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Investigating the Conversations that Occur During Undergraduate Research Experiences: A Case Study

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INVESTIGATING THE CONVERSATIONS THAT OCCUR DURING UNDERGRADUATE RESEARCH EXPERIENCES: A CASE STUDY

by

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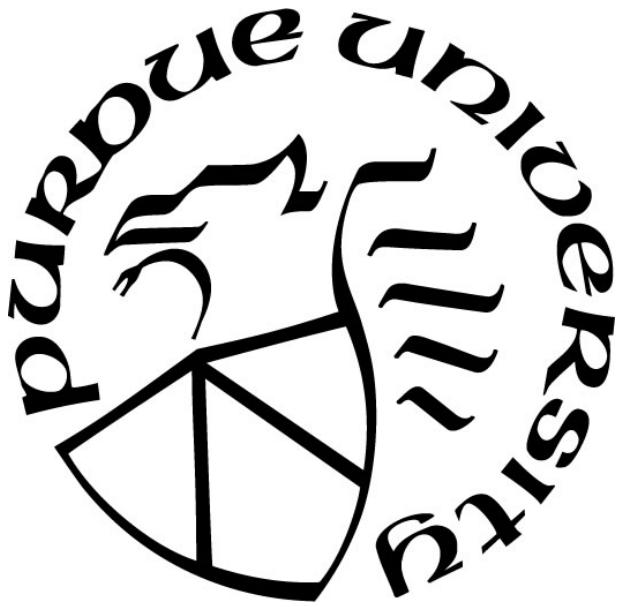

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To my parents, Greg and Linda Johnson, for their endless love and support

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GLOSSARY

activity frameworks – activities that frame lengthy stretches of interaction

anthropomorphic – related to or characterized by having human characteristics

backchannel responses – listener's responses in a primarily one-way conversation (e.g. yeah, okay, uh-huh)

collaborative conversation - conversation where two or more people work together to reach a consensus or conclusion

community of practice – group of people who share a craft or profession

conversational activities – activities and conversations about activities that frame lengthy stretches of interaction

dialogical repetitions – words of one speaker, repeated by another with whom they are having a conversation

direct instruction – explicit teaching of a skill or concept using lecture or a similar one-way communication style

disciplinary anchoring – explaining conceptual or theoretical ideas of a discipline; introducing data collection or analysis techniques

disciplinary knowledge – the expertise, theory, and concepts that relate to a specific discipline

ethnomethods – method by which persons make sense of their world

hermeneutic cycle – the process of an understanding a text hermeneutically; the idea that one's understand of the text as a whole is established by reference to the individual parts

historicity – historical authenticity

indexicality – the phenomenon of words pointing to an object in the context in which it occurs

intellectual support – helping problem-solve or identify 'next steps' in an experiment

intonation – rise and fall of voice during speaking

legitimate peripheral participation – the process by which newcomers become experienced members of a community of practice by engaging in tasks that further the goals of the community

member checking – technique where feedback is sought from participants about the findings from an investigation

(to) memo – the act of reflecting and recording notes about what is being learned from data

non-polar questions - questions to which the answer is expected to include specific information (e.g. why, how, where)

observer's paradox – situation where the phenomenon being observed is influenced by the presence of an observer or investigator

ownership as right and responsibility – taking ownership of a project by accepting responsibility for aspects of the project and acting to assert rights in making decisions in a project

personal support – comments indicating a speaker is supportive, accessible, friendly, or interested in the listener

polar questions – questions to which the expected answer is a form of 'yes' or 'no'

presupposed knowledge – knowledge assumed to be tactitly known or accepted

professional socialization – the process of learning the values and norms of a profession along with essential disciplinary knowledge and skills

reflexivity – practicing awareness about the influences a researcher's own experiences play on what is being studied and, conversely, the influences of what is being studied on the researcher

self-regulated learning – learning that is self-directed and guided by metacognition, strategic action, and motivation to learn

social currency – the entirety of resources that arise from one's presence in a social network or community

speech-act silence – acts of silence used to perform a specific task (e.g. communicate understanding, acknowledge acceptance, defer a decision)

turn-at-talk – a single participant's turn in speaking during a conversation

ABSTRACT

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Despite the increasing popularity of undergraduate research experiences across disciplines, little information currently exists to guide the design, evaluation, and improvement of these experiences. One challenge to generating such guidelines is the lack of evidence related to the processes and contexts in which undergraduate research experiences occur. My study sought to address this deficiency by exploring the norms of discourse that framed conversations between students and their mentors in biochemistry research as a model to understand the phenomenon of undergraduate research. I used a case-study approach to investigate the conversations that occurred between three student-mentor pairs as they engaged in research. Video-recorded observations of students and mentors working together helped me to identify discursive norms. I employed a stimulated recall interview protocol to identify how participants negotiated and established norms during a research experience. Analysis of discourse was informed by previous literature on undergraduate research experiences and conversation analysis theory. Viewing my analysis across cases allowed me to identify categories of conversations that framed the research experiences of student-mentor pairs. Based on these categories, I defined two distinct classes of research experiences present in my study: holistic and targeted experiences. I investigated individual turns-at-talk in conversations to generate findings on the nature of discourse present in each class of research experience. My work adds to current understandings of the processes by which undergraduate research experiences occur by

providing details about the role discourse plays in shaping these experiences. The results from this work will be used to make recommendations for researchers involved in the investigation of undergraduate research as an educational practice and educators interested in improving the research experiences of their undergraduate students.

CHAPTER 1. INTRODUCTION

My interest in undergraduate research experiences stemmed from two sources. First, as a researcher, I recognized that despite the increasing popularity of undergraduate research experiences across disciplines, little information existed to guide the design, evaluation, and improvement of these experiences. I identified that one of the challenges to generating such guidelines was the lack of evidence related to the processes and contexts in which undergraduate research experiences occur. Based on the limitations of our current knowledge related to how undergraduate students engage in research experiences, and additional factors outlined in the following section, I decided further exploration was needed into the topic of undergraduate research. Specifically, I was interested in applying previously unused methods to provide a new perspective in the field.

Second, as a student who participated in biochemistry research as an undergraduate, I found I had a personal interest in exploring the phenomenon of undergraduate research. When I began researching undergraduate research experiences, I found myself often thinking back to what I initially considered to be my negative experience in the laboratory. As I practiced reflexivity (Merriam & Tisdell, 2016) as a researcher, I noted the bidirectional interplay between my understanding of personal experiences in undergraduate research and my understanding of those of my participants. Thus, to provide a picture of the context in which I executed this study, I considered it necessary to include in my introduction my own experiences in undergraduate research and how my understanding changed through this study.

1.1 Why Do We Care About Undergraduate Research?

Widespread belief in the value of undergraduate research can be deduced from the financial and academic support given to these endeavors at both local and national levels (Merkel, 2003; Laursen, Hunter, Seymour, Thiry, & Melton, 2010; Russell, 2006). While the roots of undergraduate research can be traced back to the early 19th century (Kinkead, 2012), formal investigations into the evaluation of the benefits students gain through these experiences began in the last 30 years (Laursen et al., 2010). The findings from these works support educators' early intuitions: students who participate in undergraduate research have the potential to gain unique and valuable benefits from their experiences.

Students often gain a variety of benefits by engaging in undergraduate research (Laursen et al., 2010). Undergraduate research experience has been shown to help develop research and communication skills (Bauer & Bennett, 2003; Kardash, 2000; Lopatto, 2004; Russell, Hancock, & McCullough, 2007), enhance abilities to think and work like a scientist (Hunter, Laursen, & Seymour, 2007; Seymour, Hunter, Laursen, & DeAntoni, 2004), and promote scientific self-efficacy (Chemers, Zurbriggen, Syed, Goza, & Bearman, 2011; Robnett, Chemers, & Zurbriggen, 2015). Students who participate in undergraduate research also report improved academic and professional success (Nagda, Gregerman, Jonides, Hippel, & Lerner, 1998; Slovacek, Whittinghill, Flenoury, & Wiseman, 2012), and increased interest in pursuing graduate programs in science (Eagan et al., 2013; Lopatto, 2004; Zyndney, Bennett, Shahid, & Bauer, 2002). In recognition of the growing consensus around these benefits, the Association of American College and Universities (AAC&U) listed undergraduate research as one of ten high-impact educational practices (Kuh, 2008).

1.2 What is Missing in Our Understanding of Undergraduate Research?

One factor that may contribute to the increased interest in vetting undergraduate research as an educational practice are national calls for a highly skilled scientific and technical workforce to meet the needs of a changing global economy (National Science Board, 2015, 2016; President's Council of Advisors on Science and Technology, 2012). It is perhaps for this reason that most efforts to investigate undergraduate research have focused on the outcomes of these efforts. Through this product-focused research, undergraduate research has shown itself as a valuable practice for increasing the size, diversity, and quality of the body of students intending to enter scientific and technical fields (Chemers et al., 2011; Eagan et al., 2013; Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013; Pender, Marcotte, Sto. Domingo, & Maton, 2010; Zyndney et al., 2002). However, while this line of research is useful for validating undergraduate research, it is also limited in its ability to provide evidence-based guidance for stakeholders interested in evaluating or improving the undergraduate research experiences of students (Adedokun et al., 2012, 2014; Sadler, Burgin, McKinney, & Ponjuan, 2010).

By presenting student outcomes as the only yardstick by which we measure undergraduate research, we ignore a wide variety of meaningful benefits students may gain (Laursen et al., 2010) through their experiences. We also limit the potential of research efforts to inform and direct the decisions undergraduate research programs make (Sadler et al., 2010). Outcome-based research is useful for confirming if desired objectives are reached through undergraduate research experiences (e.g. increasing participants' interest in science professions), but it narrows the scope of potential benefits that may arise from undergraduate research experiences and provides little direction to programs that are not meeting intended goals. Furthermore, because the realization of outcomes depends on time or length of the experience (Adedokun et al., 2014;

Bauer & Bennett, 2003; Russell et al., 2007; Thiry, Weston, Laursen, & Hunter, 2012), to accurately measure the products of undergraduate research, programs often delay evaluation to the end of a student's experience in a program (Fakayode, Yakubu, Adeyeye, Pollard, & Mohammed, 2014; Hunter, Weston, Laursen, & Thiry, 2009; Kardash, 2000; Stanford, Rocheleau, Smith & Mohan, 2015). This delay disadvantages undergraduate research programs and their students by limiting the ability to detect problems and make changes while a student is still in a program.

The benefits realized by students who participate in undergraduate research are known to vary not only between universities or programs but at the individual level (Aikens et al., 2016). For programs to improve the experiences of individuals, they must be able to detect problems and make changes during a student's experience. This level of adaptability requires that models for evaluation be expanded beyond the outcomes of students' participation to the detailed investigation of the fine-grained processes that make up their experiences (Adedokun et al., 2012, 2014; Sadler et al., 2010). Such comprehensive evaluation calls for identification of the processes by which students gain benefits during undergraduate research experiences (Adedokun et al., 2012). Through characterization of these processes, comparisons can be made between how students experience processes and the benefits they realize through undergraduate research (Aikens et al., 2016; Sadler et al., 2010). Better understanding of these key processes of undergraduate research will allow educators to begin evaluating programs and making changes that improve the experiences of undergraduate researchers in real time.

1.3 Reflecting on My Experiences in Undergraduate Research

When I first decided to investigate undergraduate research experiences, I found it ironic. As a student, I had worked as an undergraduate researcher in a biochemistry laboratory for almost three years. My memories of the experience were, for the most part, negative. And for the ten years following the experience, I had considered it to be a failure because it was one of the major reasons I chose not to pursue a doctorate in biochemistry. In this section, I provide details about how the views of my experience changed through participation in this research. The account I provide here of my experience was informed both by personal reflections and journal entries I wrote while in school.

Before entering the world of discipline-based education research, I spent many years imagining myself becoming a wet-lab biochemist. In preparation for this career, I sought opportunities to work in research laboratories as early as the first semester of my freshman year in college. These efforts eventually paid off when I obtained a position as an undergraduate researcher in a biochemistry laboratory in my sophomore year. As one of only a handful of biochemistry majors at my university, I was in the position of being mentored directly by a tenured biochemistry faculty member. I worked in her laboratory as an undergraduate researcher throughout my time in college. My journal entries from this time report mainly feelings of intimidation at not knowing enough content and disappointment when experiments failed, both reasons I eventually chose to leave the field of biochemistry wet-lab research.

Because these ideas eventually led me to the belief that I was not suited for the biochemistry laboratory, I considered my undergraduate research experience to be largely unsuccessful when I reflected on it at the beginning of my own research. As I revisited these ideas, while observing participants and engaging in the analysis of resulting data, I began to

identify the many aspects of my experience that were successful. These benefits aligned closely with findings from Laursen and colleagues (2010). Through undergraduate research, I had gained a variety of laboratory skills, abilities in thinking and working like a scientist, and perhaps most importantly, career clarification.

I reflected on these aspects of my experience with my own undergraduate mentor in an informal meeting during this project. In addition to adding more benefits I gained through research to my list (i.e. experience presenting and writing up results), she mentioned that her own views of success had changed since we had worked together. As a beginning faculty member, she had considered a successful undergraduate research experience one that led to a student entering the scientific field. Now, with more experience, she believed that how the success of an undergraduate research experience was measured depended on the student in the experience.

When I considered how exploring my own experiences impacted my views on undergraduate research, I noted that expanding my definition of success allowed me to both appreciate and continue to learn from my undergraduate research experience. Rather than viewing it as a failure, because it did not meet one criteria, I could consider how it prepared me for my eventual career path. I could also consider how aspects of the experience could have been improved, regardless of their role in influencing my decision to go to study biochemistry. It is from this perspective that I chose to view undergraduate research experiences in this study. When considering undergraduates working in the laboratory, I was sensitive both to the cognitive and emotional challenges faced by students and mentors. Additionally, I viewed these experiences as collections of processes, unique to the individual, with the potential to result in a variety of long-term benefits.

1.4 Guiding Research Questions

This study adds to current identification and characterization efforts by focusing on the conversations that occur between mentors and students in undergraduate research experiences. My interest in discourse arose from work by Laursen et al. (2010) investigating the outcomes of student participation in intensive summer research experiences. Within their account of benefits, student and mentors reported gains in students' communication skills, including those communication skills that allowed them to engage with the scientific community. Laursen and colleagues (2010) highlighted gains in communication as an outcome of undergraduate research; however, they did not explore the process by which students achieve these gains. This work contributes to filling the gap in our knowledge.

I explored the discourse of students involved in biochemistry research as a model to understand the phenomenon of undergraduate research. This included the observation and recording of undergraduate students and their mentors as they interacted in a variety of settings in the laboratory. Students and mentors were interviewed about their experiences in undergraduate research. The study was based on the following guiding research questions:

1. What norms of discourse frame conversations between students and mentors in undergraduate biochemistry research experiences?
2. How are the norms of discourse established in undergraduate biochemistry research experiences?
3. How do the conversations students and mentors engage in impact the undergraduate research experiences of students?

Considering these questions helped to identify and characterize the discursive processes students engaged in while participating in undergraduate research.

CHAPTER 2. LITERATURE REVIEW

I have divided this literature review into three parts. In part one, I introduce and define undergraduate research. I provide a history of undergraduate research and include current models for undergraduate research. In part two, I discuss the investigation of undergraduate research; I compare the two dominant approaches to investigating undergraduate research that I have identified in literature. This section covers current methods of investigation, findings from these methods, and potential limitations of these studies. In part three, I conclude my synthesis by situating my own work within this body of literature.

2.1 Defining Undergraduate Research Experiences

While those in scientific disciplines may think of the laboratory when they talk about undergraduate research experiences, the term is used to describe a variety of educational experiences, including: laboratory work, field experiments, document analysis, and musical composition (Kinkead, 2003; Buckley, 2010). To provide focus in my literature review, I only considered literature related to undergraduate research experiences that occurred in the STEM fields of science, technology, engineering, and mathematics.

I defined undergraduate research experiences as investigative activities students pursue outside of the formal classroom, which are associated with an academic institution. These included intensive experiences that are conducted over a matter of weeks (usually in the summer), as explored by Laursen et al. (2010), and less-intensive experiences that occurred over months during regular academic semesters (e.g. fall or spring). I included both undergraduate research experiences led by faculty members and those led by graduate students or postdoctoral researchers (collectively referred to as “postgraduates” as per Aikens et al., 2016).

2.1.1 History of Undergraduate Research Experiences

The origin of the undergraduate research experience is debated heavily (Kinkead, 2012; Laursen et al., 2010; Merkel, 2003). Many consider the origin to be the first formal undergraduate research program established by the Massachusetts Institute of Technology (MIT) in 1969 (Merkel, 2001, 2003). This program sanctified undergraduate research as an important part of a student's undergraduate education (Merkel, 2003). Shortly after the formation of MIT's program, establishment of the Council of Undergraduate Research (CUR) in 1978 further instituted undergraduate research in higher education. Their mission was to provide undergraduate research opportunities to students at all types of undergraduate-serving universities (Council on Undergraduate Research, 2015). Formation of the CUR is considered by many the point at which undergraduate research became an educational revolution (Kinkead, 2012). However, I consider the history of undergraduate research to extends further, before the creation of its name.

Kinkead (2012) traced undergraduate research in the United States (US) back to 1886, when the Cornell chapter of Sigma Xi organized as a group of "Companions in Zealous Research." Along with Sigma Xi's continued interest, activity in the first half of the 20th century included the establishing of an award for undergraduate research by the University of Chicago in 1912, and a report in 1920 at the Indiana Academy of Sciences on the topic of "Undergraduate Research In Our Colleges and Universities" (Breeze, 1920; Kinkead, 2012).

These reported efforts appear to be the first formal recognition of the importance of undergraduate students doing research in the US, but it is in Germany that the earliest account of our current model for higher education are found, which incorporates teaching and research (Kinkead, 2012). The University of Berlin, founded by Wilhelm von Humboldt in 1810, is

considered the "mother of all modern universities." It was recorded as the first institution to combine teaching and research into one educational experience (Kinkead, 2012). It is from this educational model that I consider the foundations of undergraduate research to have emerged.

