and/or incorporation of technology into the classroom. Booth et al. (2005), for example, studied the use of software in a biochemistry classroom that could be used to build representations of the molecular structures. They noted that students who used the software to create representations of molecular structures benefitted more than those who just manipulated images they were given. They concluded that students should build structures from the beginning of the course rather than work with pre-delivered images because the more the students invested in the use of the program, the more they got out of its use. They did not, however, see any effect of using the software on students' motivation.

Research has also shown, that students experienced a higher level of satisfaction with the flipped learning classroom compared to the traditional teaching format (Ojennus, 2016). In addition, from a student perspective, the more interactive the classroom environment is the better. This is especially true for medical biochemistry classes (Palocaren et al., 2016).

Motivation and students' enjoyment of a course can be a crucial factor in determining the "success" of either lecture or laboratory courses. As noted previously, Knutson et al. (2010) incorporated by inquiry- and research-based learning into their course to bring the excitement and motivation of research to students in their year-long biochemistry course. They first built laboratory skills on the topic of protein biochemistry and then had the students use these techniques for an individual laboratory project. There was an increase in students' motivation to work in a biochemical research setting. This study also noted that the "free" and interactive learning environment increased students' confidence over the period of the course. Most students perceived the open-ended nature of the laboratory to be enjoyable and it provided the environment to acquire more skills. Later studies led to similar conclusions (Cook et al., 2015; Meyer, 2015)

The expectation that students will acquire skills in the laboratory setting presumes that they come to class prepared to do the work associated with that day's activities. Pogačnik and Cigić (2006) examined ways of motivating students to do the necessary work before they enter the lab. They modified the prelab requirements by requiring students to attend a meeting with the teaching assistant before each laboratory session to go over the procedure, calculation, and interpretation of results needed to complete the lab. Students were also expected to take a quiz before each laboratory unit. They noted that these changes almost tripled the amount of students' self-study before they attended the lab session. They also saw an improvement in students' performance on the final exam and noted that the students felt more motivated and were more successful in the laboratory.

Zhang et al (2017) elucidated in their study how important scientific training can be for test performance and level of confidence for Chinese medial students in a biochemistry and molecular biology course. They were able to proof, by investigating students' test grades, that exposure to scientific training was able to enhance academic performance. In particular, scientific training came in helpful for medical students, for example when studying for biochemistry and molecular biology classes. Not only did test scores improve when being exposed to scientific training, students did also carry out experiments more effectively. Among all these positive effects, students were also reporting an increase in confidence of their learning as well as displayed more interest, were more motivated and capable to succeed in course learning. In their study, they investigated 4 levels of scientific training: (1) only reading literature, (2) reading literature as well as joining in academic activities, (3) publishing scientific reviews, (4) execution of experiments and publishing articles. The more the students were involved in scientific training, especially students engaged on level 4, were more successful in performing well in academia.

Discussion

There are clear patterns in the biochemistry education research literature, so far. Interest in the use of visual images in teaching biochemistry is nothing new; one of the authors incorporated hand-drawn images on a routine basis into the biochemistry lecture and lab courses he taught more than 40 years ago. One can find many articles that discuss the incorporation of visualization into biochemistry courses, using a variety of different forms of technology. But, other than Anderson and co-workers and work cited herein that examines techniques such as molecular modeling, there has not been a significant amount of research that examines the effect this technology has on student learning, attitude, retention of content knowledge, or transferability to other courses of content learned through the use of this technology. Within a research tradition that assumes that changes made in a class are not likely to have a positive effect on all students, there has been relatively little biochemistry education research that differentiates between the strengths and weaknesses of various approaches. And those studies that have been carried out often focus on the training of medical professionals, which can be fundamentally different from the sample population in a typical undergraduate biochemistry lecture and/or lab course. There seems to be abundant room within the CER literature for research that examines both the positive and negative effects on student learning, attitude, retention, and/or transfer of knowledge that results from incorporation of new forms of technology into the biochemistry lecture and/or lab classroom that might augment papers that advocate its use. This research could examine the effect of technology on different student populations, based on gender, ethnicity, native vs nonnative English speakers, and so on.

Over 30 years ago, we began a description of the constructivist theory of knowledge (Bodner, 1986) by noting that "Teaching and learning are not synonymous; we can teach, and teach well, without having the students learn." It is therefore pleasing to note the search for ways of teaching biochemistry that might be more effective and even more pleasing to note that so many studies now include an explicit element of discipline-based educational research (DBER) that probes the effect these new approaches on students' performance, attitude, retention, transfer, and so on. Many of these new approaches to teaching on based on creating an interactive learning environment that often involves cooperative or collaborative learning environments or techniques such as problem-based learning. Others involve incorporating inquiry-based or authentic research approaches into the laboratory. Much of this work presumes that we expect more of our students, searching for ways to foster the development of higher-order cognitive skills, such as critical thinking or research-based thinking, which might not have been an integral component of traditional biochemistry classes. While the ground-work has been laid in many different areas, more work has to be done to better understand how we can improve teaching biochemistry to students. Fortunately, the work done so far suggests that more engaging learning environments give rise to better motivated students who have a more positive attitude toward learning the material we value most. Unfortunately, as Chi and Wylie (2014) point out, there are no rules or guidelines teachers can follow to transform their existing classroom practices into an approach that automatically optimizes "active learning." So more work still has to be done, perhaps, in particular, addressing how to achieve the goals outlined among the ASBMB foundational concepts.

In much the same manner that much the biochemistry education research literature related to the "lecture" focuses on bringing an active learning approach into that environment, the existing body of the research literature that focuses on the laboratory setting emphasizes curriculum reform that incorporates an interactive, inquiry-based approach. One of the interesting features of this work is its tendency to go beyond the goal of "learning gains" associated with increases/improvements in the students' knowledge or understanding. The goal now includes attempts to improve student attitude or motivation, or their ability to apply critical thinking to problems that come up in the laboratory, often by incorporating an authentic research experience into the lab setting. Because of the barriers to bringing model building or manipulating physical models into the lecture, these activities are more likely to found in the laboratory environment. Because of inherent differences between the student populations served by biochemistry lecture versus lab courses, changes in the lecture component of the course are often targeted at health- or life-science students, whereas changes in the lab are more likely to be targeted toward biochemistry majors.

Fundamental differences can be found in the evolution of biochemistry education research when compared with analogous work in chemistry physics and math. As noted elsewhere (Bodner, 2011): "It is almost 60 years since the *Mathematics Teacher* perceived the need to introduce a column on "Research in Mathematics Education" to familiarize its readers with the results of mathematics education research." Discipline-based education research in chemistry and physics can be traced back in time to more or less similar periods, but this work differed significantly from biochemistry education research because it often began with work done by individuals who held faculty positions in a College of Education, where their primary teaching assignment involved working with pre-service K-12 teachers. There was a gradual shift of emphasis toward college-level courses when this research began to be situated in chemistry or physics departments, and then eventually was extended to advanced-level courses (Bodner & Weaver, 2008), where the term *advanced level* could be assumed to apply to the sophomore-level course in organic chemistry. Biochemistry education research is different because, from the very beginning, attention was paid to college-level courses. Thus, it is not surprising that biochemistry education research focused less on identifying student misconception than it did on the application of recent advances in our understanding of how students learned (Bransford, Brown, & Cocking, Rodney, 1999; Cogdell et al. 2012; Maskiewicz & Lineback, 2013).

A significant fraction of the biochemistry education research literature is devoted to assessment. Without referencing a seminal book by Champagne, Lovitts and Calinger (1990) entitled *Assessment in the Service of Instruction*, much of the work that has been done in the area of assessment in biochemistry education is consistent with the philosophy of that book, which begins with an introduction by Shirley Malcolm that argues that assessment should at least: "be free of bias; reflect what is being taught and give us information to improve instruction for a class or to diagnose problems or to identify misconceptions of an individual; allow us to measure the effectiveness of a teacher or a curriculum; reflect what *should* be taught or at least what should be valued." One of the limitations of research on assessment that has been done so far is the reliance on quantitative research methods, rather than the in-depth understanding of student knowledge, attitude, motivation, and retention of information provided by qualitative research methods. (Patton, 2015).

At one point in their evolution, chemistry, mathematics and physics education research each separated themselves from "science education" by recognizing the importance of disciplinary expertise in shaping the guiding research questions that not only could but should be asked and more narrowly focusing the student and/or instructor population this research will examine. No matter how broad or interdisciplinary they might be, biochemistry education research and engineering education research have had the advantage that they can focus primarily (if not exclusively) on college/university level courses. They are ideal topics, therefore, for discipline-based educational research (DBER), which the NRC report entitled *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (Singer, Nielsen, & Schweingruber, 2012) described as having the following goals:

- understand how people learn the concepts, practices, and ways of thinking of science and engineering;
- understand the nature and development of expertise in a discipline;
- help identify and measure appropriate learning objectives and instructional approaches that advance students toward those objectives;
- contribute to the knowledge base in a way that can guide the translation of DBER findings to classroom practice; and
- identify approaches to make science and engineering education broad and inclusive. (p.9)

These goals for DBER make an important point. It is obvious that practitioners of biochemistry education research need to communicate with each, to move this field of scholarship forward. But, they also need to communicate to the classroom instructor, to guide the translation of the results of this research into classroom practice.

As biochemistry educational research develops, it might be useful to think about a model based on five domains (Bodner, 2016). Like so many other forms of DBER, biochemistry education research has looked for gains in students' conceptual knowledge of the content of biochemistry lecture and laboratory courses. But it has gone beyond that to also look at changes in the affective domain, in students' attitudes toward these courses. More attention should now be paid to other questions, such as how to improve the retention of information from one biochemistry course to another. In as much as students often take biochemistry courses because they are required as one component of an undergraduate major, it would be useful for researchers to measure the extent to which biochemistry courses are meeting the needs of students who are required to take them, or, in other words, to measure the extent to which transfer of knowledge occurs between introductory biochemistry courses and the advanced-level courses that built upon this foundation. Finally, whether it is explicitly recognized or not, examples from the biochemistry education research literature can be found where one of the primary goals is to improve the extent to which the student "thinks" the way a practicing biochemist would think.

Another topic that is needed to be investigated in biochemistry education research is transfer of knowledge. Little to no research has been done in the field of biochemistry. Biochemistry, as a science being situated in an interdisciplinary context, is in desperate need of that lens on research. As mentioned in this review already, connecting science fields such as chemistry, organic chemistry, and biology are essential to successfully continue into the scientific field of biochemistry. The most recent DBER report by Singer et al. (2012) also encourages that "research is needed in a wider variety of undergraduate course settings" as well as enhancing the contributions on "interdisciplinary studies of cross-cutting concepts and cognitive processes". This, above all, highlights the interdisciplinary call we should follow as biochemistry educators and be more than encouraged to get collaborations between departments and researchers and practitioners going.

References

Ahern, K. (2017). Teaching biochemistry online at Oregon State University. *Biochemistry and Molecular Biology Education*, *45*(1), 25-30.

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, *33*, 131-152.

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183-198.

Ainsworth, S., Prain, V., & Tytler, R. (2011). Drawing to learn in science. *Science*, *333*(6046), 1096-1097.

American Chemical Society. (2016). What is biochemistry? Retrieved February 3, 2016, from http://www.acs.org/content/acs/en/careers/college-to-career/areas-of-chemistry/-biological-biochemistry.html.html.

Allred, R., Zahilyn, D., Tai, H., Bretz, S. L., & Page, R. C. (2017). Using PyMOL to Explore the Effects of pH on Noncovalent Interactions between Immunoglobulin G and Protein A: A Guided-Inquiry Biochemistry Activity. Biochemistry and Molecular Biology Education, 45(6), 528-536.

Anders, S., Pyka, K., Mueller, T., von Streinbuechel, N., & Raupach, T. (2016). Influence of the wording of evaluation items on outcome-based evaluation results for large-group teaching in Anatomy, Biochemistry and Legal Medicine. *Annals of Anatomy - Anatomischer Anzeiger*, *208*, 222-227.