2.1.2 Current Models for Undergraduate Research Experiences

The structure of undergraduate research programs varies across institutions, programs, and disciplines. Within the STEM fields, two styles of program dominate the literature: summer undergraduate research experiences and regular academic-year undergraduate research experiences. In the sections below, I discuss the organization of each style. Following this discussion, I include a section focusing on differences that exist across both types of programs.

2.1.2.1 Summer Undergraduate Research Experiences

Summer undergraduate research experiences tend to have similar structures across institutions (Buckley, 2010). These programs generally last eight to ten weeks; students work full-time, usually in one research laboratory (Alexander, Foertsch, Daffinrud, & Tapia, 2000; Buckley, 2010; Kardash, 2000; Seymour et al, 2004). As part of the program, students often participate in professional development activities to prepare them for research, presenting, or applying to graduate school (Alexander et al., 2000; Laursen et al., 2010; Seymour et al., 2004). Many programs include initiatives to broaden participation by under-represented minorities (Alexander et al., 2000; Buckley, 2010; Laursen et al., 2010). To support these goals, such programs may include a mentoring component or other activities that foster community and student success (e.g. Fakayode et al., 2014). Most summer undergraduate research experiences also encourage dissemination of students' findings through local symposia or seminars (Fechheimer, Webber, & Kleiber, 2011; Seymour et al., 2004).

Summer undergraduate research programs may be participated in by students at their home university, or by students from other universities (Laursen et al., 2010). Because summer undergraduate research experiences are intensive, and often participated in by students from other universities, a key concern of these experiences is funding. To encourage participation, most summer undergraduate research experiences offer funding to students, usually in the form of a modest stipend (e.g. Canaria, Schoffstall, Weiss, Henry, & Braun-Sand, 2012; Fakayode et al., 2014; Zydney, Bennett, Shahid, & Bauer, 2002). Some programs also include room and board in their support (e.g. Fakayode et al., 2014). Funding for these programs comes from a variety of sources, including the university's own budget (e.g. Canaria et al., 2012). Additionally, federal agencies like the National Science Foundation (NSF) offer funding opportunities for summer undergraduate research experiences through their Research Experiences for Undergraduates (REU) program (NSF, 2013).

2.1.2.2 Academic-Year Undergraduate Research Experiences

The structure of undergraduate research experiences that occur during the academic year vary by department or laboratory in which the experience occurs (Aikens et al, 2016). Because these experiences occur during the academic year, the time students spend in the laboratory in one week is less intense, as few as 10 to 12 hours (Hathaway, Nagda, & Gregerman, 2002; Kardash, 2000). These experiences are not limited to a specific amount of time, and students may participate in academic-year research in the same laboratory for multiple semesters (Bressette & Breton, 2001). Thus, these experiences do not lend themselves to a dissemination model that includes a culminating presentation experience like summer programs. However, many students

who participate in undergraduate research find opportunities to present at regional or national conferences (Mabrouk, 2009).

Students who participate in academic-year research may participate for academic credit or for pay (Hathaway et al., 2002). The sources of funding for these opportunities is more difficult to track than summer programs. Academic-year undergraduate research opportunities are eligible for support through the NSF-REU program (NSF, 2013). However, faculty members may also support their undergraduate researchers with their own research funding (Dolan & Johnson, 2010).

Some universities coordinate their students' academic-year research experiences into university-wide programs. These include programs like the Undergraduate Research Opportunity Programs (UROPs) at the University of Michigan (Nagda et al., 1998). The primary difference between UROPs and other academic-year research experiences is that these programs include professional development as a core component of the research experience; students often participate in professional development workshops or peer mentoring through the program (Nagda et al., 1998).

2.1.2.3 Additional Variation in Experiences

While intensity is a major difference between these two types of undergraduate research programs, differences also exist within these two categories. One major way that undergraduate research experiences can differ is in the type of researcher who mentors an undergraduate (Aikens et al., 2016; Dolan and Johnson, 2010). Most students who participate in summer undergraduate research experiences are mentored by a faculty member (Laursen et al., 2010). Alternatively, students who participate in academic-year undergraduate research experiences

may be mentored by faculty members or postgraduates. Postgraduates may mentor the undergraduate student alone or in cooperation with their faculty mentor (Aikens et al., 2016).

Additional ways that undergraduate research experiences are known to differ are the student's point of entry and length of participation in the experience (Adedokun et al., 2014; Thiry et al, 2012). Summer undergraduate research experiences generally target upper-level students, who have had the opportunity to gain education in their field of interest (Kardash, 2000). Many academic-year undergraduate research experiences are designed as "capstone experiences" and occur in a student's junior or senior year (Brew, 2013). However, undergraduate students interested in doing research at their university may also contact researchers on their own to initiate a research experience (Buckley, 2010). These students may begin doing research at any point in their academic career.

2.2 Evaluating Undergraduate Research Experiences

Undergraduate research requires sizable financial support (Merkel, 2003). As a high-impact educational practice, undergraduate research has the potential to address current national calls to increase the size, diversity, and quality of our scientific and technical workforce (National Science Board, 2015, 2016; President's Council of Advisors on Science and Technology, 2012). Considering these certain costs and potential benefits, it is reasonable to expect that stakeholders who support, or stand to benefit from, undergraduate research experiences have a vested interest in evaluating the success of programs.

In my literature review, I assert that the objectives of stakeholders, to certify undergraduate research as a valid educational practice, are often conflated with educational researchers' objectives, to investigate undergraduate research's power to educate and prepare students. This

conflation has led to a field that primarily investigates undergraduate research through outcomes. While this product-focused research has successfully revealed the benefits of undergraduate research, it has failed to provide a full picture of undergraduate research. Additionally, this research is limited in its ability to provide evidence-based guidance for stakeholders interested in improving the undergraduate research experiences of students (Adedokun et al., 2012, 2014; Sadler, Burgin, McKinney, & Ponjuan, 2010).

I have organized this part of my literature review into two sections. In the first section, I summarize current product-based efforts to investigate undergraduate research experiences. I present the findings revealed by these efforts, discuss their benefits, and their limitations. In the second section, I present a review of the small but growing body of research investigating undergraduate research experiences from a process-perspective. I follow with a discussion of the benefits and limitations of these approaches.

2.2.1 Product-Based Research

Researchers began evaluating the benefits of undergraduate research in the last 30 years (Laursen et al., 2010). These efforts have been grounded primarily in product- or outcome-based research. In 2010, Laursen and colleagues published a summative report on the benefits of undergraduate research in the form of a book, *Undergraduate Research in the Sciences: Engaging Students in Real Science*. This comprehensive summary included a literature review they conducted to inform their own three-year study of undergraduate research (Seymour et al., 2004). In the original review, Seymour et al. (2004) reviewed 54 articles (including histories and reviews); Laursen et al. (2010) narrowed this body of literature to the 25 references reporting benefits from rigorous research studies.

Based on my own review of the same body of literature, it appeared that both reviews were exhaustive in their search of relevant literature. Seymour and colleague's review dated back to 1975 (Seymour et al., 2004); Laursen and colleague's review included studies that met their criteria and occurred as early as 1990. In light of the well-researched nature of Laursen and colleague's review (Laursen et al., 2010), I will begin my review of product-based research by summarizing their report. I will then continue my review by adding more recent works not reviewed by Laursen et al. (2010) or Seymour et al. (2004).

2.2.1.1 Summary of Findings from Literature

2.2.1.1.1 Undergraduate Research in the Sciences

In their literature review, Laursen et al. (2010) identified 38 unique benefits from undergraduate research, published in research studies since 1990. They categorized these gains into seven major areas. Through undergraduate research, Laursen et al. (2010) reported that students experienced: personal/professional gains, gains in thinking and working like a scientist, gains in becoming a scientist, gains in skills, enhanced career preparation, career clarification, and gains in successful career outcomes. One benefit reported by the highest number of studies (16 of 25) was an increase in the likelihood of students to attend graduate school, although a causal relationship between the two factors was reported primarily for students of underrepresented groups (Laursen et al., 2010). Additional benefits reported by over half of the studies included: increased confidence, the establishment of collegial relationships with advisors, increased understanding of research through hands-on experience, and clarification or confirmation of career interests (Laursen et al., 2010). Over one third of the studies reviewed by

Laursen et al. (2010) also reported improvements in student's ability to work independently, to communicate research, to think critically, and to problem solve.

The studies reviewed by Laursen et al. (2010) included research conducted at research institutions, laboratories, and across multiple institutions. Laursen and colleagues categorized these studies as either research studies, seeking to answer general questions about the effects of undergraduate research, or evaluations, desiring to assess the alignment between program objective and outcomes. Similar to my own assertion, Laursen et al. (2010) recognized that often studies combined these two objectives into one research study. Likewise, the programs included in these studies showed a great deal of variability in their expectations of participants. Programs varied in their expectations of dissemination, inclusion of professional development activities, and social support (Laursen et al., 2010).

The primary methods used to establish findings for these studies were survey methods, using instruments like the Survey of Undergraduate Research Experiences (SURE) by Lopatto (2004), and content analyses of open-ended evaluation questions. Laursen et al. (2010) cited the incomplete nature of this body of research, which lacked detailed descriptions of the sources of gains, to support the need for their own work (Hunter et al., 2007; Laursen et al., 2010; Seymour et al., 2004). Using qualitative methods, Laursen and her colleagues corroborated previous findings and elaborated on the source of benefits attributed to undergraduate experiences (Hunter et al., 2007; Laursen et al., 2010; Seymour et al., 2004).

Findings reported by Laursen et al. (2010) mirrored those benefits present in their literature review. As highlighted by Laursen et al. (2010), the important difference between the literature Laursen et al. (2010) reviewed and their own research (Hunter et al., 2007; Laursen et al., 2010; Seymour et al., 2004) was that the methods used by Laursen and her colleagues

allowed for in-depth investigation into undergraduate research experiences. Laursen and colleagues selected the following research question to guide their research: "What outcomes are possible from well-designed and well-implemented apprentice-model undergraduate research experiences, and by what means do these arise?" (Laursen et al., 2010, p. xix). To answer this research question, they conducted interviews at four highly ranked liberal arts colleges. The study was limited to undergraduate research programs that consisted of intensive summer research experiences. The study included interviews with 76 science students participating in undergraduate research and 55 of their faculty research advisors; 62 science students not participating in undergraduate research; 13 faculty with previous experience mentoring undergraduates in research; and 12 institutional administrators. These groups were chosen to further investigate: the benefits of academic undergraduate research experiences versus other types of research experience (e.g. internships); the perspectives of undergraduate researchers versus those of their faculty advisors; and broader institution-level perspectives (Laursen et al., 2010).

The findings from Laursen and colleague's work were presented in detail in their book (Laursen et al, 2010). However, in this review, I will discuss findings which were significant to my own work. Of interest to my own work were gains Laursen et al. reported related to discourse. These included gains in thinking and working like a scientist, gains in becoming a scientist and gains in skills. While Laursen et al. (2010) did not identify discourse as a distinct sub-category within their categories, they used discourse-related language within the discussions of all three categories. For example, while gains in communication were explicitly included in gains in skills, Laursen et al. (2010) also included learning to communicate as part of the conceptual and theoretical understanding that developed as students begin thinking and working

like scientists. As students recognized the necessity to communicate effectively in their undergraduate research experiences, they gained a better understanding of the level of theoretical and conceptual knowledge they needed to engage in discourse (Laursen et al., 2010). Likewise, as students gained these skills in communication and understanding, they began to identify or "become" scientists (Laursen et al., 2010).

In addition to reporting on benefits students gained through undergraduate research, Laursen and colleague's work (2010) revealed important information about undergraduate research experiences not previously reported. By comparing students who participated in undergraduate research with students who participated in other types of research experience, Laursen et al. determined that students gained unique benefits from participating in undergraduate research. Additionally, Laursen et al. (2010) found differences between the benefits identified by research students and those identified by their faculty advisors. While undergraduate students mentioned benefits of becoming a scientist and thinking and working like a scientist, they saw these two benefits as separate. Laursen and colleagues (2010) reported that advisors recognized the related nature of these two gains and often spoke about them together.

2.2.1.1.2 After 2010

Since the publication of *Undergraduate Research in the Sciences* (Laursen et al., 2010), researchers have continued to investigate the outcomes associated with undergraduate research. These studies have generally aligned with the findings of Laursen and her colleagues, although each study has added to our understanding through new methods and settings. In a 2-year longitudinal study involving 251 undergraduates, Robnett et al. (2015) used a cross-lagged panel analysis to test a mediation model that theorized self-efficacy to be a mediating factor in

student's scientific identity development. By comparing students' research experience, self-efficacy, and identity as a scientist at three time-points (T1, T2, and T3) in their research experience, Robnett and colleagues concluded that higher levels of undergraduate research at T1 predicted higher identity as a scientist at T3. Furthermore, the association between these two measurements was an increase in self-efficacy at T2. A study by Chemers and colleages in 2011 surveyed undergraduate members of the Society for the Advancement of Chicanos and Native Americans in Science to test a model proposing a series of mediating factors on commitment to a science career. Using structural equation model analysis, Chemers and colleagues (2011) found that both self-efficacy and identity as a scientist were strong predictors of an undergraduate student's commitment to a science career.

Similar to Chemers and colleagues' study, additional studies have investigated the role undergraduate research plays in students' commitment to science. Eagen et al. (2013) investigated the impact of undergraduate research on a student's intentions to enroll in graduate school for science. By analyzing the freshman and senior surveys of 4,152 aspiring STEM majors, Eagen and colleagues (2013) found that participation in undergraduate research significantly improved the chances that a student reported intentions to enter graduate school. Schultz and colleagues (2011) reported similar findings as a component of their study investigating whether students supported by a minority support program were more likely to persist in science. Again, Schultz et al. (2011) found that participation in undergraduate research predicted persistence in science.

2.2.1.2 Benefits and Limitations

As discussed in the introduction of this proposal, one of the primary benefits of product-focused studies has been the vetting of undergraduate research as a high-impact educational practice (Kuh, 2008). Undergraduate research is a costly endeavor, both in terms of money and time (Merkel, 2003). To justify the effort required to sustain current models for undergraduate research, it was necessary to provide evidence that these models benefit students in valuable ways that alternative models could not. This body of outcomes-based research, specifically the contribution of Laursen and colleagues (Hunter et al., 2007; Laursen et al., 2010; Seymour et al., 2004; Thiry et al., 2012), succeeded in demonstrating the importance of undergraduate research as an educational practice. Furthermore, studies like those published by Robnett et al. (2015) and Chemers et al. (2011) clarified how reported benefits interact and relate to one another, in support of measured outcomes.

The importance of establishing the unique benefits of undergraduate research cannot be overstated. Without this validation step, the purpose of all related lines of research into undergraduate research comes into question. However, there are limitations to these product-focused studies. In addition to the more obvious limitations, like the lack of generalizability to additional contexts and settings, these studies are also limited in their ability to inform evidence-based change. Just as Laursen et al. (2010) stated in their guiding research question, this type of research primarily provides information about undergraduate programs that have been designed and implemented properly. Studies which focus on the products (i.e. outcomes) of successful undergraduate research programs do so at the cost of ignoring the processes by which they occur (Adedokun et al., 2012, 2014). Without investigation into the processes that make up

undergraduate research experiences, programs desiring to increase the benefits their students realize through research are left without direction to improve outcomes.

2.2.2 Process-Based Research

One of the major limitations of current research on undergraduate research experiences is the focus on outcomes, without consideration of the processes that make up undergraduate research experiences (Adedokun, et al., 2012, 2014; Sadler et al., 2010). To date, the body of literature that has investigated the processes and contexts in which successful undergraduate research experiences occur is limited to less than half a dozen articles (Adedokun et al., 2012, 2014; Aikens et al., 2016; Dolan & Johnson, 2010). In the sections below, I review each of these articles and discuss their major findings. I separate this discussion into two parts to reflect the two processes of interest in these studies. Within each part, I include a discussion of benefits to demonstrate the value process-based research can bring to our current understanding of undergraduate research and conclude with the limitations of current work.

2.2.2.1 Findings

2.2.2.1.1 Mentorship

In 2010, Dolan and Johnson investigated the relationships existing between undergraduates, postgraduates, and a faculty member who participated in undergraduate research in a single research group. This exploratory study collected data about participants' experiences through interviews and included both past and present members of the group. In total, Dolan and Johnson (2010) interviewed eight undergraduates (one male and seven female), eight postgraduates (one postdoctoral research and seven graduate students; six males and two

females), and one female faculty head of the group. Dolan and Johnson's study revealed unique differences between the relationships within their "undergraduate-postgraduate-faculty triad."

While member of each part of the triad reported positive benefits from interactions with other types of members, members reported negative influences as well. Dolan and Johnson (2010) presented their findings as a set of five tensions that existed within the undergraduate-postgraduate-faculty triad. Tension one balanced the enhanced socialization benefits postgraduates provide to undergraduates against the negative sense of hierarchy undergraduates reported postgraduates generate. Tension two weighed the increased productivity offered by undergraduates against the increased time and effort needed to train them. Tension three compared the need undergraduates have for high-quality mentorship to the related need postgraduates have for developing those skills. Tension four balanced the lack of recognition faculty receive for including undergraduates in research against their need to include undergraduates to grow the scientific community. Tension five addressed the need for faculty to identify whether postgraduates' interests in mentoring comes from a genuine desire to mentor or a desire to satisfy the faculty member.

Of note in Dolan and Johnson's study was the difference in mentorship undergraduates received from postgraduates as compared to faculty. Undergraduates reported postgraduates to be more accessible, approachable, and able to help them transition to independent work (Dolan and Johnson, 2010). At the same time, undergraduates felt increased pressure to work long hours from postgraduates, and reported postgraduates emphasized technical aspects of projects over conceptual. While undergraduates were not as comfortable approaching the faculty member, they reported that she provided "big picture" advice and established the research culture in the laboratory (Dolan & Johnson, 2010).