Anderson, T. R. (2007). Bridging the Gap: Bridging the Educational Research-Teaching Practice Gap. *Biochemistry and Molecular Biology Education*, *35*(6), 465-470.

Anderson, T. R., Crossley, L. G., & Grayson, D. J. (1999). Identifying students' conceptual and reasoning difficulties with biochemistry. *Research in Science Education - Past, Present, and Future Vol.1*, 86-88.

Anderson, T. R., & Grayson, D. J. (1994). Improving students' understanding of carbohydrate metabolism in first-year biochemistry at tertiary level. *Research in Science Education*, *24*, 1-10.

Anderson, W. L., Mitchell, S. M., & Osgood, M. P. (2005). Comparison of student performance in cooperative learning and traditional lecture-based biochemistry classes. *Biochemistry and Molecular Biology Education*, *33*(6), 387-393.

Anderson, W. L., Mitchell, S. M., & Osgood, M. P. (2008). Gauging the gaps in student problem-solving skills: Assessment of individual and group use of problem-solving strategies using online discussions. *CBE-Life Sciences Education*, *7*(2), 254-262.

Arneson, J. B., & Offerdahl, E. G. (2018). Visual Literacy in Bloom: Using Bloom's Taxonomy to Support Visual Learning Skills. *CBE-Life Sciences Education*, *17*(1), ar7.

Ausubel, D. (1963). *The Psychology of Meaningful Verbal Learning*. New York: Grune & Stratton.

Ausubel, D. (1978). In defense of advance organizers: A reply to the critics. *Review of Educational Research*, *48*, 251-257.

Bain, K., Moon, A., Mack, M. R., & Towns, M. H. (2014). A review of research on the teaching and learning of thermodynamics at the university level. *Chemistry Education Research and Practice*, *15*(3), 320-335.

Bell, E. (2001). The future of education in the molecular life sciences. *Nature Reviews Molecular Cell Biology*, *2*(3), 221-225.

Berliner, D. C. (2004). Toiling in Pasteur's quadrant: the contributions of N.L. Gage to educational psychology. *Teaching and Teacher Education*, *20*, 329–340.

Berndsen, C. E., Young, B. H., Mccormick, Q. J., & Enke, R. A. (2016). Connecting common genetic polymorphisms to protein function: A modular project sequence for lecture or lab. *Biochemistry and Molecular Biology Education*, 526-536.

Bevan, S. J., Chan, C. W., & Tanner, J. A. (2014). Diverse assessment and active student engagement sustain deep learning: A comparative study of outcomes in two parallel introductory biochemistry courses. *Biochemistry and Molecular Biology Education*, *42*(6), 474-479.

Biochemical Society. (2016). What is biochemistry? Retrieved January 1, 2016, from http://www.biochemistry.org/?TabId=456.

Bobby, Z., Nandeesha, H., Sridhar, M. G., Soundravally, R., Setiya, S., Babu, M. S., & Niranjan, G. (2006). Identification of mistakes and their correction by small group discussion as a revision exercise at the end of a teaching module in biochemistry. *National Medical Journal of India*, *27*(1), 22-23.

Bodner, G. M. (1986). Constructivism: A Theory of Knowledge, *Journal of Chemical Education, 63*, 873-878.

Bodner, G. M. (1992). Refocusing the General Chemistry Curriculum, Why Changing the Curriculum May Not Be Enough, *Journal of Chemical Education*, *69*, 186-190.

Bodner, G. M., & Orgill, M. (2007). Theoretical frameworks for research in chemistry/science education.

Bodner, G. M. & Weaver, G. (2008). Research and practice in chemical education in advanced courses, *Chemistry Education Research and Practice*, *9*, 81-83.

Bodner, G. M. (2011). Status, contributions, and future directions of discipline-based education research: The development of research in chemical education as a field of study. In *Second Committee Meeting on the Status, Contributions, and Future Directions of Discipline-Based Education Research*. Available: http://www7. nationalacademies. org/bose/DBER_Bodner_October_Paper. pdf.

Bodner, G. M. (2017). Changing How Data Are Collected Can Change What We Learn From Discipline-Based Educational Research, in 2016 Physics Education Research Conference, edited by D. L. Jones, L. Ding and A. Traxler (College Park, MD), in press.

Bonafe, C. F. S., Bispo, J. A. C., & de Jesus, M. B. (2018). The polygonal model: A simple representation of biomolecules as a tool for teaching metabolism. *Biochemistry and Molecular Biology Education*, *46*(1), 66-75.

Boyd-Kimball, D., & Miller, K. R. (2017). From Cookbook to Research: Redesigning an Advanced Biochemistry Laboratory. Journal of Chemical Education, 95(1), 62-67

Bransford, J. D., Brown, A. L., & Cocking, Rodney, R. (1999). *How People Learn: Brain, Mind, Experience, and School: Expanded Edition* (Expanded e). Washington, D.C.: National Academy Press.
Bretz, S. L., & Linenberger, K. J. (2012). Development of the enzyme-substrate interactions concept inventory. *Biochemistry and Molecular Biology Education*, *40*(4), 229-233.
Bussey, T. J. (2013). What Can Biochemistry Students Learn about Protein Translation? Using Variation Theory to Explore the Space of Learning Created by Some Common External Representations. *ProQuest LLC*.
Bussey, T. J., & Orgill, M. (2015). What do biochemistry students pay attention to in external representations of protein translation? The case of the Shine-Dalgarno sequence. *Chemistry Education Research and Practice*, *16*, 714-730.
Campbell, P. N. (2005). Biochemical education emerges. *IUBMB Life*, *57*(4-5), 243-244.
Canning, D. R. (2001). Teaching the structural nature of biological molecules: molecular visualization in the classroom and in the hands of students. *Chemistry Education Research and Practice*, *2*(2), 109-122.
Champagne, A. B., Lovitts, B. E., & Calinger, B. (Eds.). (1990). *Assessment in the Service of Instruction*: Papers from the 1990 AAAS Forum for School Science. American Association for the Advancement of Science.Chemical Abstracts Service (CAS). https://scifinder.cas.org/ Accessed 10 February 2017.
Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes. *Educational Psychologist*, *49*(4), 219-243.
Cicuto, C. A. T., & Torres, B. B. (2016). Implementing an Active Learning Environment To Influence Students' Motivation in Biochemistry. *Journal of Chemical Education*, *93*, 1020-1026.
Clark, D. D., & Edwards, D. J. (2018). Virtual protein purification: A simple exercise to introduce ph as a parameter that effects ion exchange chromatography. Biochemistry and Molecular Biology Education, 46(1), 91-97.
Cogdell, B., Torsney, B., Stewart, K., & Smith, R. A. (2012). Technological and Traditional Drawing Approaches Encourage Active Engagement in Histology Classes for Science Undergraduates. *Bioscience Education*, *19*(1), 1-15.
Coleman, A. B., Lam, D. P., & Soowal, L. N. (2015). Correlation, necessity, and sufficiency: Common errors in the scientific reasoning of undergraduate students for interpreting experiments. *Biochemistry and Molecular Biology Education*, *43*(5), 305-315.
Conway, C. J. (2014). Effects of guided inquiry versus lecture instruction on final grade distribution in a one-semester organic and biochemistry course. *Journal of Chemical Education*, *91*(4), 480-483.
Cook, A. L., Snow, E. T., Binns, H., & Cook, P. S. (2015). Self-reported student confidence in troubleshooting ability increases after completion of an inquiry-based PCR practical. *Biochemistry and Molecular Biology Education*, *43*(5), 316-323.
Cook, R., Hannon, D., Southard, J. N., & Majumdar, S. (2018). Small laccase from streptomyces coelicolor—an ideal model protein/enzyme for undergraduate laboratory experience. Biochemistry and Molecular Biology Education, 46(2), 172-181.

Cookmeyer, D. L., Winesett, E. S., Kokona, B., Huff, A. R., Aliev, S., Bloch, N. B., ... & Khromava, M. (2017). Uncovering protein–protein interactions through a team-based undergraduate biochemistry course. *PLoS biology*, *15*(11), e2003145.

Cooper, A. K., & Oliver-Hoyo, M. T. (2017). Creating 3D physical models to probe student understanding of macromolecular structure. *Biochemistry and Molecular Biology Education*, *45*(6), 491-500.

Corbin, J. M. & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria, *Qualitative Sociology, 13*(1), pp. 3-21.

Costa, M. J., Howitt, S., Anderson, T., Hamilton, S., & Wright, T. (2008). A concept inventory for molecular life sciences: how will it help your teaching practice?.

Cowden, C. D., & Santiago, M. F. (2016). Interdisciplinary Explorations: Promoting Critical Thinking via Problem-Based Learning in an Advanced Biochemistry Class. *Journal of Chemical Education*, *93*(3), 464-469.

Dash, S., Kamath, U., Rao, G., Prakash, J., & Mishra, S. (2015). Audio–visual aid in teaching "fatty liver". *Biochemistry and Molecular Biology Education*.

Davis, E. A., Hodgson, Y., & Macaulay, J. O. (2012). Engagement of students with lectures in biochemistry and pharmacology. *Biochemistry and Molecular Biology Education*, *40*(5), 300-309.

de Fátima Wardenski, R., de Espíndola, M. B., Struchiner, M., & Giannella, T. R. (2012). Blended learning in biochemistry education: Analysis of medical students' perceptions. *Biochemistry and Molecular Biology Education*, *40*(4), 222-228.

Del Carlo, D., & Bodner, G. (2006). Dishonesty in the Biochemistry Classroom Laboratory A synthesis of causes and prevention. *Biochemistry and Molecular Biology Education*, *34*(5), 338-342.

dos Santos, V. J. S. V, & Galembeck, E. (2015). Metabolic pathways visualization skills development by undergraduate students. *Biochemistry and Molecular Biology Education*, *43*(3), 162-167.

Dries, D. R., Dean, D. M., Listenberger, L. L., Novak, W. R., Franzen, M. A., & Craig, P. A. (2017). An expanded framework for biomolecular visualization in the classroom: Learning goals and competencies. *Biochemistry and Molecular Biology Education*, *45*(1), 69-75.

Eisner, E. (1984). Can Educational Research Inform Educational Practice?, *Phi Delta Kappan*, *65*, p. 447-52.

Ferguson, R. L. & Bodner, G. M. (2008). Making Sense Of Arrow-Pushing Formalism By Chemistry Majors Enrolled In Organic Chemistry, *Chemistry Education Research and Practice*, *9*, 102-113.

Fernández-Santander, A. (2008). Cooperative learning combined with short periods of lecturing: A good alternative in teaching biochemistry. *Biochemistry and Molecular Biology Education*, *36*(1), 34-38.

Forbes-Lorman, R. M., Harris, M. A., Chang, W. S., Dent, E. W., Nordheim, E. V., & Franzen, M. A. (2016). Physical models have gender-specific effects on student understanding of protein structure–function relationships. *Biochemistry and Molecular Biology Education*.

Gage, N. L. (1963). *The handbook of research on teaching*. Chicago: Rand McNally.