Based on these qualitative differences in mentoring, Aikens and colleagues (2016) chose to explore outcomes reported from varying combinations of the undergraduate-postgraduate-faculty triad. Using the undergraduate-postgraduate-faculty triad as a base, Aikens et al. generated a list of the various triad combinations that could exist to mentor undergraduates. For example, an undergraduate could be mentored by both a postgraduate and a faculty member who communicate regularly about the undergraduate's progress (a closed triad). In contrast, an undergraduate could be mentored by both a postgraduate and a faculty member who never communicate about the undergraduate's work. In total, Aikens and colleagues (2016) generated seven potential mentoring triads that could occur based on the undergraduate-postgraduate-faculty triad.

Using a social capital theory framework, Aikens et al. (2016) hypothesized that different mentoring triads would offer undergraduates varying access to resources. They hypothesized that a closed triad, where all members of the triad were in communication, would provide undergraduates with access to the most resources (Aikens et al., 2016). Aikens and colleagues investigated the relationship between outcomes and mentoring models by surveying 842 life-science undergraduate students across 50 institutions and 25 states. Aikens et al. (2016) asked undergraduates to identify the mentoring triad to which they belonged and report on a variety of known outcomes related to research experiences.

Aikens and colleagues (2016) performed a variety of triadic comparisons to investigate the impact triad combinations had on outcomes. As hypothesized, undergraduate students mentored in closed triad models reported the most gains from undergraduate research. While many of the comparison lacked statistical significance due to sample size, Aikens et al. included reports of the holistic findings of the study. Undergraduates mentored by only a faculty members

generally reported more positive outcomes than those mentors by only a postgraduate (Aikens et al., 2016). Additionally, undergraduates mentored by both a postgraduate and faculty mentor were approximately four times more likely to report increased intentions to enroll in a graduate program after completing research than those with only a postgraduate mentor.

The two studies summarized above demonstrate different ways researchers have investigated the process of mentoring undergraduates. First, in an exploratory study, Dolan and Johnson (2010) investigated whether differences existed between the experiences of undergraduates who were mentored by postgraduates or faculty. Based on these findings, Aikens et al. (2016) were then able to investigate how these differences in mentoring impacted undergraduates reporting of positive outcomes. Aikens and colleague's study was limited by small sample size which prevented them from making many claims about the statistical significance of differing mentor triads. However, through their investigation Aikens et al. (2016) were able to draw general conclusions about the important impact mentoring triads had on students' outcomes.

2.2.2.1.2 Time

A study by Adedokun et al. in 2014 investigated the effects of time on students' perceived gains from an undergraduate research experience. To investigate time effects, Adedokun and colleagues administered a survey to 27 undergraduates three times over a one-year period. Students completed questionnaires before they began participating in undergraduate research, after a summer of undergraduate research, and after a full year of undergraduate research. Undergraduates were evenly distributed across sophomore, junior, and senior academic standing. The survey consisted of known outcomes resulting from undergraduate research

experiences like increases in research skills, awareness of career options, and gains in research confidence. Adedokun and colleagues (2014) used repeated-measures analysis of variance (ANOVA) to examine the effects of time on students' reported outcomes.

Findings from Adedokun and colleague's study indicated that students experienced different gains and benefits at specific stages of their undergraduate research experience. Statistically significant gains occurred in the skills of observing and collecting data at the end of the summer experience. However, at the end of the first year of experience, students reported additional gains in research skills that are considered to require time to develop (e.g. oral communication, working independently, analyzing data).

2.2.2.2 Benefits and Limitations

I have summarized the studies in this section to demonstrate the importance of process-focused research for informing our understanding of undergraduate research. Unlike outcomes-focused research, process-focused studies offer detailed analyses about how undergraduate research experiences occur. These studies can contribute to a deeper understanding of the phenomenon of undergraduate research. Additionally, studies have the potential to help explain why benefits are experienced by some students in undergraduate research experiences and not others (demonstrated by Aikens and colleague's application of the findings from Dolan and Johnson, 2010).

2.3 Conclusion

My study builds on these product and process-focused investigations by exploring the role discourse plays in undergraduate research experiences. This work made use of the findings reported in outcomes-based studies like those by Laursen and colleagues (Hunter et al., 2007;

Laursen et al., 2010; Seymour et al., 2004) to explore processes of undergraduate research. My work was also informed by the process-based research literature I have reviewed (Adedokun et al., 2014; Aikens et al., 2016; Dolan & Johnson, 2010). These works led me to recruit students at different points in their undergraduate research experience, being mentored through a variety of models. At the same time, my study extends this body of work by introducing methods previously unused to investigate undergraduate research.

My study was based on the observations of students and mentors working in their natural environment. One major limitation of the current process-based research summarized was a strong reliance on participant interviews. As demonstrated in Laursen et al. (2010), perspectives of undergraduate students differed from those of their mentors. Therefore, when considering the findings of these studies, it was necessary to remember that most of these findings reflected students' perceptions of the process of undergraduate research. These perceptions may differ from those of mentors or of independent observers. By investigating discourse both through observations and interviews with students and mentors, my study provides a more detailed picture of a previously uninvestigated aspect of the undergraduate research experience.

CHAPTER 3. METHODS

My initial interest in this research began as a desire to investigate how students learned to speak as scientists in research settings. I was therefore motivated to better understand what made undergraduate research uniquely beneficial for developing students' communication skills (Laursen et al., 2010). As I began to work in this area, it became clear to me that the lack of evidence in the literature on how students learned to communicate as scientists in research settings necessitated that I begin my work with a pilot study. In the first section of this chapter, I include a brief summary of a pilot study I conducted and the relevant findings. I end the section by identifying the ways my pilot studies informed future data collection before moving on to describing the methodology for the current research.

3.1 Pilot Study

I began my pilot study with the goal of exploring the role of scientific discourse in undergraduate research experiences. Because an unambiguous definition of scientific discourse did not exist in literature, my own understanding of scientific discourse was informed by multiple sources, including work by Berland and Reiser (2009), Berland and McNeill (2012), Duschl (2007), Duschl and Grandy (2007), Driver and colleagues (2000), Kuhn (2010), Lawson (2010), and Osborn and Patterson (2011). From these perspectives, I conceptualized scientific discourse as collaborative discourse that examined and assessed the transformation of evidence into explanation (Duschl, 2007).

My interest in scientific discourse was supported by prior research asserting the importance of scientific discourse to scientific discovery (Lawson, 2010). Moreover, the benefits Laursen and colleagues (2010) reported concerning the growth of undergraduate research

students in two categories, thinking and working like a scientist and becoming a scientist, led me to anticipate that evidence of these skills may be detectable through observing the scientific discourse students participated in while working in the laboratory. I developed two research questions to guide by investigation:

1. What norms of scientific discourse frame verbal interactions in undergraduate biochemistry research experiences?
2. How are the norms of scientific discourse established in undergraduate biochemistry research experience?

3.1.1 Pilot Study Design

I used purposeful sampling (Patton, 1990) to select a student-mentor pair as participants in a pilot study that included a graduate student mentor working with a newcomer (i.e. a novice) (Thiry & Laursen, 2011) to research. This pair consisted of an undergraduate who was given the pseudonym "Sam," who was participating in his second semester of research, and a graduate-student mentor who was given the pseudonym "Mary." Sam and Mary elected to continue participating in my research after the pilot study ended and more details about each of their backgrounds will be described in Chapter 4.

I observed Sam and Mary working together for about two hours on three consecutive days. The observations were audio recorded using an Olympus digital recorder equipped with a lapel microphone worn by Sam. I also recorded the research space using an Apple iPhone 5 placed on Mary's bench. I was physically present for all observations, during which time I collected field notes focusing on data that the recording devices might miss (e.g. gestures). I conducted interviews with Sam and Mary within two weeks of my final observation that were audio-recorded. These interviews were semi-structured and informed by the literature on

communities of practice (Lave & Wenger, 1991) and cognitive apprenticeship (Collins, Brown, & Newman, 1989).

I transcribed both observations and interviews verbatim. I then explored the use of a variety of coding schemes to identify patterns in my data. These included open-coding approaches informed by argumentation and explanation (Berland & Reiser, 2009; Braaten & Windschitl, 2011; Brigandt, 2016; Osborne & Patterson, 2011), and scientific discourse (Duschl, 2007; Duschl and Grandy, 2007; Driver, Newton, & Osborne, 2000). It eventually became clear that neither approach was appropriate for my analysis because my data contained little evidence of argument and explanation construction or scientific discourse.

At this point, I chose to analyze my data from a broader perspective. I used an open-coding approach informed by Gee's 27 discourse analysis tools (Gee, 2011b) to code both observations and interviews. Details about this approach appear in the Section 3.4.3 Data Analysis. After multiple coding iterations, I generated themes to describe the norms of discourse present in the case and the ways those norms were established.

3.1.2 Relevant Findings and Implications

During the course of this pilot study, it became clear that viewing my observations of discourse in undergraduate research settings through the lens of scientific discourse was not a productive path because I observed no evidence of collaborative explanation or argument construction between Sam and Mary. I did observe evidence of Mary providing explanations to Sam; however, these were not abundant incidents. As a result of these findings, I decided my research questions were too narrow because they excluded the majority of discourse I observed. For example, my questions did not allow me to explore conversations where Mary instructed

Sam in techniques, offered Sam support as he worked, or spoke about her experiences in research. These types of conversations represented the majority of Mary and Sam's discourse. Therefore I chose to modify my research questions to expand the scope of my lens to all discourse, in order to explore these types of conversations.

Additionally, I found that the interview protocol I developed required modification. The initial design resulted in Sam and Mary speaking more in their interviews about their relationship as student and mentor and less about how they spoke while working together. From this experience, I decided that to explore the nature of participants' discourse, I needed to adopt an interview protocol which emphasized reflection on specific conversations.

3.2 Guiding Research Questions

The goal of my study was to explore the nature of the conversations undergraduate students and their mentors had in undergraduate biochemistry research experiences. As a first step in exploring this little "d" discourse (Gee, 2011a), I chose to revise the first research question so that it focused on the following question:

1. *What norms of discourse frame conversations between students and mentors in undergraduate biochemistry research experiences?*

As I characterized the conversations between students and mentors, three secondary questions were asked that were informed by my theoretical perspective, discussed in the following section. To investigate norms of discourse, I first had to parse multi-hour conversations into manageable units or activities. These activities were further separated into individual participants' contributions to the conversation and, finally, the features that characterized these individual

turns-at-talk. Consequently, I generated the following as extensions of the language in the first research question.

a. *What activities frame conversations between students and mentors?*
b. *What discursive practices do students and mentors engage in during individual turns-at-talk?*
c. *What vocal and non-vocal features characterize the individual turns-at-talk of students and mentors?*

Once I had identified the norms of discourse that framed conversations, I wanted to understand how these norms were established. I therefore modified my second research question to read:

2. *How are the norms of discourse established in undergraduate biochemistry research experiences?*

Finally, I observed that the conversations I was investigating were set both within the context of individual student-mentor relationships and within the larger frame of students' experiences in undergraduate research. I was interested in exploring how these conversations shaped the research experiences for my participants. I therefore developed a third research question:

3. *What impact do conversations between students and their mentors have on the undergraduate research experience?*

3.3 Theoretical Underpinnings

Designing a research project requires the researcher to make a series of decisions. For qualitative research, one of the most important choices is the selection of a theoretical frame. It has been said that all research is guided by some theoretical perspective, regardless of whether

these assumptions are stated (Bogdan & Biklen, 1998; Merriam, 2009). However, for a researcher to take full advantage of the power of a theoretical frame, they must be precise in communicating both their interpretation and application of theory (Bodner, 2004).

Multiple perspectives exist on the role that theory plays in a qualitative research project (Anfara & Mertz, 2015). In this project, I took the broadest position identified by Anfara and Mertz (2015). While a theoretical framework can be called the "lens" through which a researcher views their data, I considered the theoretical underpinnings of my project to play a role throughout the design and execution. In this work, the theoretical underpinnings provided guidance far beyond selection of the appropriate methodological and analytical approaches (Denzin & Lincoln, 2011). Identification of these core assumptions shaped all my thoughts related to this project, from informing the development of my research questions to clarifying and communicating my own reasons for proposing this project (Merriam, 2009).

To reflect my opinion of theory as the foundation of my project, I used the term theoretical underpinnings when describing the assumptions I brought to this project. The foundation on which I built my research drew from hermeneutics, ethnomethodology, and conversation analysis, a sub-field of linguistic analysis existing under the umbrella of discourse analysis theory. In the following sections, I provide details about my interpretation of these bodies of literature. I then describe how these underpinnings provided support and guidance in my work. I end with a synthesis of the three into a cohesive framework.

3.3.1 Hermeneutics

Hermeneutic studies (Laverty, 2003; Patton, 2002) focus on interpretation of texts as a way of understanding (Gadamer, 1965/1985, 1976; Laverty, 2003; Patton, 2002). Hermeneutics

finds its roots in the practice of interpreting religious texts; however, modern-day hermeneutical studies may interpret texts from a variety of original forms, including spoken language (Patton, 2002; Shane, 2007). It is common for a hermeneutic study to use multiple types of text to aid investigation (Patton, 2002).

Studies in this domain seek to investigate how participants construct meaning (Patton, 2002; van Manen, 1990). These studies emphasize understanding, diverging from research approaches that seek to offer an explanation or solve a problem (Patton, 2002). Within this perspective, the meaning constructed by language and the language itself are inseparable and should be considered together (Gadamer, 1965/1985, 1976; Laverty, 2003).

A key characteristic of hermeneutic studies is the consideration of context. To interpret texts, a researcher must consider the context in which participants created the text (Gadamer, 1965/1985, 1976; Laverty, 2003; Shane, 2007). One aspect of this context is consideration of the time in which the text was constructed, known as the *historicity* (Gadamer, 1965/1985, 1976). Likewise, the interpretation of a text is bound by the context in which it was interpreted (Gadamer, 1965/1985, 1976). The goal of a hermeneutic study is not to generalize across audiences or reveal the truth of participants (Gadamer, 1965/1986, 1976; Laverty, 2003; van Manen, 1990). Instead, interpretation of a text is subjective; it is specific to both the context in which the text was created and the context in which the researcher interpreted it (Gadamer, 1965/1985, 1976; van Manen, 1990). This rejection of objectivism and acceptance of the role a researcher plays in interpretation is referred to as a fusion of horizons (Gadamer, 1965/1985; Laverty, 2003).

Because of the role the researcher plays in interpretation of text, it is important for studies that use a hermeneutic approach to clearly express the context in which the researcher

approaches interpretation, i.e. the role of the researcher. To provide information about how I approached interpretation of data for this study, I included a reflection at the end of this chapter on my role as the researcher. This discussion includes not only the roles I played in the research, but also an analysis of the perspective in which I began interpreting data and any biases I may knowingly brought to the research. Additional details about my experiences and perspective appear in the introduction to this study in Chapter 1.

In addition to acknowledging the perspective a researcher brings to interpretation of texts, hermeneutic studies recognize the dynamic nature of a researcher's perspective. While a researcher may begin approaching interpretation in one way, by repeatedly interacting with texts their understanding of the meaning of the texts may change (Gadamer, 1965/1985). The practice by which interpretation of text informs perspective, and thus, interpretations of future analyses of texts is referred to as the *hermeneutic cycle* and is a core component of hermeneutic studies (Bodner, 2004; Laverty, 2003; Shane, 2007).

In this study, hermeneutics guided my choice of a case-study approach in which to ask my research questions. The interpretation of text requires rich, descriptive knowledge about the context in which the text was constructed. In order to collect the level of detailed data needed for interpretation, it became clear to me that the best approach for my study was a case-study approach. I support my choice to use a case study approach to the analysis of the data collected in this study in the research design section below.

3.3.2 Ethnomethodology

Ethnomethodologists seek to explore the practice of understanding the world, with the goal being to make the common sense, invisible components of humans' interactions in the

world visible (ten Have, 2004). Ethnomethodology finds its roots in sociology, specifically the work of Harold Garfinkel (Coulon, 1995), whose *Studies in Ethnomethodology* (1967/1984) served as a foundational book for ethnomethodological research (Coulon, 1995). In this work, Garfinkel asserted social facts to be unstable and produced by the continuous activities of people. This viewpoint conflicted with that of many sociologists, establishing ethnomethodology as a technique apart from conventional sociology (Coulon, 1995). While this is a distinct approach to research, many of the concepts of the approach are borrowed from related social sciences (Coulon, 1995).

A core component of ethnomethodology is "the documentary method", which borrows *indexicality* from linguistics and *reflexivity* from phenomenology (Coulon, 1995; David & Sutton, 2010). Indexicality is the recognition that all representational forms (e.g. words) have a vague or incomplete aspect to them, which only begins to disappear when performed (Coulon, 1995; David & Sutton, 2010). This is consistent with the assumption that these phrases only have meaning when placed in context, acted out by a 'speaker' in the presence of a 'listener'. Reflexivity refers to how meaning is applied to specific representational forms through the referral to patterns (David & Sutton, 2010). This referral is not reflective, but is an unconscious and instantaneous process that the listener goes through in order to understand (Coulon, 1995). Together, these terms describe the circular accounting method by which people make sense and sustain a social order (David & Sutton, 2010).

Unique to ethnomethodology is the view that social science research is bound by this same documentary method (David & Sutton, 2010). Because the data that is used to create theories is also used to support the validity of those theories, Garfinkel criticized this process of finding 'truth' by calling it a self-referential ploy (David & Sutton, 2010). In response,

ethnomethodology takes a stance of indifference towards what is the truth, focusing instead on the process or interaction by which meaning is communicated and created (David & Sutton, 2010). Ethnomethodology considers the process by which a member of a group describes and extracts meaning to hold a higher value than the information itself (Coulon, 1995).

To become a member of a group, Garfinkel explains that one must master the common language of that group (Coulon, 1995). Practicing mastery is not a conscious process or a difficult one; for a member, mastery involves everyday social practices. While foreign to an outsider, a member cannot identify the nuances of their *ethnomethods* or the ethnomethods of their group, as they have been transformed into a member. Membership in a group therefore describes the embodiment of the language and ethnomethods of the group (Coulon, 1995). Because of this embodiment, members take for granted the methods by which they make meaning within their social structure (Garfinkel, 2002).

Ethnomethodologists have used a variety of methods to explore the practices of everyday interactions that include interviews, case-studies, comparative analysis, secondary data analysis and ethnomethodological methods (David & Sutton, 2010). Traditionally, Garfinkel relied on a theory of disruption of norms to uncover unseen practices (David & Sutton, 2010). Garfinkel's historical experiments in many cases involved unknown recording or deception, methods that would now be considered unethical (David & Sutton, 2010).

More recently, the method of taking accounts of a newcomer has been identified as useful to ethnomethodology (Bhattacharyya, 2007). In this method, a researcher listens to a participant make sense of their daily practices in a new culture. The researcher places emphasis on the participant's account, in an effort to uncover the sense-making process of the newcomer. This

method has also been identified as useful to educators interested in student sense-making (Bhattacharyya, 2007).

In this study, ethnomethodological principles guided my development of participant selection criteria. Because I was interested in ethnomethods (Coulon, 1995) of students and mentors in undergraduate research experiences, this body of work guided me to investigate the experiences of newcomers to undergraduate research experiences. Likewise, ethnomethodological principles guided my choice to use the disruption of norms to uncover unseen practices by including interviews that required participants to reflect on their discourse mid-observation, instead of only after my data collection was complete.

3.3.3 Conversation Analysis

Conversation analysis is the exploration of language in action (Antaki, 2011). As a sub-field of discourse analysis, conversation analysis shares many goals with discourse analysis. Both seek to understand the world (Gee, 2011b), specifically as it is constructed through discourse in context (Marra, 2013). Because conversation analysis is a type of discourse analysis, my research was informed by both bodies of literature. Therefore, in this section, I provide background and theory related first to discourse analysis and then to conversation analysis.

Jørgensen and Phillips (2002) contended that discourse analysis could not be used as an analytical method independent from theoretical and methodological underpinnings. As a method of analysis, discourse analysis should be applied in conjunction with additional theoretical guidance. Although many theoretical approaches that use discourse are available, it is acceptable to construct one's own perspective (Jørgensen & Phillips, 2002). In these cases, Jørgensen and Phillips (2002) advised that care be taken to select commensurate theories by comparing

approaches to determine what knowledge each approach can bring to a study and how they may work together.

Gee (2011b) shared this perspective, adding that the analysis of language should have purpose. In his view, discourse analyses should have two purposes: to gain evidence for theories that explain how and why language works when enacted and to contribute to issues and problems that motivate at the global level (Gee, 2011b). Historically, these two purposes have been viewed as separate types of discourse, descriptive and critical (Gee, 2011b). While it is considered possible for a study to be interested only in the description of language (Gee, 2011b), or the role language plays in world problems, I shared Gee's view that the critical perspective was inherent to my analysis of discourse. Discourse analysis involves the investigation of details of speech, within the context in which it is spoken (Gee, 2011a; 2011b; Jørgensen & Phillips, 2002). Therefore, in this work, I did not differentiate between descriptive and critical discourse analysis, as my research questions were served by consideration of both aspects of discourse.

Discourse analysis is not a single, linear approach to data collection; the method of analysis is guided and informed by supporting theory (Gee, 2011a). As a method of analysis, discourse analysis works with supporting frameworks to investigate the details of language which are determined relevant, through theory, to the research interest in the desired context (Gee, 2011a). The details of interest in language may include a variety of aspects, like grammar, gestures, or emphasis used in speech (Gee, 2011a, 2011b). The defined context may be framed by specific physical environments, social hierarchies, shared knowledge, or other aspects that aid in understanding how meaning is constructed through language (Gee, 2011a, 2011b).

In the case of discourse framed by social interaction, a more appropriate term to refer to this analysis may be conversation analysis (Marra, 2013). Conversation analysis emerged from

sociology and was founded as a discipline by Harvey Sacks (Clayman & Gill, 2011; Sacks, 1984). As a domain of study, the creation of conversation analysis was heavily influenced by ethnomethodologists of the day, including Harold Garfinkel (Clayman & Gill, 2011). This influence can be seen in Sacks' description of conversation analysis as, "the methods persons use in doing social life" (Sacks, 1984, p. 21). It is also evident in his description of some of the central findings of his research, as summarized below,

> The detailed ways in which actual, naturally occurring social activities occur are subjectable to formal description.
> Social activities—actual, singular sequences of them—are methodical occurrences. That is, their description consists of the description of sets of formal procedures persons employ.
> The methods persons employ to produce their activities permit formal description of singular occurrences that are generalizable in intuitively nonapparent ways and are highly reproducibly usable. (p. 21).

Conversation analyses are concerned with naturally occurring interactions (Clayman & Gill, 2011). While conversation analysts acknowledge the *observer's paradox* (Labov, 1972), the effects of being observed are generally considered trivial since behaving as if observed is a natural part of conversation (Goodwin, 1981). Furthermore, while the act of being observed may become part of the conversation, ten Have (2007) contended that the effects extend only to surface features. Regardless of the topic being discussed, the structures of discourse present in the conversation remain intact (ten Have, 2007).

Of particular interest to my study was theory supporting a form of conversation analysis referred to as institutional applied conversation analysis (Antaki, 2011). This applied form of conversation analysis seeks to shed light on conversations occurring in 'institutions' or places separated from casual life (Antaki, 2011). Institutions are physical and metaphorical spaces separated from casual life by a variety of barriers including the rules that direct conversation (Antaki, 2011). While this form of conversation analysis may assist in assisting improvement of

an institution, it is usually initiated from an interest in exploring the inner workings of an institution's operation (Antaki, 2011). In my own work, I considered undergraduate biochemistry research experiences, which are separated most clearly from casual life by their occurrence in laboratory spaces, to meet the given definition of an institution.

Clayman and Gill (2011) provided a set of guidelines for how to approach the analysis of conversation, which may be explored at a variety of levels of granularity. In this approach, they asserted that all aspects of interaction are possible sources for analysis. To organize units of conversation, Clayman and Gill (2011) introduced the term *activity frameworks*. These interactions are episodes focusing on singular actions, for example, "greeting a person" or "talking about class." Beyond this level, Clayman and Gill (2011) identified conversations to be made up of sequences of actions, like two speakers engaging in a question—answer sequence, and, at an even finer level, independent actions that make up such sequences (e.g. a speaker's turn-at-talk used to ask a question). Beyond this level, Clayman and Gill (2011) described a fine-grain analysis focusing on a variety of features mobilized within independent actions. These features included aspects like intonation, gesture, and choices of language (Clayman & Gill, 2011).

While Clayman and Gill (2011) spoke about features in the context of conversation analysis, Gee described the analysis of these fine-grain details of discourse as the questions a researcher asked about the discourse of interest (Gee, 2011b). To support this approach to discourse analysis, he published a set of 27 discourse analysis tools in the form of questions. In the Data Analysis section below, I describe how guidance from Clayman and Gill (2011) and Gee (2011b) informed my analysis of conversations. My analysis of these conversations

emphasized the little “d” discourse (Gee, 2011a) that occurred between students and mentors as they engaged in research together.

Theory from conversation analysis and discourse analysis provided a frame around which I constructed my analytical approach. I made use of the flexible nature of discourse analysis to integrate hermeneutics and ethnomethodology into my analysis. This integration was supported by the close ties between ethnomethodology and conversation analysis (Clayman & Gill, 2011). The suggested guideline by Clayman and Gill (2011) provided a starting point for my analysis. I began my analysis by identifying activity frameworks and individual actions by speakers. When I began to explore conversations at a fine-grain level, Gee (2011b) provided a deeper approach to the analysis, as described in Section 3.4.3.

3.3.4 Synthesis and Critique of Theory

Because the guiding research questions for this study focused on the conversations between students and their mentors, it was necessary for my theoretical underpinnings to be able to provide direction in the understanding of words. This condition was met by all three of the frameworks I have discussed. In the cases of hermeneutics and conversation analysis, both theoretical approaches include commensurate assumptions about the role words play in meaning-making. Words (or text) are at the core of both theories; in each case, the meaning of words can only be determined by considering the context in which the words were created. While not as confined in application, ethnomethodological theory can also be used to guide the investigation of words. The practice of discourse is an everyday interaction, guided by norms determined by the community of interest; discourse is a type of ethnomethod. Furthermore, like hermeneutics

and discourse analysis, ethnomethodology contends that the understanding of this ethnomethod can only be achieved by considering the context of the interaction.

The role context plays in hermeneutics, ethnomethodology, and conversation analysis is not limited to the participants. All three theories embrace the influential role of the researcher, acknowledging that the context in which the researcher views the data will also have an impact on interpretation. At the heart of these theories is an implicit assumption about the nature of truth and knowing (David & Sutton, 2010; Gadamer, 1965/1986, 1976; Gee, 2011a; Laverty, 2003; van Manen, 1990). The theoretical assumptions that guided my research reject the idea that absolute truth exists; they function from an *interpretivist* standpoint (Patton, 2002). In this way, these views arise from compatible philosophies, which were also in line with my own research approach and the goals of this study.

One way to demonstrate the alignment between the goals of this project and the chosen theory is to consider the impact applying an alternative theory would have on execution. For example, if the chosen focus of research (i.e. undergraduate research experiences) were approached from the perspective of critical theory (Patton, 2002), I could still have investigated the conversations between students and mentors in undergraduate research experiences, but my research would have been informed and guided by issues of power or justice (Patton, 2002). Rather than seeking to understand the institution of undergraduate research, my approach would have included a desire to address some issue I identified as important (e.g. the role discourse plays in female students gaining access to community resources during undergraduate research experiences).

3.4 Research Design

To answer my proposed questions, I approached this study from a case-study perspective. Merriam (2009) highlighted the difficult nature of talking about case-study research, which originated in part from the tendency of researchers to use the term *case study* when referring both to the process and product of research. Further confusion comes in as discussion evolves into descriptions of *cases*, the unit of analysis for a case study (Merriam, 2009). To prevent this confusion, I use the term to refer exclusively to the process of research in this chapter of my document. When discussing the unit of my analysis, I use the term *case* to refer to each separate unit.

A case-study approach was appropriate for my research because it allowed me to collect rich, descriptive data about students' experiences in undergraduate research (Creswell, 2007; Eisenhardt, 1989). As demonstrated in my literature review, there was limited research on the unique processes that make up an undergraduate research experience (Adedokun et al., 2012, 2014). This lack of information necessitated that my research be exploratory in nature. While useful for research at a variety of stages, a case-study approach is considered particularly useful for early stages of research (Creswell, 2007; Eisenhardt, 1989).

A case-study approach was also beneficial because it provided direction and focus to my research. As demonstrated by Laursen et al. (2010), undergraduate research is a complex experience, made up of several distinct but interrelated components. Students from a variety of backgrounds engage in undergraduate research in many different contexts (Lopatto, 2004). To approach exploration of this complicated topic in an effective manner required a methodology that would direct and limit my investigation to a well-defined context. Merriam (2009) considers a key characteristic of the case-study approach to be its focus on a clear unit of analysis, the case.

This approach relies on the researcher's identification of a bounded context (Merriam, 2009). To investigate undergraduate biochemistry research experiences, I identified my bounded system as the student-mentor pair, which functioned as the unit of analysis for the study. I will discuss further details concerning my choice of cases below in the following section on participants.

3.4.1 Participants and Setting

My goal for this study was to explore the language used by a specific population, those undergraduate students and mentor pairs that participated in biochemistry research together. I collected data at a large Midwestern, research-intensive public institution that belongs to the Association of American Universities (AAU). Data was collected in the form of observations in the laboratories of participants and interviews in a dedicated space in the department.

To investigate these communication practices, I made use of purposeful sampling, which Patton (1990) described as a design strategy where specific cases are selected for study because they provide information about the phenomenon of interest. The purpose of this approach was not to make generalizations about a population, but to study a chosen phenomenon in depth (Patton, 1990).

Since I was interested in methods of communication that existing members may take for granted in their community (Garfinkel, 2002), I used theory-based sampling (Patton, 1990) to guide recruitment in my study. One common ethnomethodological approach to investigating those seemingly invisible phenomena is to focus on the experiences of newcomers in a community (Bhattacharyya, 2007; Roth, Bowen, & McGinn, 1999). In my own work, I used this approach to guide my recruitment of participants at different times in their experience of

undergraduate research. I recruited two types of student-participants: novice and experienced undergraduate student researchers.

No definitive guideline existed for an *a priori* differentiation between novice and experienced undergraduate research students. I therefore used previous work on undergraduate research students to guide my own definitions. In line with the classifications by Thiry and Laursen (2011), I considered students who had completed two semesters or less of undergraduate research as novice participants (i.e. newcomers). Students with three or more semesters of experience were considered experienced research students. Intensive summer research experiences were considered equivalent to one semester of research.

I also used a theory-based sampling approach to differentiate my selection of student-mentor pairs further based on the identity of the mentor. This decision was guided by work by Dolan and Johnson (2010), which suggested qualitative differences exist between the undergraduate research experiences of those students mentored by faculty members, compared to those mentored by postgraduates. Based on these findings, I sought to recruit a variety of mentors. My student-mentor pairs included students working with a faculty mentor and two types of postgraduate mentors, a graduate student and a postdoctoral associate.

My choice to explore three distinct types of cases was an effort to increase the variability across my cases (Merriam, 2009), as the diversity in cases has been argued to strengthen both the validity and stability of findings (Miles & Huberman, 1994). The decision to limit my study to three cases was guided by the primary benefit a case-study approach provided; the opportunity to analyze and explore a bounded system in an in-depth manner (Merriam, 2009). The goal of my work was to collect rich data. This contrasted with alternative approaches that may desire to maximize the information gained from collection (Lincoln & Guba, 1985). By limiting the

number of cases I observed, I increased the time I could spend with each case and the quality of data I collected.

3.4.2 Data Collection

Simultaneous data collection for multi-case studies is difficult to manage (Merriam, 2009). To reduce the confusion that could come with collecting data from multiple cases at once, I conducted data collection for my cases in sequence. In addition to simplifying the process of data collection, this approach allowed me to apply knowledge and experience I gleaned from previous cases to future ones (Bogdan & Biklen, 1998).

Three primary sources of data were used in this study: (a) observations of student-mentor pairs working in the laboratory, (b) individual interviews with students and mentors, and (c) documents such as laboratory notebooks, protocols, group webpages, and published articles. Because of the variety in the four cases I observed, the role each data source played differed. In the descriptions below, I discuss how I collected each source of data.

For each case, my general data-collection approach followed a stimulated recall design (Lyle, 2003). Student-mentor pairs were observed and recorded in the laboratory working together. After observation, each participant was interviewed using a semi-structured interview protocol (Creswell, 2009) that included prompts in the form of video recorded data from their working together (Lyle, 2003). Details concerning these interviews appear in Section 3.4.2.2. I referred to this combination of observation and interview as a cycle. The number of cycles conducted was unique to each case. My decision to continue or end data collection with a case was determined by the nature of each individual case and my assessment of whether I have reached theoretical saturation (Merriam, 2009).

3.4.2.1 Collecting Observational Data

Observations were conducted in the laboratories of student-mentor pairs. All observations were audio and video recorded. I used two audio recorders. An Olympus digital recorder, equipped with lapel microphone, was worn by the student participant. Audio and video were also recorded using a Drift Ghost-S Professional HD Action Camera, mounted to a headband worn by the student. The decision to use both audio and video recorders was guided by my pilot study and theoretical underpinnings. Although my research questions focused on norms of discourse, it became apparent while analyzing the audio-data collected that interpretation depended on my ability to see the student and mentor working together in the laboratory. Because the researchers moved around the laboratory while working, I determined a stationary camera would be unsuitable for collection.

The Drift Ghost-S provided two advantages. First, its small, head-mounted design allowed for noninvasive, continuous data collection while the student and mentor moved about the space. Second, by mounting the camera to the student, the video collected was from the participant-perspective. This mounting-style allowed me to see details of what the student was doing (e.g. reading a protocol, preparing chemicals, writing notes) and could provide context for my interpretation of dialogue. This second role was particularly important to my study since context was an essential aspect that must be considered in the interpretation of texts (Gadamer, 1965/1985, 1976; Laverty, 2003; Shane, 2007).

For each cycle, I conducted two to five “observations”; an observation ranged from two to four hours. I was physically present during the first observation. For this observation, I collected field notes (Corbin & Strauss, 2008) focusing on data that the audio and video recording devices could miss (e.g. gestures outside the camera’s line of sight, soft spoken

dialogue). I also recorded observations about the student-mentor pair's discourse and interactions that could be relevant to my analysis. When possible, I synced and reviewed the data collected by audio and video the same day as the first observation using QuickTime Player.

This review helped me determine whether my physical presence was needed for future observations. When reviewing, my primary concern was that the audio-data was clear enough for future transcription. I also compared my field notes to the video-data to see if the video-recorded data provided sufficient context for my interpretation of dialogue. I *memoed* about potential norms I detected in the data while conducting this review (Corbin & Strauss, 2008). Details of this process are discussed in the data analysis section. When I determined both sources of data were high enough quality for me to analyze, I conducted future observations using only audio and video recording as described above.

Because each case was unique, I was unable to predict how many observations would be needed to begin identifying the norms of discourse present in an individual case. To make this judgement, I compared the data collected from the first observation to that of the second to determine if more observations were necessary. If the data recorded in the two observations was different enough that I was unable to begin identifying discursive norms, I conducted additional observations. My goal was for each observational cycle to occur in the same seven-day time-period; however, this was dictated by participant availability. Some undergraduate participants had limited availability and worked in the laboratory only a couple of days a week.

3.4.2.2 Collecting Interview Data

After completing the first set of observations in a cycle, I reviewed the cycle's audio and video data. In this review, I took notes about both the student's and mentor's discourse, and

selected clips to be used in the subsequent individual interviews. I used purposeful sampling (Patton, 1990) to select clips that were useful for shaping the interviews to yield data that addressed my research questions. I selected clips of conversations based on the following selection criteria: both the mentor and student participated in the conversation, the conversation met Clayman and Gill's (2011) definition of an activity framework, and the conversation was representative of my observations. For example, in each case I selected a clip where the mentor explained a conceptual or logistical aspect of a protocol to the student as the student responded with affirmations or questions. These clips were selected both because they included a high level of interaction between student and mentor, and because the incident could be described as a discrete activity (i.e. explaining background information) (Clayman & Gill, 2011). The nature of these selections was guided by the norms of discourse made evident from observations of each case. I selected the same clips for interviews with the student and mentor. The length of clips was between 30 seconds and two minutes. After identification, I used QuickTime player to isolate individual clips.