Gage, N. L. (1989). The Paradigm Wars and their aftermath: A "historical" sketch of research on teaching since 1989. *Educational Researcher*, *18*(7), 4-10.
Gerczei, T. (2016). Impact of an In-Class Biochemistry Mini-conference on Students' Perception of Science. *Journal of Chemical Education*, *93*, 1521-1527.
Glaser, B. G. (1998) *Doing Grounded Theory – Issues and Discussions*. Sociology Press.
Goeden, T. J., Kurtz, M. J., Quitadamo, I. J., & Thomas, C. (2015). Community-Based Inquiry in Allied Health Biochemistry Promotes Equity by Improving Critical Thinking for Women and Showing Promise for Increasing Content Gains for Ethnic Minority Students. *Journal of Chemical Education*, *92*, 788-796.
Gray, C., Price, C. W., Lee, C. T., Dewald, A. H., Cline, M. a., McAnany, C. E., ... Mura, C. (2015). Known structure, unknown function: An inquiry-based undergraduate biochemistry laboratory course. *Biochemistry and Molecular Biology Education*, 245-262.
Grayson, D. J., Anderson, T. R., & Crossley, L. G. (2001). A four-level framework for identifying and classifying student conceptual and reasoning difficulties. *International Journal of Science Education*, *23*(6), 611-622.
Gunersel, A. B., & Fleming, S. (2014). Bio-organic reaction animations (BioORA): Student performance, student perceptions, and instructor feedback. *Biochemistry and Molecular Biology Education*, *42*(3), 190-202.
Haas, K. L., Heemstra, J. M., Medema, M. H., & Charkoudian, L. K. (2017). Collaborating with Undergraduates To Contribute to Biochemistry Community Resources. Biochemistry, 57(4), 383-389.
Hall, M. L., & Vardar-Ulu, D. (2014). An inquiry-based biochemistry laboratory structure emphasizing competency in the scientific process: A guided approach with an electronic notebook format. *Biochemistry and Molecular Biology Education*, *42*(1), 58-67.
Harle, M., & Towns, M. H. (2012a). Students' understanding of external representations of the potassium ion channel protein, part I: Affordances and limitations of ribbon diagrams, vines, and hydrophobic/polar representations. *Biochemistry and Molecular Biology Education*, *40*(6), 349-356.
Harle, M., & Towns, M. H. (2012b). Students' understanding of external representations of the potassium ion channel protein part II: Structure-function relationships and fragmented knowledge. *Biochemistry and Molecular Biology Education*, *40*(6), 357-363.
Harle, M., & Towns, M. H. (2013). Students' understanding of primary and secondary protein structure: Drawing secondary protein structure reveals student understanding better than simple recognition of structures. *Biochemistry and Molecular Biology Education*, *41*(6), 369-376.
Hicks, K. A. (2016). Measuring Norfloxacin Binding to Trypsin Using a Fluorescence Quenching Assay in an Upper-Division, Integrated Laboratory Course. *Journal of Chemical Education*, *93*, 380-382.
Horowitz, S., Koldewey, P., & Bardwell, J. C. (2014). Undergraduates improve upon published crystal structure in class assignment. *Biochemistry and Molecular Biology Education*, *42*(5), 398-404.

House, C., Meades, G., & Linenberger, K. J. (2016). Approaching a Conceptual Understanding of Enzyme Kinetics and Inhibition: Development of an Active Learning Inquiry Activity for Prehealth and Nonscience Majors. *Journal of Chemical Education*, *93*(8), 1397-1400.

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, *7*, 75-83.

Karatas, F.O, Bodner, G. M. & Unal, S. (2015). First-year engineering students' views of the nature of engineering: Implications for engineering programmes, E*uropean Journal of Engineering Education*, *41*(1), 1-22.

Knutson, K., Smith, J., Wallert, M. A., & Provost, J. J. (2010). Bringing the excitement and motivation of research to students; Using inquiry and research-based learning in a year-long biochemistry laboratory: Part I-guided inquiry-purification and characterization of a fusion protein: Histidine tag, malate dehydrogen. *Biochemistry and Molecular Biology Education*, *38*(5), 317-323.

Kühl, S. J., Toberer, M., Keis, O., Tolks, D., Fischer, M. R., & Kühl, M. (2017). Concept and benefits of the Inverted Classroom method for a competency-based biochemistry course in the pre-clinical stage of a human medicine course of studies. *GMS journal for medical education*, *34*(3).

Kulak, V., Newton, G., & Sharma, R. (2017). Does the Use of Case-Based Learning Impact the Retention of Key Concepts in Undergraduate Biochemistry?. *International Journal of Higher Education*, *6*(2), 110-120.

Lamb, T. (2005). The Retrospective Pretest: An Imperfect but Useful Tool. Harvard Family Research Project , **11**(2), http://www.hfrp.org/evaluation/the-evaluation-exchange/issue-archive/evaluation-methodology/the-retrospective-pretest-an-imperfect-but-useful-tool. Accessed 10 February 2017.

Leopold, C., & Leutner, D. (2012). Science text comprehension: Drawing, main idea selection, and summarizing as learning strategies. *Learning and Instruction*, *22*(1), 16-26.

Lewis, R. L., Seal, E. L., Lorts, A. R., & Stewart, A. L. (2017). Circular dichroism spectroscopy: Enhancing a traditional undergraduate biochemistry laboratory experience. *Biochemistry and Molecular Biology Education*, *45*(6), 515-520.

Linenberger, K. J., & Bretz, S. L. (2012). Generating cognitive dissonance in student interviews through multiple representations. *Chemistry Education Research and Practice*, *13*(3), 172-178.

Linenberger, K. J., & Bretz, S. L. (2014). Biochemistry students' ideas about shape and charge in enzyme-substrate interactions. *Biochemistry and Molecular Biology Education*, *42*(3), 203-212.

Linenberger, K. J., & Bretz, S. L. (2015). Biochemistry students' ideas about how an enzyme interacts with a substrate. *Biochemistry and Molecular Biology Education*, *43*(4), 213-222.

Lipchock, J. M., Ginther, P. S., Douglas, B. B., Bird, K. E., & Patrick Loria, J. (2017). Exploring protein structure and dynamics through a project-oriented biochemistry laboratory module. *Biochemistry and Molecular Biology Education*.

Loertscher, J. (2014a). Biochemistry and molecular biology education research: Moving from ideas to action. *Biochemistry and Molecular Biology Education*, *42*(3), 257-258.
Loertscher, J. (2014b). Student Centered Education A Call to Action Answered : Highlights from the ASBMB Student-Centered Education in the Molecular Life Sciences Symposium Strengthening the Future of BMB Through Improvements in the. *Biochemistry and Molecular Biology Education*, *42*(1), 79-80.
Loertscher, J., Green, D., Lewis, J. E., Lin, S., & Minderhout, V. (2014). Identification of Threshold Concepts for Biochemistry. *Cell Biology Education*, *13*(3), 516-528.
Loertscher, J., Villafane, S. M., Lewis, J. E., & Minderhout, V. (2014). Probing and improving student's understanding of protein α-helix structure using targeted assessment and classroom interventions in collaboration with a faculty community of practice. *Biochemistry and Molecular Biology Education*, *42*(3), 213-223.
McPartland, A., & Segel, I. H. (1986). Equilibrium Constants, Free Energy Changes, and Coupled Reactions: Concepts and Misconcepts. *Biochemical Education*, 14(3), 137-141.
Mallick, A. K., & Ahsan, M. (2017). A Study to Assess the Impact of Biochemical Laboratory Reports as a Tool to Promote Active Learning in Biochemistry Lectures. *Journal of Contemporary Medical Research*, *4*(10), 2198-2201.
Maskiewicz, A. C., & Lineback, J. E. (2013). Misconceptions are "so yesterday!" *CBE Life Sciences Education*, *12*(3), 352-356.
Mathews, M. B., & Stagnaro-Green, A. (2008). Teaching of biochemistry in medical school: A well-trodden pathway? *Biochemistry and Molecular Biology Education*, *36*(6), 402-406.
Mattos CM, Johnson M, White H, Sears D, Bailey C, Bell E (2013). Introduction: promoting concept driven teaching strategies in bio- chemistry and molecular biology. *Biochemistry and Molecular Biology Education*, *41*, 287-288.
Meyer, S. C. (2015). 3D Printing of Protein Models in an Undergraduate Laboratory: Leucine Zippers. *Journal of Chemical Education*, *92*(12), 2120-2125.
Meyer, J. H. F., & Land, R. (2006). *Overoming barriers to student understanding: Threshold concepts and troublesome knowledge*, Routledge: Oxon
Miao, Y., & Thomas, C. L. (2017). Using Myoglobin Denaturation To Help Biochemistry Students Understand Protein Structure. *Journal of Chemical Education*, *94*(10), 1498-1501.
Miles, N., & Soares da Costa, T. P. (2016). Acceptance of clickers in a large multimodal biochemistry class as determined by student evaluations of teaching: Are they just an annoying distraction for distance students?. *Biochemistry and Molecular Biology Education*, *44*(1), 99-108.
Milner, R. E. (2014). Learner differences and learning outcomes in an introductory biochemistry class: Attitude toward images, visual cognitive skills, and learning approach. *Biochemistry and Molecular Biology Education*, *42*(4), 285-298.
Miller, K., & Kim, T. (2017). Examining student heuristic usage in a hydrogen bonding assessment. *Biochemistry and Molecular Biology Education*.
Minderhout, V., & Loertscher, J. (2007). Lecture-free biochemistry. *Biochemistry and Molecular Biology Education*, *35*(3), 172-180.

Mitchell, S. M., Anderson, W. L., Sensibaugh, C. A., & Osgood, M. (2011). What really matters: Assessing individual problem-solving performance in the context of biological sciences. *International Journal for the Scholarship of Teaching and Learning*, *5*(1), 17.

Mnguni, L., Schönborn, K., & Anderson, T. (2016). Assessment of visualisation skills in biochemistry students. *South African Journal of Science*, *112*(9-10), 1-8.

Murthy, P. P. N., Thompson, M., & Hungwe, K. (2014). Development of a Semester-Long, Inquiry-Based Laboratory Course in Upper-Level Biochemistry and Molecular Biology. *Journal of Chemical Education*, *91*(11), 1909-1917.

Muth, G. W. (2016). Biochemistry and the Liberal Arts: Content and Communication in a Flipped Classroom. In *The Flipped Classroom Volume 2: Results from Practice* (pp. 127-138). American Chemical Society.

Nagata, R. (2007). Students' ability to organize biochemical and biochemistry-related terms correlates with their performance in a biochemical examination. *Biochemistry and Molecular Biology Education*, *35*(2), 97-100.

National Research Council. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. National Academies Press.

National Science Board, *Preparing Our Children: How Research Can Better Inform Practice*; https://www.nsf.gov/pubs/1999/nsb9931/nsb9931-7.htm

Naveed, T., Bhatti, N. M., & Malik, R. (2017). Perception of Medical Students Regarding Case Based Learning. *Journal of Rawalpindi Medical College (JRMC)*, *21*(3), 303-305.

NVivo 11, QSR International. http://www.qsrinternational.com/products_nvivo.aspx. Accessed February 9, 2017.

Offerdahl, E. G., & Montplaisir, L. (2014). Student-generated reading questions: Diagnosing student thinking with diverse formative assessments. *Biochemistry and Molecular Biology Education*, *42*(1), 29-38.

Ojennus, D. D. (2016). Assessment of learning gains in a flipped biochemistry classroom. *Biochemistry and Molecular Biology Education*, *44*(1), 20-27.

Oliveira, G. a., Sousa, C. R., Da Poian, a. T., & Luz, M. R. M. P. (2003). Students' Misconception About Energy-Yielding Metabolism: Glucose As the Sole Metabolic Fuel. *AJP: Advances in Physiology Education*, *27*(3), 97-101.

Ooi, G., & Sanger, M. J. (2009). " Which Pathway Am I ?" Using a Game Approach To Teach Students about Biochemical Pathways. *Journal of Chemical Education*, *86*(4), 454-455.