Because the purpose of the audio and video clips was to help participants recall and reflect on their experiences in the laboratory, I selected a maximum of 10 clips per interview. Clips were prioritized with the most promising ones occurring at the beginning of the interview. I used these selected clips to design unique interview questions for each individual participant. For each clip, I asked questions to help the participant reflect on and speak about their discourse. Figures 3.1 and 3.2 provide examples of how these interviews were constructed for each participant based on their case's clips. Examples of the full semi-structured interview protocol I created for mentors and students appear in Appendices A and B.

MENTOR INTERVIEW PROTOCOL
CASE 3 ROUND 1

Introduction
Thank you for agreeing to participate in this study on discourse in undergraduate research. I have two purposes for this interview. First, I would like to talk about your experiences working with your student in undergraduate research. Second, I want to play some video clips of you and your student working in the laboratory together and have you reflect on them.

1. How did you begin working with Simon?
    a. When did you begin working together?
    b. How was the experience initiated?
2. How do you see your role working with Simon?
3. Approximately how many students have you worked with before Simon?
    a. Undergraduate students?
    b. Graduate students?
4. Please tell me about your experiences doing research as an undergraduate.
    a. How does your experience in undergraduate research inform how you mentor your undergraduate student?
5. Please tell me about your experiences doing research as a graduate student and postdoc.
    a. How does your experience in graduate or postdoctoral research inform how you mentor your undergraduate student?
6. What other types of experiences guide how you shape Simon's undergraduate research experience?
7. Please tell me about your current research and the project you are working on with Simon.
8. What kinds of changes have you noticed in how you and Simon interact since she began working with you?
    a. Changes in you?
    b. Changes in Simon?

Video Clips
I have selected 8 clips that I would like to play for you of different conversations you and Simon have had in the lab since I began observing. After listening to a clip, I would like for you to reflect on the conversation you were having with Simon by answering some questions.

Clip 1 Beginning of the day
How would you describe what you and Simon are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What previous experience has Simon had with this procedure?
What did you mean by "this time, I'll let you lead the way and I'll just follow you"?
What do you think Simon meant by "you won't let me mess something up real bad"?

Figure 3.1 Excerpt from mentor interview protocol for case three round one

STUDENT INTERVIEW PROTOCOL
CASE 3 ROUND 1

Introduction
Thank you for agreeing to participate in this study on discourse in undergraduate research. I have two purposes for this interview. First, I would like to talk about your experiences working with your mentor in undergraduate research. Second, I want to play some video clips of you and your mentor working in the laboratory together and have you reflect on them.

1. Please tell me a bit about yourself.
    a. What's your major?
    b. Year in school?
    c. Where are you from?
    d. What classes are you taking this semester?
    e. What kinds of questions do you ask in class?
2. How did you begin working with Mia?
    a. When did you begin working together?
3. What previous experience have you had doing research?
4. How do you see your role working with Mia?
5. Please tell me about the current project you are working on with Mia.
6. What kinds of changes have you noticed in how you and Mia interact since you began working with her?
    a. Changes in you?
    b. Changes in Mia?

Video Clips
I have selected 8 clips that I would like to play for you of different conversations you and Simon have had in the lab since I began observing. After listening to a clip, I would like for you to reflect on the conversation you were having with Mia by answering some questions.

Clip 1 Beginning of the day
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
What previous experience have you had with this procedure?
What do you think Mia meant by "this time, I'll let you lead the way and I'll just follow you"?
What did you mean by "you won't let me mess something up real bad"?

Figure 3.2 Excerpt from student interview protocol for case three round one

Interviews lasted between 45 minutes and an hour. I started each interview by reviewing the voluntary nature of the interview and explaining the purpose for the interview. Part one of interviews in round one focused on questions about the participant, their relationship with their student or mentor, and how they began working together. These questions were included both to create rapport and to gain information that could be helpful in future analysis. When additional interviews were needed in specific cases, this portion of the interview was still present but reduced to questions about changes the participant had observed since our last interview. Part

two of each interview was based on the clips selected from observations. I used the same clips to develop questions for mentors and students in each case, although questions were specific to the participant. The purpose of these questions was to explore the perspectives of my participants as they related to specific conversations they had participated in with their students or mentors.

My primary goal for these interviews was to collect participants' reflections about their discourse and experience, not to have them listen and reflect on all prepared clips. In cases where participants demonstrated a natural proclivity for reflection on their discourse, I used the interview to further explore their reflection, in accordance with my semi-structured interview approach (Creswell, 2009) and interview protocol. In such cases, all clips were not covered during any interview. I memoed about the experience of each interview afterward to inform myself on the design of future interviews with participants.

During my pilot study, I encountered multiple instances where participants were not confident speaking about their experiences in the laboratory without documentation. One participant also mentioned the need to draw when answering interview questions. To support discussion for those types of participants, I asked participants to bring any documents they used during the time I observed them in the laboratory, such as laboratory notebooks, protocols, or published articles. I also provided pencil and paper to support participants that needed to write or draw to recall and reflect on experiences.

Interviews occurred within a week of the final observation in a cycle. This time between observation and interview was longer than traditional stimulated recall studies (Lyle, 2003). However, the choice to deviate from standard stimulated-recall practices was informed by a combination of three considerations: guidance from literature (Calderhead, 1981; Lyle, 2003;

Reitano & Sim, 2010), my research questions, and recognition of participants' schedule constraints.

Stimulated recall studies generally emphasize that the time between observational data collection and interview be as short as possible, often during or directly after the event of interest (Lyle, 2003, Gass, 2001). The purpose of decreasing the time between observation and interview is to increase the likelihood that a participant is recalling their experience as opposed to reflecting on it (Lyle, 2003). This distinction between recall and reflection is considered key by many researchers who make use of stimulated recalled (Gass, 2001). However, Lyle (2003) contended that stimulated recall approaches may not always result in participants recalling an event, even with reductions in time. He argued further that the distinction between approaches valuing recall and those valuing reflection was unnecessary, as both sets of information may be useful and can be prompted by stimulated recall (Lyle, 2003). For my study, both recall and reflection were considered useful in answering the stated research questions. Therefore, while it was important that interviews occur after observation, it was not necessary that they occur directly after observation.

3.4.2.3 Collecting Additional Data Sources

In addition to field notes, audio and video recorded observations, and interviews, I collected data in the form of written documents or artifacts such as laboratory notebooks, protocols, group webpages, and YouTube® videos. Collection of these items was determined by the nature of each specific case. I used the audio and video observations to identify additional data sources that could be useful in answering my research questions. When it became apparent through observation that a student or mentor relied heavily on a specific type or source of

documentation, I asked the participant to bring the document with them for interviews. This decision was guided by my pilot interviews, where in multiple instances participants suggested they needed specific documents to help answer my questions. In practice, only one of my participants referred to the documents they brought during interview.

I did not ask for still images of participants' entire laboratory notebooks since it was possible that a participant could be working on topics of a confidential nature. Furthermore, my research questions could be answered without including this data source. Whenever possible, I collected screen shots from the video collected by the Drift Ghost-S camera worn by student participants. The Drift Ghost-S is a high definition camera that recorded video at high enough quality that screens shots of documents were legible. I also collected the publically available sources that participants mentioned during observations or interviews, like protocols, published articles, and YouTube® videos. These data sources were used to inform my analysis of observations and interviews.

3.4.3 Data Analysis

Hermeneutic scholars contended that analysis of data begins with the first experience of the data (Gadamer, 1965/1985; Laverty, 2003; Shane, 2007). In my case, this was when I first observed participants interacting. By observing my participants, I learned things about their interactions that affected how I viewed all future data. To acknowledge and make use of this situation, I memoed continuously throughout the data collection and analysis processes (Corbin & Strauss, 2008). This memoing was not intended to be a formal analytical process; however, it was the point at which I began looking for norms and the ways they were established to answer my research questions.

After collecting observations, interviews and additional data sources for a cycle of data collection, I transcribed observations and interviews verbatim. I began transcribing as soon as I collected a day of observation for a student-mentor pair. Coding began as soon as transcription was complete. Transcripts were uploaded to NVivo 11 for Mac for coding; I also uploaded video and audio data for reference when coding data.

Formal analysis of the collected data was executed using an inductive approach (Corbin & Strauss, 2008). While previous literature on undergraduate research experiences shaped my expectations of the nature of my data, during my pilot study I observed that previous literature was not sufficient in helping me understand the conversations between students and mentors in research experiences. Thus, I approached the analysis of my data from an open perspective. I used an open-coding approach (Corbin & Strauss, 2008), which was guided by literature related to discourse analysis (Gee 2011a, 2011b) and undergraduate research (e.g. Dolan & Johnson, 2010; Hanauer et al., 2012; Laursen et al., 2010; Thiry & Laursen, 2011). However, in instances where my cases diverged from this literature, my analysis was grounded in the data itself (Merriam & Tisdell, 2016).

3.4.3.1 Analyzing Observational Data

Observational data served to inform how I answered each of my research questions. I used an open-coding approach (Corbin & Strauss, 2008) to analyze all observations, with interpretation of the conversations grounded in the data and context (Merriam & Tisdell, 2016). I began my analysis by identifying the activity frameworks (Clayman & Gill, 2011) which made up each case's interactions. To identify activities frameworks, I used an open coding approach (Corbin & Strauss, 2008). Activity frameworks were unique to each case, but generally were

identified by a change in topic or focus of a conversation. After isolating conversations into discrete activities, I analyzed each individual activity. For each activity, I identified individual actions and sequences of actions (Clayman & Gill, 2011). The identification of these two levels of conversation proceeded simultaneously. Once I identified individual actions, I characterized the features mobilized within these actions (Clayman & Gill, 2011).

I used an open-coding approach, informed by Gee's toolkit of discourse analysis (2011b), to approach characterization of individual actions within each case. This toolkit included 27 tools or ways a researcher could look at discourse, generally presented as questions a researcher could ask about their data (Gee, 2011b). Table 3.1 provides select tools from Gee's toolkit that I found useful for considering my data; a complete list of Gee's 27 tools is in Appendix C.

Table 3.1 Select tools from Gee's toolkit

Tool	Excerpt of Description
Fill In	"Based on what was said and the context in which it was said, what needs to be filled in here to achieve clarity?"
Doing and Not Just Saying	"Ask not just what the speaker is saying, but what he or she is trying to do with their communication."
Intertexuality	"Ask how words and grammatical structures…are used to quote, refer to, or allude to other 'texts'."

Note. Adapted from Gee (2011, pp. 195-201).

Because each of my cases was unique, it was not possible to predict which of these tools would be most useful for identifying norms in interactions. Therefore, I remained open to considering all tools in the analysis of my data, and the possibility that additional resources may be needed in the analysis. In addition to Gee's toolkit, I found it useful to consider previous literature on the role of mentors in undergraduate research experiences (Dolan & Johnson, 2010;

Thiry & Laursen, 2011). I also sought out linguistic resources, like Ann Wennerstrom's *The Music of Everyday Speech*, as the discourse in each case required.

I approached analysis by first asking Gee's questions of each speakers' individual actions. As analysis proceeded, I began to identify which questions were most useful for exploring individual participants' turns-at-talk. For example, as I explored conversations between Mary and Sam, I found it useful to consider both what Mary said to Sam and her motivation behind specific turns-at-talk. As I considered what she was trying to do with her communication, I determined that Mary's motivation for much of her discourse was to provided Sam *personal support*. By integrating previous literature, I identified that Mary's efforts to support Sam aligned with previous findings of how mentors interacted with undergraduate researchers (Thiry & Laursen, 2011). This allowed me to revisit additional portions of Mary's turns-at-talk through the lens of personal support to identify specific discursive methods she used to provide Sam support.

3.4.3.2 Analyzing Interview Data

I analyzed interviews using an open coding approach (Corbin & Strauss, 2008). This approach was informed by my literature review and theoretical underpinnings. My primary goal in analyzing interviews was to identify ways by which the norms of discourse I discovered in observations were established. As each case was unique, I sought out additional literature to understand and interpret a case's discourse if needed. I used constant comparison of emergent themes and categories within the data to inform my analysis (Taber, 2000). This practice is a standard qualitative data analysis approach and commensurate with the hermeneutical cycle.

3.5 Cross-case Analysis

I used a case-oriented strategy to approach my cross-case analysis (Miles & Huberman, 1994). This strategy was rooted in my conversation analysis of observational data for individual cases. I began by comparing the activity frameworks (Clayman & Gill, 2011) which made up the conversations from my three cases. In my original analysis for individual cases, I identified activities both by the topic of conversation and the roles each speaker (i.e. mentor or student) played in the conversation. Each activity represented a conversation about a specific type of topic, where speakers participated in the conversation in consistent and identifiable ways during their turns-at-talk. Table 3.2 displays the activities I identified for individual cases.

Table 3.2 List of conversational activities arranged by case and family

	Holistic Experiences		Targeted Experience
	Case 1	Case 3	Case 2
Conversational Activities	Assignment Checking-in Collaborative working Demonstration Explanation Helping Instructional Leaving Personal sharing Updating	Assessing Checking-in Collaborative working Demonstration Explanation Instructional Introduction Documenting Personal sharing Updating	Checking-in Collaborative planning Collaborative working

This comparison allowed me to identify that while students and mentors in all three of my cases participated in conversations about research, in only two cases (i.e. cases one and three) did students and mentors also participate in social conversations. Using these broad conversational

activities, I grouped my cases into two families: holistic and targeted experiences. I then explored these families by considering the specific activities undertaken by my students and mentors in each family.

To compare activities, I constructed critical incident charts (Miles & Huberman, 1994) for individual cases' activities. These charts were constructed from the findings of my conversation analyses, presented in chapters four through six. I constructed charts by considering all conversations in a case that were categorized as a specific activity. I used the individual speakers' turns-at-talk and features of these turns (Clayman & Gill, 2011) to create general outlines of critical incidents that summarized the normative conversational events that occurred in activities.

On comparison, I saw a number of similarities between the critical incident charts constructed for the cases in my holistic family of undergraduate research experiences. My two holistic cases both participated in many of the same activities. In some instances, I identified that while I had categorized the activities differently in the individual case, I could now consolidate the individual activities into broader categories that represented both cases. For example, the conversations appearing in the assignment activity for case one were similar to those conversations held between members of case three during the introduction activity, so I combined these into a general activity called introducting. I also observed that case one's conversations related to helping and leaving were similar in structure and purpose to the activity of checking-in, observed in both cases one and three. Based on this observation, I combined helping, leaving, and checking-in into the broader category of monitoring activities. I made these types of choices using an open-coding approach (Corbin & Strauss, 2008), based on the

similarity of the critical incident charts. Table 3.3 provides a summary of the *conversational activities* I identified for each family.

Table 3.3 List of conversational activities observed in each family of research experience

	Holistic Experience	Targeted Experience
	Case 1 and Case 3	Case 2
Conversational Activities	Collaborative working Demonstrating Documenting* Explaining Instructing Introducing Locating Monitoring Personal sharing Updating	Collaborative planning Collaborative working Monitoring

*Unique to Case 3

By considering how the activities within each of my cases related to one another, I explored how the norms of discourse within and across these cases framed conversations. This exploration allowed me to further address my research questions, by providing me a method to identify how norms were established in conversations and how conversations impacted the undergraduate research experiences of students.

3.6 Role of Researcher

As the researcher, I was responsible for data collection and analysis for this project. I observed participants in the laboratory, took field notes while observing, interviewed participants, and transcribed data. I hold a Bachelor of Science degree in biochemistry and a Master of Science degree in Science Education with emphases in biology and chemistry. In the

course of my education, I have completed doctoral level courses in biochemistry, education, qualitative research methods, gender and culture, and psychology, which qualified me for this research project. I have also participated in two previous qualitative research projects which have helped to improve my observation and interview skills.

These courses and experiences informed how I looked at and understood undergraduate research experiences. For example, my experience in biochemistry allowed me to be able to identify what content information was not being said during discourse in a laboratory. By identifying the absence of information, I could investigate in the interviews the types of *presupposed knowledge* that were taken as shared in research experiences. In addition to my biochemical knowledge and experience conducting educational research projects, I also have experience in undergraduate research.

As part of my preparation for data collection and analysis, I reflected on my own undergraduate research experience in an essay before beginning to collect data. As I collected and analyzed data, I continued to practice reflexivity in my work by reflecting on my own experiences and how that experience influenced my perception of discourse in my cases. This reflection eventually led me to analyze my own journal entries from college where I wrote about my experiences doing undergraduate research, and to interview my undergraduate research mentor. The product of these reflects helped reshape my original essay into part of the introduction for this study.

Reflecting on my own undergraduate experience, I saw it framed by a lack of discourse, on my part. I also observed that while my advisor and other members of the laboratory took steps to include me in the culture of the laboratory, my own feelings were that I did not belong. These experiences made me sensitive to both what students said and to what they withheld during

conversations. When reflecting on my undergraduate research experience, I characterized it as a series of intentional choices on the part of the advisor to include and support me in my work, and a personal lack of confidence in identity that prevented me from accessing the myriad of opportunities and support the entire laboratory provided. In light of my own experience in undergraduate research, I found I had an increased sensitivity to the struggles of undergraduate research students in the laboratory. This sensitivity took the form of a heightened awareness to discourse that communicated the difficulty of specific tasks or research, by either the student or the mentor. I was also sensitive to how the absence of discourse may be even more indicative that a student was experiencing difficulties.