Orgill, M. & Bodner, G. M. (2004). What Research Tells Us About Using Analogies to Teach Chemistry, *Chemical Education Research and Practice*, *5*(1), 15-33.
Orgill, M. & Bodner, G. M. (2005). Chapter 8: The Role of Analogies in Chemistry Teaching, In *Chemists' Guide to Effective Teaching*, N. Pienta, M. Cooper, and T. Greenbowe, Ed. Prentice-Hall: Upper Saddle River, NJ, 2005, pp. 90-105.
Orgill, M. & Bodner, G. M. (2006). An Analysis of the Effectiveness of Analogy Use in College-Level Biochemistry Textbooks, J*ournal of Research in Science Teaching*, *43*(12), 1040-1060
Orgill, M., & Bodner, G. N. (2007). Locks and Keys. *Biochemistry and Molecular Bioloy Education*, *35*(4), 244-254.
Orgill, M., Bussey, T. J., & Bodner, G. M. (2015). Biochemistry instructors' perceptions of analogies and their classroom use. *Chemistry Education Research and Practice*, *16*(4), 731-746.
Orgill, M., & Sutherland, A. (2008). Undergraduate chemistry students' perceptions of and misconceptions about buffers and buffer problems. *Chemistry Education Research and Practice*, *9*(2), 131-143.
Palocaren, J., Pillai, L. S., & Celine, T. M. (2016). Medical biochemistry: Is it time to change the teaching style?. *The National medical journal of India*, *29*(4), 222.
Parslow, G. R. (2015). Commentary: Golden years and a bright future for biochemical education. *Biochemistry and Molecular Biology Education*, *43*(2), 65–65.
Patton, M. Q. (2015). *Qualiative Research and Evaluation Methods*, 4th Ed. Sage: Los Angeles
Pennington, B. O., Sears, D., & Clegg, D. O. (2014). Interactive Hangman teaches amino acid structures and abbreviations. *Biochemistry and Molecular Biology Education*, *42*(6), 495-500.
Pogačnik, L., & Cigić, B. (2006). How To Motivate Students To Study before They Enter the Lab. *Journal of Chemical Education*, *83*(7), 1094-1098.
Prakash, S. S., Muthuraman, N., & Anand, R. (2017). Short-duration podcasts as a supplementary learning tool: perceptions of medical students and impact on assessment performance. *BMC medical education*, *17*(1), 167.
Ramsay, C. M., Guo, X., & Pursel, B. K. (2017). Leveraging Faculty Reflective Practice to Understand Active Learning Spaces: Flashbacks and Re-Captures. *Journal of Learning Spaces*, *6*(3).
Rauschenberger, M. M., & Sweeder, R. D. (2010). Gender performance differences in biochemistry. *Biochemistry and Molecular Biology Education*, *38*(6), 380-384.
Richardson, D. C., Richardson, J. S., Sirochman, R., Weiner, S. W., Farwell, M., Putnam-Evans, C., ... & Bateman Jr, R. C. (2005). Assessment of molecular construction in undergraduate biochemistry. *J. Chem. Educ*, *82*(12), 1854.
Roberts, J. R., Hagedorn, E., Dillenburg, P., Patrick, M., & Herman, T. (2005). Physical models enhance molecular three-dimensional literacy in an introductory biochemistry course. *Biochemistry and Molecular Biology Education*, *33*(2), 105-110.

Rodrigues, J. P. G. L. M., Melquiond, A. S. J., & Bonvin, A. M. J. J. (2016). Molecular Dynamics Characterization of the Conformational Landscape of Small Peptides : A Series of Hands-on Collaborative Practical Sessions for Undergraduate Students w Overview of the Practical Sessions for Undergraduate Students. *Biochemistry and Molecular Biology Education*, *44*(2), 160-167.
Rowland, S. L., Smith, C. A., Gillam, E. M. A., & Wright, T. (2011). The concept lens diagram: A new mechanism for presenting biochemistry content in terms of "big ideas." *Biochemistry and Molecular Biology Education*, *39*(4), 267-279.
Schoenfeld-Tacher, R., Jones, L. L., & Persichitte, K. A. (2001). Differential effects of a multimedia goal-based scenario to teach introductory biochemistry -- Who benefits most? *Journal of Science Education and Technology*, *10*(4), 305-317.
Schoenfeld-Tacher, R., Persichitte, K. A., & Jones, L. L. (2000). Relation of Student Characteristics to Learning of Basic Biochemistry Concepts from a Multimedia Goal-Based Scenario.
Schönborn, K. J., & Anderson, T. R. (2009). A model of factors determining students' ability to interpret external representations in biochemistry. *International Journal of Science Education*, *31*(2), 193-232.
Schönborn, K. J., & Anderson, T. R. (2010). Bridging the educational research-teaching practice gap. *Biochemistry and molecular biology education*, *38*(5), 347-354.
Schönborn, K. J., Anderson, T. R., & Grayson, D. J. (2002). Student difficulties with the interpretation of a textbook Sensibaugh, C. A., Madrid, N. J., Choi, H. J., Anderson,
W. L., & Osgood, M. P. (2017). Undergraduate Performance in Solving Ill-Defined Biochemistry Problems. *CBE-Life Sciences Education*, *16*(4), ar63.
diagram of immunoglobulin G (IgG). *Biochemistry and Molecular Biology Education*, *30*(2), 93-97.
Shaw, G. P., & Molnar, D. (2011). Non-native English language speakers benefit most from the use of lecture capture in medical school. *Biochemistry and Molecular Biology Education*, *39*(6), 416-420.
Shi, J., Knight, J. K., Chun, H., Guild, N. A., & Martin, J. M. (2017). Using Pre-Assessment and In-Class Questions to Change Student Understanding of Molecular Movements. *Journal of microbiology & biology education*, *18*(1).
Silva, T., & Galembeck, E. (2016). Developing and Supporting Students' Autonomy To Plan, Perform, and Interpret Inquiry-Based Biochemistry Experiments. *Journal of Chemical Education*, *94*(1), 52-60.
Silva, T., & Galembeck, E. (2017). AN INQUIRY-BASED FRESHMAN BIOCHEMISTRY LAB SET TO ENHANCE STUDENTS'AUTONOMY. *Química Nova*, *40*(4), 465-468.
Silverstein, T. P. (2016). The Alcohol Dehydrogenase Kinetics Laboratory: Enhanced Data Analysis and Student-Designed Mini-Projects. *Journal of Chemical Education*, *93*(5), 963-970.

Singer, S. R., Nielsen, N. R., & Schweingruber, H. A. (2012). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. National Academies Press: Washington, DC.

Stockwell, B. R., Stockwell, M. S., & Jiang, E. (2017). Group problem solving in class improves undergraduate learning. *ACS Central Science*, *3*(6), 614-620.

Strauss, A., & Corbin, J. (1990). Open coding. *Basics of qualitative research: Grounded Theory Procedures and Techniques*, *2*, 101-121.

Strauss, A. & Corbin, J. (1994). Grounded theory methodology: An overview. *Handbook of qualitative research*, Chapter 17, 273-85.

Streu, C. N., Reif, R. D., Neiles, K. Y., Schech, A. J., & Mertz, P. S. (2016). Drug Synthesis and Analysis on a Dime: A Capstone Medicinal Chemistry Experience for the Undergraduate Biochemistry Laboratory. *Journal of Chemical Education*, *93*(12), 2084-2088.

Susantini, E., Lisdiana, L., Isnawati, Tanzih Al Haq, A., & Trimulyono, G. (2016). Designing easy DNA extraction: Teaching creativity through laboratory practice. *Biochemistry and Molecular Biology Education*, (1), 1-10.

Tansey, J. T., Baird, T., Cox, M. M., Fox, K. M., Knight, J., Sears, D., & Bell, E. (2013). Foundational concepts and underlying theories for majors in "biochemistry and molecular biology." *Biochemistry and Molecular Biology Education*, *41*(5), 289-296.

Terrell, C. R., & Listenberger, L. L. (2017). Using molecular visualization to explore protein structure and function and enhance student facility with computational tools. *Biochemistry and Molecular Biology Education*.

Towns, M. H., Raker, J. R., Becker, N., Harle, M., & Sutcliffe, J. (2012). The biochemistry tetrahedron and the development of the taxonomy of biochemistry external representations (TOBER). *Chemistry Education Research and Practice*, *13*(3), 296-306.

U.S. Department of Education. (no date). Use of Technology in Teaching and Learning. https://www.ed.gov/oii-news/use-technology-teaching-and-learning. Accessed 10 February 2017.

Van Dyke, A. R., Gatazka, D. H., & Hanania, M. M. (2017). Innovations in Undergraduate Chemical Biology Education. ACS chemical biology, 13(1), 26-35.

Van Dyke, A. R., & Smith-Carpenter, J. (2017). Bring Your Own Device: A Digital Notebook for Undergraduate Biochemistry Laboratory Using a Free, Cross-Platform Application.

Van Meter, P., & Garner, J. (2016). The Promise and Practice of Learner-Generated Drawing: Literature Review and Synthesis. *Educational Psychology Review*, *17*(4), 285-325.

Vanderlelie, J. (2013). Improving the student experience of learning and teaching in second year biochemistry: assessment to foster a creative application of biochemical concepts. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, *21*(4).

Villafañe, S. M., Bailey, C. P., Loertscher, J., Minderhout, V., & Lewis, J. E. (2011). Development and analysis of an instrument to assess student understanding of foundational concepts before biochemistry coursework. *Biochemistry and Molecular Biology Education*, *39*(2), 102-109.

Villafañe, S. M., Heyen, B. J., Lewis, J. E., Loertscher, J., Minderhout, V., & Arnold Murray, T. (2016). Design and testing of an assessment instrument to measure understanding of protein structure and enzyme inhibition in a new context. *Biochemistry and Molecular Biology Education*, *44*(2), 179-190.

Villafañe, S. M., Heyen, B. J., Lewis, J. E., Loertscher, J., Minderhout, V., & Arnold Murray, T. (2015). Design and testing of an assessment instrument to measure understanding of protein structure and enzyme inhibition in a new context. *Biochemistry and Molecular Biology Education*.

Villafane, S. M., Loertscher, J., Minderhout, V., & Lewis, J. E. (2011). Uncovering students' incorrect ideas about foundational concepts for biochemistry. *Chemistry Education Research and Practice*, *12*(2), 210-218.

Weaver, G. C., Russell, C. B., Wink, D. J.. (2008). Inquiry-based and research-based laboratory pedagogies in undergraduate science. *Nature Chemical Biology*, 4(10), 577-580.

Wei, C. C., Jensen, D., Boyle, T., O'Brien, L. C., De Meo, C., Shabestary, N., & Eder, D. J. (2015). Isothermal Titration Calorimetry and Macromolecular Visualization for the Interaction of Lysozyme and Its Inhibitors. *Journal of Chemical Education*, *92*(9), 1552-1556.

Wenger, E. (2000). Communities of practice and social learning systems. *Organization*, *7*, 225-246.

White, H. B. (2002). Commentary: The Promise of Problem-based Learning Biochem. *Biochemistry and Molecular Biology Education*. *30*, 419.

White, H. B., Benore, M. A., Sumter, T. F., Caldwell, B. D., Bell, E. (2013).What skills should students of undergraduate biochemistry and molecular biology programs have upon graduation? *Biochemistry and Molecular Biology Education*, *41*, 297-301.

Wolfson, A. J., Rowland, S. L., Lawrie, G. a, & Wright, A. H. (2014). Student conceptions about energy transformations: progression from general chemistry to biochemistry. *Chemistry Education Research and Practice*, *15*(2), 168–-183.

Wood, E. J. (1990). Biochemistry is a difficult subject for both student and teacher. *Biochemical Education*, *18*(4), 170-172.

Wood, E. J. (2001). Biochemistry and molecular biology teaching over the past 50 years. *Nature Reviews Molecular Cell Biology*, *2*(3), 217-221.

Wright, A., Provost, J., Roecklin-Canfield, J. A., Bell, E. (2013). Essential concepts and underlying theories from physics, chemistry, and mathematics for "biochemistry and molecular biology" majors. *Biochemistry and Molecular Biology Educatio*n, *41*, 302-308.

Xu, X., Lewis, J. E., Loertscher, J., Minderhout, V., & Tienson, H. L. (2017). Small Changes: Using Assessment to Direct Instructional Practices in Large-Enrollment Biochemistry Courses. *CBE-Life Sciences Education*, *16*(1), ar7.

Yan, Q., Ma, L., Zhu, L., & Zhang, W. (2017). Learning effectiveness and satisfaction of international medical students: Introducing a Hybrid–PBL curriculum in biochemistry. *Biochemistry and Molecular Biology Education*, *45*(4), 336-342.

Zhang, L., Zhang, W., Wu, C., Liu, Z., Cai, Y., Cao, X., ... & Miao, H. (2017). Undergraduate medical academic performance is improved by scientific training. *Biochemistry and Molecular Biology Education*.

Zuidema, D. R., & Herndon, L. B. (2016). Using the Poisoner's Handbook in Conjunction with Teaching a First-Term General/Organic/Biochemistry Course. *Journal of Chemical Education*, *93*(1), 98-102.

Figure 1
A "wordle" or "word cloud" of key terms in this paper