In my study, it was expected and accepted that my own view play a part in my interpretation of text (Gadamer, 1965/1985; Laverty, 2003). This fusion of horizons is a key aspect of hermeneutic studies. At the same time, I was aware that my experiences could also introduce bias into my interpretation that prevented me from giving my participants a voice and fully understanding their discourse. To interpret texts in an authentic manner, that considered both the contexts of my participants and my own context in interpretation, I practiced reflexivity through memoing and taking fields notes (Corbin & Strauss, 2008). I also continually considered the literature related to my theoretical underpinnings to guide my interpretation of data and sought out discrepant cases during analysis (Merriam & Tisdell, 2016).

3.7 Trustworthiness

All research is concerned with the uncovering of information that is valid and reliable (Merriam, 2009). However, the way these aspects of rigor are measured and discussed differ between types of research. In choosing to use a case-study approach, I chose to focus on specific

cases of interest to collect rich and descriptive data about undergraduate research. My work aimed to capture and describe the perspectives and experiences of my cases (Merriam, 2009). Therefore, in this research, I chose to consider the validity and reliability of my data as a measure of *trustworthiness* and *authenticity*. Patton (2002) describes an emphasis on trustworthiness and authenticity as "being balanced, fair, and conscientious in taking account of multiple perspectives, multiple interests, and multiple realities" (Patton, 2002, p. 575). To establish trustworthiness in my study, I took the steps described below.

Because my research was interested in the perspectives of participants, I used *member checking* (Lincoln & Guba, 1985) as a primary way to establish the trustworthiness of my cases. After completing a case, I provided a case summary to both the student and mentor participants separately (Lincoln & Guba, 1985). I asked each participant to review the summary and reflect on how they saw my interpretation of their experience. I made changes to my cases based on each participant's feedback. These changes included spelling and grammar corrections, modification of the official title of my mentor in case two, modification of an award received by my student in case two, and the addition of clarifying sentences in cases two and three. For case two, I added sentences to clarify that my student's primary reason for working with her mentor was her interest in his research. For case three, my mentor provided statements to clarify the process of homogenization she spoke about with her student. No additional action was requested by the participants.

As mentioned in my discussion of the role of the researcher, I practiced reflexivity throughout analysis by way of memoing (Corbin & Strauss, 2008). One aspect of memoing was discrepant case analysis, the practice of actively seeking data which disconfirmed expectations (Merriam & Tisdell, 2016). My data collection methods included long-term observations, which

allowed for collection to continue until reaching a saturation point (Merriam, 2009). I triangulated (Merriam & Tisdell, 2016; Taber, 2000) within cases by comparing observations, interviews, and additional data sources.

I made use of peer review (Merriam & Tisdell, 2016) by graduate students with similar backgrounds to review emergent findings while analyzing my data. Interpretations of hermeneutical studies rely on the experiences of the researcher; therefore, my goal in peer review was to confirm if the codes I had developed from my interpretation reflected the collected data. I provided portions of my raw data and analysis to peers. Peer review consisted of peers examining this information to determine if they considered the findings plausible. In the event that there was not agreement, we discussed interpretation until reaching consensus.

3.8 Ethical Considerations

This research design was approved by the Institutional Review Board (IRB) at this university before data collection began (Appendix D). To protect the rights of my participants, I constructed informed consent forms for both my mentor (Appendix E) and student (Appendix F) participants. These forms included a description of the purpose of my study, what participation entailed, the length of my study, any potential risks and benefits, my plan to keep data confidential, how I planned to disseminate findings, and how I could be contacted. Before I began collecting data, I presented the form and reviewed it with each participant to answer any questions they had about the study. I also explained the voluntary nature of their participation.

One consideration when providing details about cases in a case study is the danger of breaching anonymity. Merriam (2009) considers anonymity at the local level to be nearly impossible to maintain. Cases are often picked because they are unusual, unique, or otherwise

representative of a specific research focus (Merriam, 2009). Dissemination of selection criteria for these cases can make it possible for readers to connect back to the identities of participants (Merriam, 2009). For my study, selection criteria did not disclose enough information to pose a risk in identifying participants. I recruited across campus and my selection criteria described the identities of a considerable number of students and mentors.

It was possible that the data I collected could provide enough information about the participants for readers to make identifications. The discourse I collected during observations included conversations about specific research projects and identifiable components of these projects. To reduce the chances that such identifications were attempted or made, I de-identified not only the names of participants but also identifiable aspects of their discourse, including names of other laboratory members, specific compounds or fields of research. I consulted with participants to confirm that the alternative identifications I chose were suitable replacements that still reflected the intended meaning of their discourse. I also verified that the participants approved of the level of information I provided about their research as part of member checking.

CHAPTER 4. CASE ONE

4.1 Introduction

The first case I observed included an experienced undergraduate student, Sam, working with a graduate-student mentor, Mary. The pair had worked together in a biochemistry research laboratory for a little over a year. I chose pseudonyms for all participants and members of the laboratory. To help clarify Sam and Mary's identities when discussing their case, I assigned Sam, the student, a name beginning with 's'; Mary, the mentor, was assigned a name beginning with 'm.' To provide context for my interpretation of the case, I begin by introducing Sam and Mary. I provide details about how they came to do research together and describe what a typical day looked like when they worked in the laboratory. I noted that Sam's experience working with Mary carried a high degree of structure in conversations. Therefore, I chose to organize my discussion about their discourse using the same structure I observed.

Sam and Mary were first recruited from a chemistry department to participate in my pilot study. Sam participated in my pilot study as a novice student in his second semester in undergraduate research the summer after his freshman year. I observed him working again in the spring of his sophomore year. At this point, Sam was an experienced student in his fourth semester of undergraduate research with his mentor, Mary, and therefore an appropriate participant in the study. Mary was in her third year and had achieved candidate status.

Sam was a motivated, high-achieving student. He was a member of the Dean's list both years I observed him and had initiated contact to begin doing research in his first semester at Purdue. He began participating in undergraduate research by speaking with one of his professors who had a biochemistry research laboratory. He sought a research opportunity because one of his

courses encouraged him to pursue research as early as possible. He chose this specific professor because of previous positive interactions and the description of the research listed on the departmental webpage. Sam was a biochemistry major from a biology department; he was also pre-medical and intended to apply for medical school. While Sam planned to attend medical school, he expressed a desire to maintain his options. He viewed this research experience as an opportunity to do that.

> The thing that I want to do the most right now is I'm pre-med, so I hope to go to medical school. But I wanted to leave that option open of doing research because it always sounded interesting to me. And I had chemistry with Professor Tate and I thought she was like an awesome professor and then I looked up to see what she did and it looked really cool. . . . And I knew I was interested so I thought well this would be a perfect opportunity so . . . I came to her office with a resume. And we sat down and talked for a little bit, and she was like sure, why not. (Pilot study, Interview)

Sam was a traditional, domestic student. He grew up approximately an hour's drive from the university and enrolled the fall after graduating high school. He kept close ties to his hometown and family, and returned regularly enough that he still got his hair cut in his hometown. Sam lived off-campus in an apartment with roommates; but he was still active in university life. He was a member of a fraternity which had a house on campus, but chose not to live there because he was concerned it would distract him from his academic goals. As Sam explains

> Like part of me wants to because it'd be fun but part of me is just like it would be a hassle. . . . [W]e're going to start having parties at our house now and stuff. . . . I feel like that would just be a huge distraction especially for junior year. (Round 1, Observation 2)

Sam served as a group leader for his university's annual orientation program when he was a sophomore, and had been accepted to serve again as a junior. Selection for these positions was competitive. As a group leader, Sam received training in mentoring new students and was

expected to represent the program and university, both during orientation and afterward. Sam found the experience enjoyable for multiple reasons, which he described to Mary.

> Sam: It was a lot of fun. . . . It's awesome. It's a great experience and it's like super rewarding when . . . you see your new students just like . . . around campus. And you say hi to them. And you see how their classes are going because like you know, you were their first like . . . interaction with Purdue.
> Mary: Do you still keep in touch with your [group]?
> Sam: Yeah, for sure! I'm still really close with like my buddy [leader] too. So it's just . . . all a cool little community. (Round 1, Observation 3)

Sam enjoyed participating both because it allowed him the opportunity to meet and help new students, and to establish long-term relationships as a source of help and connection to the university lifestyle.

In addition to his work with orientation, Sam sought out opportunities to be a teaching intern for biology and chemistry courses. Teaching interns assisted instructors and teaching assistants with a variety of tasks, including grading and working closely with students both during classroom activities and outside during office hours. These positions earned academic credit or pay under some circumstances. Sam had yet to successfully obtain one of these positions by the time of my observations; however, he continued to speak about his interest in working with students in this way.

Mary was a domestic graduate student, originally from outside of Chicago. She moved from home after high school to attend college out-of-state. She was a traditional student, attending college directly after high school and beginning graduate school, again out-of-state, right after graduating college. It was important to Mary that she move away from home to attend college.

> Whereas like, by the time that I went to college. My parents were like, oh you should apply [near home]. And I was like, I don't want stay here. . . . I don't want to stay here.

> Gotta change it up. . . . I think I would've lost it a little bit. (*Mary laughs.*) (Pilot study, Observation 1)

Although Mary lived in a different state from her parents and sister, she remained close to them. Her family regularly visited one another, coordinated vacations and even called each other during the day to chat.

In addition to her teaching and research responsibilities, Mary participated in a variety of volunteer positions at the university. She was a member of the local chapter of Iota Sigma Pi, a national honor society for women in chemistry, and held a position of leadership in this group. Mary volunteered annually for science outreach and student orientation events as part of these and other organizations. She was also an athlete who trained for and competed in races. Mary's volunteering and physical recreation doubled as social activities. Many of her friends participated in the same activities, including her boyfriend who was attending graduate school in another region of the country. One way Mary maintained her long-distance relationship was by traveling and competing together in races.

Before graduate school, Mary participated in research as an undergraduate student for two summers, in two different laboratories. Her first experience, after her sophomore year, was at her home university in a biophysical laboratory in the physics department. Mary had attended a small, private not-for-profit, liberal arts college as an undergraduate. She was the only chemistry undergraduate student in the program, so she had worked closely with physics students participating in summer research. One significant aspect of the experience mentioned by Mary was weekly meetings arranged by the program.

> So . . . that program was actually really great. Cause we did, we worked with the whole, all the undergrads from the physics department so there's about twelve of us. And . . . we'd always have a lunch on Wednesday and we would get pizza—like the department would provide it. But then there would always be like a task like, one time we had to each give like a two-minute presentation on the background of our project kind of thing. Or we

> would have to bring up a problem that we had, kind of like a mini-group meeting kind of thing. And we . . . would have to discuss with each other how we might want to solve that or something like that. So I think that really helped. We had to do a lot of presenting I would say. (Pilot study, Interview)

Mary's second research experience was the summer after her junior year, which was done at a large, doctoral-granting research-intensive university, as part of a Research Experience for Undergraduates (REU) program. In this second experience, Mary worked with a graduate student in an organic and analytical laboratory. She called her two research experiences "very different" with the latter having less structure. This second experience informed how Mary approached working with Sam.

> [T]here wasn't as much guidance . . . so I think from that I realized okay like, cause like I was more quiet so sometimes I didn't ask questions. Or something like that because you know you don't want to look stupid or whatever . . . as the you know undergrad that's there. So I think I try to be better about that just because I know that like that's what I did. Or like I had awkward down time and it would be like two hours and I'd be like well I don't want to leave cause then I don't want to look like I'm just ditching or something like that so. I just try to make sure at least I'll have like options for things that [Sam] can do. (Pilot study, Interview)

Mary indicated in her interview that she empathized with Sam as a new student in the laboratory. The experience encouraged her to be mindful of ways she could provide guidance during Sam's experience.

Mary was financially supported as a teaching assistant (TA) in the fall and spring semesters; her professor supported her through a research assistantship in the summers. For her TA, Mary worked in courses taught by her professor. Both of these courses were required for Sam's degree and he took them while Mary was a TA. Mary was not Sam's TA for either class, but he did have increased contact with her because of the courses. When Mary learned Sam would be working with her the following semester, she took steps to get to know him better by speaking with him when she had the opportunity during class or laboratory. During the spring

semester, when Sam was both working in the laboratory and enrolled in a class for which Mary was the TA, they often walked together from class to the laboratory.

Sam began working with Mary in the spring of his freshman year. Mary mentioned that, because of Sam's heavy class load, his time in the laboratory was limited his first semester. During their first semester together, Mary focused her efforts on familiarizing Sam with the background of the project and the methods she used in the laboratory.

> I've given him some papers and one day we even like went out and got coffee and like he had to explain the paper kind of to me. Like, big picture, and I helped him out and so, yeah, I've given him some stuff to like read and kind of figure out. I'm not sure how much like detail or how concise he could you know spew that back. Cancer, research, mutations, who knows. (Pilot study, Interview)

> I had him watching a lot of things that I did, just kind of observing. . . . [I]t was a lot more watching and . . . not as scienc-y tasks. So it was more like . . . washing dishes and reading a little bit more and like doing overnight cultures for me. . . . I would do it and then he would watch and then he would do his own kind of thing. And then kind of as he learned a little bit more I had him making like negative and positive controls for stuff just so he could see how it worked. And then he started doing like, we would each do our own and then we could compare if we got the same results kind of thing. So, like we'd do an activity assay and he could see if he got the same activity or if he was as consistent or whatever. (Pilot study, Interview)

When I observed Sam and Mary in his second semester, he had increased his confidence and competence to the point of being able to work without Mary in many tasks. While Sam worked alone, Mary tended to stay nearby when he worked. Sam was aware of this transition.

> We used to do it that way that she would do it . . . at the same time as I would. But I think she trusts me now just to like, we can just do one and she can still like watch me. (Pilot study, Interview)

I observed a similar level of responsibility when I revisited the laboratory the following spring, during Sam's fourth semester of research experience, when I noted that Mary had started to let Sam work on his own without her supervision. As Sam expressed it,

> She's not really like overseeing me as much. Kind of giving me my own like little things to do here and there. It used to be like, oh, in the beginning it was like "ok go and do like

> this small little thing right here" like I can't even think of one thing. Like go make a gel. She still tells me to do that. But a lot of it's like, instead of telling me like go make a gel, it's like go make a gel and go run the gel with the samples that you can make. Kind of thing. It's more like bigger project she's giving me or bigger jobs that she's giving me. Rather than just one small little procedure to do and that's it. (Round 1, Interview)

The laboratory where I observed Mary and Sam was made up of approximately 10 graduate students and three undergraduate students during the time of my observations. The research Sam worked on with Mary related to the Principle Investigator's (PI) cancer research line. Four graduate students and one undergraduate student worked on related projects.

The laboratory was managed primarily through delegation of responsibilities to senior laboratory members; the PI spent most of the time working in the office or from home. The PI did not work in the laboratory during any of my observations, though they would pass through and speak to students. Undergraduate and graduate students worked in a shared laboratory made up of several rooms, with students' desks located in two separate spaces. This physical separation was reflected in the interactions that occurred most often between graduate students. Students kept to their rooms in the laboratory, unless tasks or equipment deemed it necessary for them to visit additional rooms. This meant that, although the atmosphere of the laboratory space was friendly, Sam and Mary interacted mainly with members on their side of the lab. These laboratory members included male and female graduate students at a variety of stages in their degree. Their conversations were both of a social nature and related to the research they were doing.

While Mary was Sam's primary mentor, the group worked collaboratively to help all members. This collaboration was limited by the particular project each student was working on, since many of the methods and expertise students possessed depended on their specific project. Sam directed most questions to Mary, but he did ask other students questions, particularly if

Mary was not in the room or appeared busy. He generally directed his questions towards one of the senior graduate students whose research focus was different than his own.

When I observed Sam and Mary working together in the spring, Sam was taking a full-time course load. He received academic credit to do research and worked in the laboratory approximately 12 hours a week, split across three days. Doing research while also taking classes left Sam with a tight schedule. He fit his research experience in between two classes, during what would have normally been his lunch break.

4.2 Typical Day

A typical day in the laboratory began with Mary introducing what Sam would be doing for the day. These were normally tasks Sam had experience in and would be completing alone. For example, Sam would perform agarose gel electrophoresis to confirm the size of deoxyribonucleic acid (DNA) samples he or Mary had made through polymerase chain reaction (PCR); check the optical densities (ODs) of cells to determine if they were growing as desired; or centrifuge cell cultures to collect them. The conversations usually lasted five to ten minutes. The tasks Mary assigned were related to her own research and were generally continuations of work she was doing. Sam's responses to Mary's instructions were generally backchannel confirmations (e.g. okay) (Wennerstrom, 2001) of her plans.

After Sam received his instructions for the day, he would begin working on his own. Once Sam was working, Mary would return to her own work. When working on their individual tasks, Mary and Sam spoke about a variety topics. These conversations were both about Mary and Sam's lives as students and about their interests outside of their academic commitments.

Mary periodically checked on Sam's progress while he worked; she asked about his progress and gave him new tasks to complete. When assigning new tasks, she either gave instructions for how to proceed after he completed a current task or provided him with suggestions of tasks he could work on next. The tasks Mary suggested were generally forms of personal support (Thiry & Laursen, 2011). She either provided the next step in the procedure he was working on or offered tasks he could do related to maintenance of the laboratory, including making solutions, autoclaving materials, or filling pipette tip boxes. These were tasks that would benefit both himself and other lab mates who shared the supplies.

Sam asked Mary few questions related to his work. When he did, Sam's questions most often involved asking for help finding materials in the laboratory. Outside of questions, Sam spoke to Mary most often about his work when he had completed a task. In these conversations, he would report data or observations he made while working. Sam worked each day until it was time for him to go to class. He usually left without reporting back to Mary, since he had often completed and reported back to Mary on individual assigned tasks. When finished with his daily assignments, Sam usually filled the rest of his time by working on tasks that helped maintain the laboratory. His most common upkeep activity was filling the empty pipette tip boxes that quickly accumulated in the laboratory.

4.3 Norms of Discourse

Mary and Sam's conversations centered around two broad topics: research and personal lives. While their conversations about these topics were interwoven, I observed distinct differences in the ways Mary and Sam engaged in the two contexts. I provide an analysis of the norms of discourse in both settings separately in the sections below.

4.3.1 Conversations about Research

When speaking about research, Sam and Mary's conversations followed a pattern of communication where both speakers participated in identifiable roles. The sequence began when Mary assigned Sam a new task. After completing the task, Sam reported back to Mary with observations or results, which Mary would interpret to determine future steps. One example that illustrates Sam and Mary's participation in this pattern is a conversation on the second day of my observations about checking ODs. Mary began the day by assigning Sam a series of tasks to be completed while she was in a meeting. One task was to check the ODs of their wild-type and mutant cell cultures to determine when the cell cultures should be collected.

> Mary: But yeah, if you wanna do that. So I left . . . a post it on here if you forget. Because I have a meeting at 12:30, but you can stay here and keep doing stuff. So just check ODs, harvest what we can harvest, finish destaining and if it looks good we can like cast it together. (Round 1, Observation 2)

After Sam has finished checking the ODs, he returned to Mary to report his results. He hands her a print-out of the ODs and says, "most of the [wild-types] are ready except for one. So maybe like thirty minutes on all of them and then. Or, I don't know" (Round 1, Observation 2). At this point, Mary began to read the data. Sam stopped talking and waited to hear Mary's instructions. Underlined text indicates emphasis through tone of voice.

> Mary: Yeah, so why don't you wait until a bit after noon . . . and check 'em again. <u>Oh yeah</u>, the [mutants] are not growing at all.
> Sam: Yeah.
> Mary: Hmm. . . . Why don't you, we'll wait a half an hour and then recheck the ODs and harvest [wild-type]. . . . So why don't you in this thirty minutes you can take out the mutant ones and just bleach 'em, wash 'em, and trash 'em.
> Sam: Sounds good. (Round 1, Observation 2)

This pattern of Assign-Report-Interpret repeated for each task Mary gave Sam, sometimes occurring multiple times within a task when Sam encountered a problem that he

needed to report. Within each of these activities, both Sam and Mary mobilized unique discursive elements in their turns at talk.

4.3.1.1 Mary Assigned Tasks

When providing Sam with an assignment, Mary positioned herself as a credible resource through her discourse. Mary regularly engaged in a number of *disciplinary anchoring* practices described by Thiry and Laursen (2011) when assigning Sam tasks. I describe examples of these practices in the sections below. Sam's discourse during this time was limited; he general provided single-word replies to indicate that he accepted or understood the assignment. Many of Sam's responses were dialogical repetitions (Bazzanella, 2011). He did not challenge Mary's instructions or make suggestions of alternant ways they could proceed. I interpreted his silence as a form of speech-act silence (Huckin, 2002) communicating that he either accepted or agreed with Mary's decision. It is also possible that his silence communicated a general acceptance of Mary's role as a resource or authority in the context, one whose instructions he did not question. It was Mary's discourse that guided these discussions; she introduced topics and chose how they would be discussed. As part of Mary's introduction, she would update Sam on work she had completed while he was not in the laboratory and include any relevant results that occurred, demonstrated in the following example.

Mary:	I haven't had time to look at those primers yet, but first I'll have you check the ODs.
Sam:	That's right.
Mary:	I checked just one of them this morning just to see like roughly where it was at and I think it was at like 2 point 5. . . . And that was at like 9 . . . so I'm sure they'll be good to go by now.
Sam:	Yeah.
Mary:	But yeah. . . . I would do that and I'm sure they'll be ready for harvest and I'll have you do that mostly today. . . . I'm going to go get a new battery for Professor Tate's microphone.

Sam: Sure.
Mary: So I'll be back, I just have to go down to that room again. (Round 1, Observation 5)

Mary would make sure to tell Sam where she would be while he was working in the laboratory. She used her discourse to assure Sam of her continued presence and availability (Dolan & Johnson, 2010). Although not seen in the example above, she sometimes paired that information with an explicit offer of help if Sam needed anything while working in the laboratory.

Mary supported her role as an expert by demonstrating her preparedness and knowledge of the work Sam would be doing each day. While Mary assigned Sam tasks, she would ask if he remembered past times he did something. When Sam was working on a task with which he communicated he was less familiar, she would elaborate on how the method worked and what information would be gained, as in the following example.

Mary: I was going to have you do a gel. . . . So basically it's the same thing [as a Western blot] except for once it's done running we just put it straight into the Coomassie stain, so you don't have to do the transfer or any of the antibodies . . . tomorrow when you come in I'll just show you how to destain it. It's really easy, you just dump off the stain, put on the destain so it starts taking off the excess blue color. Whereas where the protein is on the gel the blue won't wash off. . . . So then we'll be able to see if my samples have protein. Cause these are—so you've run a Coomassie with purified protein, because then you can see, you should just have one band at the molecular weight that you think that your protein should be at. And if you see a bunch of bands you know that your sample is not pure. That there's other proteins somehow in there. (Round 1, Observation 1)

Mary would also provide *intellectual support* (Thiry & Laursen, 2011) to Sam by describing how he should approach the procedure, including reminders about specific considerations and suggestions of how to begin. She also regularly mentioned how the procedure related to what Sam would be doing in the future. During interview, Mary spoke about her desire to be prepared.

> I want to make sure that I have it down for explaining it to them. So I did do a lot of like going back and making sure I could explain everything. . . . [L]ike why we use certain

> chemicals and stuff like that. So I definitely went back and looked through it because I personal just hate if I'm just like oh I don't know. (Pilot study, Interview)

Mary compared working with Sam to teaching in the laboratory. In both cases, she did not want to be met with a situation where she did not know the answer.

In addition to establishing Mary as an authority, the information she provided Sam was one way she supported his learning (Thiry & Laursen, 2011). When assigning Sam tasks for the day, Mary used his previous experiences to build his understanding of the new task. This is demonstrated in the conversation above where Mary discussed Coomassie staining, a technique she used to visualize proteins in a gel using a blue-colored dye.

> I was going to have you do a gel. . . . So basically it's the same thing [as a Western blot] except for once it's done running we just put it straight into the Coomassie stain, so you don't have to do the transfer or any of the antibodies. (Round 1, Observation 1)

To explain Coomassie stains, Mary referenced Western blots, a technique which also includes the step of separating a protein sample on a gel. Sam had performed a Western blot recently. Mary's discourse suggested that she may have believed Sam would remember Western blots, since she does not go into specific detail about the technique. Instead, she explains it's "the same thing"—possibly referring to the separation of protein on a gel—and then describes how the techniques differ.

Mary further supported Sam's understanding of techniques by explaining how results would be interpreted (Thiry & Laursen, 2011). Again, as she said in the example of the Coomassie stain,

> Where the protein is on the gel the blue won't wash off. . . . So then we'll be able to see if my samples have protein. Cause these are—so you've run a Coomassie with purified protein, because then you can see, you should just have one band at the molecular weight that you think that your protein should be at. And if you see a bunch of bands you know that your sample is not pure. (Round 1, Observation 1)

Although Mary mentioned in her interview that she prepared herself to be able to explain the concepts behind techniques, her explanations of tasks were often more practical or technical in nature. This feature of Mary's discourse reflected previous reports on the type of mentorship provided by postgraduates (Dolan & Johnson, 2010; Thiry & Laursen, 2011). She tended to explain techniques by focusing on the information that could be ascertained through interpretation of data, rather than providing scientific explanations of how techniques worked.

A key characteristic of Mary's discourse when assigning Sam work was the concern she communicated to assure that Sam felt comfortable working in the laboratory. Mary used her discourse to present herself as a source of personal support (Thiry & Laursen, 2011). This concern was demonstrated overtly in her discourse when she asked Sam questions or offered him help. For example, when assigning Sam the job of preparing a gel, Mary asked, "Do you want me to watch you load it? Or do you feel confident in loading it?" (Round 1, Observation 1). However, Mary's concern for Sam's comfort while working in the laboratory was also communicated through how she described tasks to Sam.

When describing techniques to Sam, Mary tended toward informal terminology (e.g. "blue color") over scientific language. She used her language, along with hand gestures, to help Sam participate in the research (Thiry & Laursen, 2011). To illustrate Mary's use of colloquial terminology, consider the following excerpt where she described the process of protein extraction from a membrane. Biological membranes are amphiphilic, they possess both hydrophobic and hydrophilic properties. The structure of a membrane-bound protein can be destroyed if proper technique is not used to remove the protein from this environment. In the example, Mary provided details about how she used a detergent, which is also amphiphilic, to protein her protein during extraction.

> So basically what I'm doing is taking [the protein] out of the membrane because it's like a membrane protein . . . and right now I'm like ripping it out of the membrane so like breaking up the membrane . . . but since it's in the membrane parts of it are hydrophobic, so it doesn't want to be in water . . . so you add detergent, so that it forms a little micelle around it (*Mary waves her cupped hands in a ball shape.*), so you won't kill the protein. (Round 1, Observation 3)

When speaking about the method, Mary chose a more informal term (i.e. ripping) over one that would traditionally be used in the laboratory (i.e. extracting). As she continued her description, she began to use scientific terminology (e.g. hydrophobic, micelle). For these more technical terms, Mary provided clarification through an *anthropomorphic* definition, "it doesn't want to be in the water", and hand gestures.

As demonstrated in the above example, Mary did make use of scientific terminology when she considered it necessary. However, her discourse suggested she also remained aware that these terms could be perceived as arcane, and may not be easily understood by Sam. One term she used regularly when giving Sam assignments was "inoculate." Inoculate, deriving from the Latin *inoculare* "to graft", was used as early as the 18th century to describe the process of introducing the smallpox virus into nonimmune individuals to induce an immune response (Riedel, 2005). In the context of the biochemistry laboratory, inoculation is used to describe the process of introducing a smaller sample of a living organism into a larger culture, for the purpose of producing more of the organism. Mary told Sam about the first time she heard the term used in the laboratory when she was being trained by another graduate student, Martha.

> I remember [when Martha] said that to me for the first time and I was like <u>what is that</u>? Like I had no [idea]. . . . Cause it was like, overnight culture, inoculate, harvest. I was like <u>what do you mean</u>? I have no idea. (Round 1, Observation 1)

Using stories like the one above, Mary positioned herself not only as a credible resource but also someone who could understand what it was like for Sam to work in the laboratory. Through her discourse, Mary presented herself as accessible, one category Dolan and Johnson (2010)

identified as a positive influence on the experiences of undergraduate students mentored by graduate students.

4.3.1.2 Sam Reported Results

While Sam worked in the laboratory, he would report his progress to Mary. Although Mary did not explicitly instruct Sam to report to her during the time I observed, she would approach Sam to check in on his progress if he did not initiate an interaction. Mary's actions may have provided a form of non-verbal communication about the expectations of how Sam should engage in research (Thiry & Laursen, 2011). Sam reported multiple types of information to Mary. At the end of a task, he usually provided Mary with either data or a product which resulted from the task. When providing these reports, he would make brief comments about their contents, as in the case when he provided Mary with a print-out of ODs and said, "most of the [wild-types] are ready except for one. So maybe like thirty minutes on all of them and then. Or, I don't know" (Round 1, Observation 2). Although Sam's discourse suggested he understood at least some of meaning of the data he was reporting, he stopped speaking as soon as Mary began to look at the data. Similar to when Sam was silent as Mary assigned work, I interpreted this as a form of speech-act silence (Huckin, 2002) where Sam deferred to Mary's judgement.

As demonstration of this pattern in a different context, consider the excerpt below where Sam and Mary view an agarose gel containing four PCR samples. Before loading the PCR samples into the gel, Sam mixed them with a blue loading dye to help visualize the samples as they migrated across the gel. Sam commented on this dye as he carried the gel to the ultraviolet transilluminator stage which helped them further detect the presence of individual bands of DNA of different sizes.

Sam: The [loading dye] bands ran well but I don't know if anything will show up. Okay. (*Sam places the agarose gel on the ultraviolet transilluminator stage and turns on the light. He looks at the gel but does not speak.)*
Mary: A whole lot of nothing.
Sam: A lot of nothing. (Round 1, Observation 4)

In the example above, Sam made a brief observation about how the gel he and Mary are going to look at appears, in visible light. Once the light is on, he waits to hear Mary's assessment, which he then repeats. As they look at the gel together the conversation continues.

Sam: You can see four bands right here. (*Sam points to a place about one third of the way down the gel. Mary takes Sam's place at the transilluminator and inspects the gel more closely.*) . . . Do you see that though?
Mary: Yeah yeah yeah. And a lot of times too that's just when you load stuff into that lane. So that could just be from the loading dye too.
Sam: Mmm. Okay. That makes sense. (Round 1, Observation 4)

Sam began to discuss his opinion about the gel in a similar manner to how he talked with Mary about his OD data. However, once Mary had access to the data, Sam stopped providing input and asked for her assessment.

I asked Sam about this experience of looking at the gel during his interview, after providing him with a brief clip of the interaction.

Sam: I was just—I don't know. To be fair I've never looked for them. They were very faint. I was just trying to look for something. Just cause, I don't know. . . . I saw four bands that were like identical like going across. They were very faint but still there. I just thought it was interesting that they were at the exact same position for all four of our mutant bands. That's why I was trying to point it out to her, I was like that's like it might be something. I don't really know what that is. . . . And she was like that was just the loading buffer. Because, so we put our PCR [product] in there. . . . I'm not exactly sure what the loading buffer does. The loading buffer gives it the purple color.
Researcher: So . . . [the band] was just the loading buffer in there?
Sam: That's what she said, that it was probably the loading buffer. So yeah. Okay. (Round 1, Interview)

When Sam spoke about his experience of looking at the gel, he began with a tone of admission saying, "I don't know. . . . I was just trying to look for something." Although looking

at agarose gels was a new experience for Sam, he communicated in his interview a desire to participate in the conversation. He participated by accessing his observational abilities and pointing out a pattern he saw in the gel. Sam knew that he lacked the knowledge to be able to decide what the pattern meant, so he then pointed it out for Mary to assess. He accepted her assessment without question.

Sam often made contributions to his reports through observations. In addition to reporting to Mary at the end of tasks, he also provided her with updates while working. These reports were almost always observational in nature. For example, consider the following excerpt occurring from the transcript that occurred on the fourth day of observations. Shown in a previous example, Mary had observed that the mutant cultures were not growing during observation two, as indicated by their low OD values. She instructed Sam to discard the samples. On the fourth day of observations, she assigned Sam the task of inoculating the large flasks of media again. Sam pointed out a difference in the cloudiness of these cultures, an observation that could indicate the step at which the last cultures stopped growing.

Sam:	You know, the flask that I had them in for the—I don't know what you'd call that. Is that another, would you call that the overnight culture? The one—
Mary:	Yep. The one that you just put in, like what you inoculated with?
Sam:	Yeah. . . . It looks a lot—
Mary:	Better?
Sam:	Cloudier.
Mary:	Okay. Last time it wasn't very cloudy?
Sam:	No. (Round 1, Observation 4)

When reporting to Mary, Sam was not sure of the terminology he should use to describe his observation. Sam was inoculating a large flask of media that he usually referred to as the overnight culture. During the inoculation, he had observed the small flask of media with which he was inoculating looked different than last time. He was not sure what this flask was called, so

he begins by asking Mary for help in anchoring his discourse in disciplinary language (Thiry & Laursen, 2011) so that he can communicate effectively about his observation. Once receiving assistance, Sam proceeds to describe his observation.

In contrast to when Sam spoke about data, he tended to appear confident when reporting about observations, engaging in conversation with Mary rather than allowing her to lead. In the excerpt above, for example, Mary interrupted Sam's observation by asking if the culture looked "better", a term indicating judgement. Instead of repeating Mary's term (Bazzanella, 2011), as Sam often did, he used his turn to modify the description with his own word, "cloudier", returning the subject of the conversation to his observation rather than an interpretation of the meaning of the observation.

4.3.1.3 Mary Interpreted Results

Once Sam had reported his observations or data to Mary, she again would lead the conversation. Mary usually interpreted Sam's reports in his presence. Unlike Sam, who verbalized his observations about the data, Mary often quickly moved past vocalizing observations to talking about what the data meant for future plans. When looking at data, her turns-at-talk included interpretation but remained silent on observation. One possible explanation for her silence was that she considered observational information to be presupposed knowledge (Huckin, 2002) already shared by Sam. For example, when viewing the agarose gel, Mary looked at the gel and said, "a whole lot of nothing." She then transitioned into a statement of what she thought this meant for the project and what Sam needed to change the next time he set up a PCR.

> Maybe that means just the PCR didn't work. I'll have to look at it. We might have to change the temperatures on the thermocycler. Just for the annealing and (*Mary puts her hands together then pulls them apart rapidly.*) melting temperature—or the separating temperature. (Round 1, Observation 4)

Mary's style of discourse when interpreting Sam's reports lacked the intellectual support present when assigning Sam tasks (Thiry & Laursen, 2011). She tended to provide less detail about how the data was interpreted. Instead, her discourse emphasized what she concluded, potential problems that could have occurred, and how she planned to move forward.

As a second example, consider an excerpt taken from day two of observing. At the beginning of this day, Mary and Sam talked about the Coomassie stained protein gel she had assigned him to prepare the day before. It had been destaining overnight. Most of the gel was tinted light blue, indicating an absence of protein but the need to continue destaining. Dark blue bands were present in some lanes, indicating the presence of protein at those points in the gel. Mary compared these dark blue bands to her positive control that she knew possessed her desired protein.

> So overall it looks really good, like my protein is pure. The only bad thing is like for some reason it's way more blown out than the positive control. There's just a lot more and they should look fairly similar. So I'm going to remake—I think my positive control sample was old—so I'm remaking it. (Round 1, Observation 2)

In contrast to when Mary spoke to Sam about Coomassie staining the previous day, she did not discuss how to tell that the protein was pure, instead concluding, "it looks . . . like my protein is pure." It is possible that Mary's silence is a sign that she assumed Sam would remember their discussion from the previous day, bringing that knowledge to the current conversation (Huckin, 2002). During Mary's interpretation, Sam does not ask questions or participate in the conversation; he stands quietly and listens.

Because Sam rarely spoke when Mary was interpreting data, I used time during our interviews to explore his understanding of the protein gel Mary had discussed. During the interview, he provided a well-developed explanation of the theory behind protein gels.

> If there are multiple bands then we know it's not pure. . . . [W]hen you do a gel it runs off of molecular weight and all the proteins have different molecular weights. I mean I'm sure there are some that are the same, but most don't have the same molecular weight. So if you see . . . a bunch of different bands, then you know it's not pure because there's a ton of proteins there. And you haven't purified it for your protein. If there's one band then there's one protein there, and if it's at the correct molecular weight then you know that's yours. (Round 1, Interview)

In addition to explaining what the number of bands means on a protein gel, Sam continued by elaborating on why proteins separate in a gel (i.e. different molecular weights). This was information not provided by Mary during the observations, although it is possible that she explained it at an earlier time. However, regardless of the source of this information, I interpreted his familiarity with the method to suggest that he may also have been able to fill in the information Mary excluded during her interpretation of the gel. His competence in theory suggested to me than Sam could fill in (Gee, 2011) Mary's silence to understand her interpretation of the data.

In a later portion of the interview, I asked Sam to reflect more specifically on Mary's discourse when interpreting the gel. After watching a brief clip of the interaction, he spoke about his understanding of her statement, "for some reason it's way more blown out than the positive control. . . . I think my positive control sample was old—so I'm remaking it." (Round 1, Observation 2) While reflecting on this interaction, Sam began to demonstrate that he may not have fully understand Mary's meaning.

> That kind of means—I guess I can—no, it's still on the gel, so it wouldn't be that. That could happen for a multitude of reasons but, usually the ones that we deal with it's about when you imprint it onto a piece of paper. If you like shift it around a little bit it'll be like blown out a little bit. But I think, I'm trying to remember. We've talked about this before, but I cannot remember why. (Round 1, Interview)

Sam was familiar with the term "blown out" and began to explain what it would mean in the context of a Western blot (i.e. "when you imprint it onto a piece of paper"); he was unsure of its

significance in the context of a Coomassie stain. He was able to describe its general meaning, saying, “it just means that it’s supposed to be very like fine and short, but it was probably like bigger and thicker.” However, as we continued to speak about the interaction, he could not fill in (Gee, 2011) the gaps in Mary’s interpretation to fully explain what she was saying about the gel.

4.3.2 Conversations About Personal Lives

In contrast to when Sam and Mary spoke about research, they participated equally in conversations about their personal lives. Most distinct were the ways in which Sam participated in these conversations versus those about research. Sam’s single-word answers or acceptance of ideas that occurred during discussions of research were rarely present during social conversations. Both Mary and Sam selected topics for conversations, asked and answered questions, and offered opinions. These conversations focused on a variety of topics not related to the research Sam was working on with Mary. Similar to reports by undergraduates in Dolan and Johnson’s (2010) study, these conversations provided Sam insight into Mary’s experiences as a graduate student. While working near each other, they spoke often about: food, Sam’s courses, Mary’s responsibilities as a graduate student, general science, and the experience of working in the laboratory. From these conversations, I identified themes and underlying ideas which Mary and Sam communicated about each other and themselves.

4.3.2.1 Sam’s Membership in the Group

The most predominant message communicated by Mary through conversations about personal life were related to her views that Sam was a valued member of the laboratory whose experiences and knowledge were valid social currency (Bourdieu, 1986). One way Mary regularly communicated the value of Sam’s experience was through asking him about classes.

Mary: Do you know most of the people in your classes?
Sam: Yes.
Mary: It's like the same people?
Sam: Pretty much. Why do you ask?
Mary: Like obviously you're not going to know probably everyone.
Sam: No no no. But I would say there's a group . . . of people that I know because they all sit close to the front of the room. . . . [S]o I pretty much know everyone that did that but . . . there's definitely new people that I meet all of the time, but I would say that I can probably recognize 75% of the people in [my major]. Why do you ask?
Mary: I was just curious. (Round 2, Observation 2)

Mary asked Sam about aspects of his classes almost every day, keeping up with his previous stories and mentioning past experiences he spoke about. She asked both about the content of courses and about his experiences as a student, as demonstrated in the above example.

When Mary asked Sam about the content of his courses, it was common for him to provide elaborate descriptions of what he was learning. For example, Sam learned an extensive amount about lysergic acid diethylamide (LSD) in his history class. He often told Mary stories about what he learned.

Sam: There's like this really famous doctor who was very into LSD and like all of the scientific methods.
Mary: Is this what you were talking about before, who accidentally took LSD?
Sam: No. That was the guy who made it, he was like a chemist. . . . I don't know if you've ever heard of that guy before. I didn't hear about it until this class. . . . I can't remember what the drug was—oh it was methylene blue, which is actually a dye. Isn't it like a protein dye? . . . [T]hey gave people methylene blue and they wouldn't have any effects of LSD. And it's his name was . . . Fischer. And I was wondering if that has any connection with Fischer biotech because this was a long time ago.
Mary: Maybe. I don't know.
Sam: And it was spelled the exact same way as Fischer biotech, so I don't know.
Mary: Are you—you should see how Fischer biotech started.
Sam: Yeah, I should! (Round 1, Observation 4)

In addition to asking questions, Mary found ways to relate Sam's experiences in classes to either her research or other student's research in the laboratory.

Sam: It's kind of interesting to hear about some of the drugs because I've heard about them from psych classes. Like chloro-chloromeprozine or something like that, which is used for schizophrenic people. . . . When you give people that drug, they don't have the effects of LSD.
Mary: You should ask when Clara gets back, because she looks at some stuff with schizophrenia.
Sam: Oh really? Interesting.
Mary: Yeah. So she might know what you're talking about (*Mary laughs.*). (Round 1, Observation 4)

Even when Mary was unfamiliar with the topics Sam spoke about, she communicated interest and encouraged him to continue learning. Through her discourse, I noted that Mary gave Sam's contribution value in the laboratory (Bourdieu, 1986).

Mary also used her discourse to communicate that Sam was a member of the research group. She did this primarily by inviting him to social events and including him in conversations about the laboratory. Mary's research group regularly had social activities; they went to lunch together or threw parties at Professor Tate's home. Many of these events were organized outside of the times when Sam worked in the laboratory. When events were planned outside of Sam's regular schedule, Mary made sure to invite him.

Mary: Are you able to come back tonight at all for our [celebration]?
Sam: Yeah, I'll do it! I'll be there.
Mary: Sweet. I also bought sparkling grape juice.
Sam: Perfect! Yeah, so it wouldn't be weird (*Sam laughs.*). (Round 2, Observation 2)

During the interview, Sam reflected on another way Mary communicated that he belonged.

> There's a tradition in the lab where if it's your birthday, someone will make you a cake and then everyone sings happy birthday to you. And my birthday happened to fall while I was working over the summer. . . . [S]o she made me a cake and stuff and the lab came and said happy birthday. (Round 1, Interview)

As demonstrated in both examples above, besides inviting Sam, Mary took additional steps (i.e. purchasing non-alcoholic beverages as Sam was underage, making Sam a cake) to provide Sam

support (Thiry & Laursen, 2011) to assure that he was comfortable and felt welcome in the laboratory.

4.3.2.2 Positive Aspects of Working in the Laboratory

Mary and Sam both used their discourse to convey that they enjoyed working in the laboratory, a factor which may have been influenced by Sam's presence (Dolan & Johnson, 2010). When Mary spoke about laboratory work, she approached the conversations optimistically. She regularly highlighted positive aspects of both her and Sam's experience, even in the case of smaller events like getting new equipment.

Mary:	I'm really excited . . . we bought this tool so we could recalibrate all the pipettors—
Sam:	Oh great.
Mary:	Cause sometimes they get off. Like this [pipette] says, if you set it to a thousand mil— or microliters, it would only aliquot like 700. Because I took it apart and tried to clean it, so I don't think I put it back together right. But we have this tool now so it's pretty cool.
Sam:	That is awesome.
Mary:	It's, you know, it's the little things. (Round 1, Observation 1)

Mary would also comment about positive aspects of tasks in the laboratory like filling tips.

Mary:	That'd be a pretty good way [to] like . . . take a break [from studying].
Sam:	Yeah, cause like filling tips is just something kinda chill.
Mary:	Yeah. Mindless, not a whole lot of thought. . . . And it's kind of meditative.
Sam:	You're right. (Round 1, Observation 4)

In the conversation above, Mary contrasted one of Sam's responsibilities in the laboratory (i.e. filling tips) with a responsibility as a student (i.e. studying). Mary often compared working in the laboratory with taking courses. When doing so, she tended toward describing the laboratory as a relaxing place. As in the example above, Sam agreed.

Sam was carrying a full course load the semester I observed him and, in order to fit research in, had chosen to skip the only break he had between classes during the day. In the excerpt below, Mary had just learned of Sam's schedule for the semester.

Mary:	If you ever need to eat lunch or sit down for a second—
Sam:	Sure. I mean the thing about [the laboratory] is you know, I'm not necessarily relaxing but at the same time it's not anything that's like—
Mary:	It's not like quick memorize or like, it's not like you're going to have a quiz.
Sam:	Exactly. It's not too intense and I enjoy it. (Round 1, Observation 4)

When Mary learned of Sam's busy schedule, her first comment was about his comfort while working in the laboratory. She expressed concern for him not having enough time to take care of basic needs (i.e. lunch). Sam, recognizing her comment as concern for his needing a break, explained that he viewed working in the laboratory as, "not relaxing but . . . not too intense" (Round 1, Observation 4).

Although participating in research used up some of the small amount of free time Sam had outside of classes, he viewed the experience as enjoyable rather than adding to his load. Like Mary, Sam communicated his positive feelings about daily tasks saying on the second day of observations, "every time I finish harvesting I always like to look at the pellet. It just feels so rewarding. It's like you get that much yeast out of these, out of the liquid media" (Round 1, Observation 2). Similar to Mary, it appeared Sam appreciated, "the little things" (Round 1, Observation 1).

4.3.2.3 Engaging in Research Communities

Outside of discussions related to working in the laboratory, Sam and Mary also participated in conversations about what it was like to engage in research as a profession. Because Mary's daily life revolved around research, she provided Sam with a model of how a

scientist participated in professional practices (Thiry & Laursen, 2011). Consider the excerpt below where Mary begins to tell Sam about a conference she would be attending.

Mary:	So we started figuring out—we're going to a conference this summer.
Sam:	Oh really? . . . [T]hat's cool. . . . Where is it?
Mary:	Yeah. . . . It's like in a real small town, it's almost like a camp kind of situation. You stay in more dorm-style rooms and—
Sam:	That's cool.
Mary:	Yeah, yeah. It's like a week long. And we'll probably present a poster and Professor Tate gives a talk, but it's like pretty big. There's a lot going on.
Sam:	Really? That's awesome. (Round 1, Observation 1)

For Mary, this was the first time she would get to attend the conference. The conference occurred every other year and Professor Tate only took older students. She was familiar with many details, suggesting that other students had spoken to her about it. Mary appeared to be looking forward to it based on her description. Similarly, Sam's discourse suggested that he considered the opportunity in a positive light.

When Mary began speaking about the conference, Sam indicated he was interested in learning more by asking questions. Sam asked questions on a variety of aspects of the conference including which laboratory members would be attending and what research topics would be covered.

Sam:	Is it all about [our protein]? Or is it like membranes?
Mary:	It's about membrane proteins and lipidation. . . (28.0) . . . it's like membrane proteins, lipidation and disease or something like that. How they're studied.
Sam:	That's cool.
Mary:	Yeah! Yeah, so it should be pretty interesting. (Round 1, Observation 1)

As in the first excerpt, Sam contributed a positive opinion to the conversation. From his question, it appears that he had some context for understanding how scientific conferences were organized, usually around themes. However, because Professor Tate's group worked on multiple projects, he was not sure to which project the conference was relevant.

Once Sam understood which members in the laboratory would be participating, he continued to ask questions, transitioning to the logistical details of the conference.

Sam:	Is it like a big thing?
Mary:	I don't know how many people go. I mean it's pretty big, but it's not as big as like the [American Chemical Society] conferences where it's thousands and thousands of people. It's probably a few hundred people.
Sam:	Okay. Is it going to be at a college or?
Mary:	I think it might be a boarding school. . . . It's a private institution of some kind. . . . It's like a camp. Like summer camp.
Sam:	(*Sam laughs.*) Summer camp, it'll be fun. Are you going to do any activities outside?
Mary:	Yeah, you can go kayaking I know.
Sam:	Really? That's funny. (Round 1, Observation 1)

As Mary began to talk about aspects of the conference that were not directly related to research, Sam's response suggested that he was surprised to hear her description. He reacted with amusement, particularly as Mary introduced the new idea that the conference was "like summer camp." When Sam, perhaps inspired from Mary's description of the conference, asked about activities, his intonation (Wennerstrom, 2001) suggested he was surprised to learn that a research conference would also include kayaking.

Sam also initiated his own conversations about engaging in research, usually within the context of asking Mary about her life. In the semester I observed Sam, he had begun participating in a journal club with Mary. Participation was not a compulsory part of his research experience. It was Sam's choice whether he attended journal club; in previous semesters he had not been able to because of his schedule. Sam read the papers that were covered and often asked Mary questions after the meeting when they were working in the laboratory. His attendance opened new opportunities for him to have conversations about research when working in the laboratory. Sam spoke positively about the experience.

Sam: Yeah, I like it!
Mary: Cause . . . you get to learn about topics that you would normally not choose to read about.
Sam: Oh yeah. Yeah, I don't know about presenting. That's a little daunting. (Round 1, Observation 4)

Attending the journal club also gave Sam the opportunity to learn more about one common aspect of the graduate school experience for Mary. Attending the journal club was a new experience and he was not aware of how the club normally functioned. In the example below, Sam introduced the topic of journal club to ask which professors regularly attended.

Sam: So, Professor Smith . . . was in the . . . journal club meeting today because they were presenting something similar to what they do in their lab. Does that mean that next week Professor Tate is going to be there or?
Mary: No. . . . Professor Tate is invited to come too but she's not available at this time . . . but [Professor Smith] comes all of the time. It helps that she knows a lot about this paper so she could give more input about it.
Sam: Yeah, she seemed to really know a lot about it.
Mary: Yeah, that's what their lab is using a lot. . . . So I hope she would know. [The technique] is like a really big, I don't want to say a new technique but it's definitely like . . . a pretty popular and trending technique right now. (Round 1, Observation 4)

While Sam's question revealed what he did not understand about the club, it also revealed a number of potential aspects of his current approach to understanding.

When Sam asked about Professor Smith, he began by assuming that their presence at the club was because it related to their research. Based on that assumption, he asked if a different Professor would attend for future weeks when the topic changed. It is possible that Sam made this assumption because he observed Professor Smith taking the role as an expert during the journal club. However, a second possibility is that Sam, who was more familiar with the context of a classroom where Professors are in charge, began from an understanding that a journal club may function like a classroom. As Mary answered, she did not explain the motivation behind Professor Smith's attending the journal club. Instead, she chose to describe why their presence at

the club was beneficial on that day saying, “[they] knows a lot about this paper so she could give more input about” (Round 1, Observation 4). With this answer, Mary shifted the focus on the conversation from Professor Smith to what she sees as one of the goals of the journal club, “to learn about [new] topics” (Round 1, Observation 4).

4.3.2.4 Pursuing Academic Success

Both Mary and Sam spoke about the value they placed on academic success and the ways that they worked toward this goal. For Sam, the majority of his conversations related to academic success were about classes that he was taking. These conversations were usually initiated by Mary asking Sam about his classes. In the example below, it was the end of the semester when Mary asked Sam about his course finals. In his answer, he described how he was approaching his final in the biology laboratory.

> I have my bio lab final which I . . . need to figure out what I need to get on that final to keep my A. But I’m going to guess that I’m probably going to study like one day for it just cause we have so many points in that class and the final is worth ten percent of our grade. (Round 2, Observation 1)

Sam was aware of his current average in the class and, based on his answer, would normally calculate what score he needed to maintain his average before taking his finals. He was aware of how much the final would contribute to his final grade and had already estimated how much time he would contribute to studying, based on his perception of its low contribution to the total points.

Mary was not taking courses the semester I observed her working with Sam. For her, academic success involved a variety of goals she had chosen to pursue. One goal Mary spoke about with Sam was external funds. Mary was applying for a scholarship to help support her research.

Mary: [I am] trying to apply for a scholarship. But you need to submit like an abstract on your research, so I'm going to do that.
Sam: So, you get paid more or how's it work?
Mary: It's just like an outside organization that supports [students]. . . . [Y]ou have to submit a research abstract and then . . . your resume and stuff like that. And then if you win, you get five hundred dollars. (Round 1, Observation 2)

Sam and Mary were interrupted during their conversation on this day and continued speaking about Mary's efforts to gain external funding a couple of days later.

Sam: What is it for?
Mary: It's . . . just a specific scholarship and if you win you get five hundred dollars.
Sam: For what, just to have?
Mary: Yeah. To enhance your learning abilities and education. And I'm also applying for other travel grants cause this summer I'm going to a conference. So it'll pay for your airfare and stuff like that. . . . They're a lot of work though, because you have to talk about your research or your future plans. It's basically writing a personal statement . . . and sometimes they want transcripts or things like that. (Round 1, Observation 4)

Mary communicated through her discussion of applying for scholarships and grants that it was important to her that she continue advancing herself. Mary described the process of applying for these funds as "a lot of work." However, she still chose to take the time to write applications and apply. Furthermore, when Sam asked Mary what the money would be for, Mary explained she would use it to help attend conferences, one standard practice of her profession (Thiry & Laursen, 2011).

4.3.2.5 Importance of Life Balance

Mary and Sam shared many interests outside of school and the laboratory. In addition to spending time with family and friends, they volunteered, travelled, and participated in a variety of physical recreation activities. Despite having busy academic schedules, Mary and Sam both made time for their interests. When working in the laboratory, Mary particularly would speak

about organizing her schedule to maintain a life outside of her research. This including making time to visit her boyfriend, Tom.

> I have to figure out—because I want to help out with girl scout day—but I might be out of town. Because apparently in the past it's been in April, but one is the last two weeks of April are Easter and—or near the end it's Easter. And then I'm going to go [out of town] because [Tom]'s graduating. (Round 1, Observation 1)

Mary used her discourse to convey the importance she placed on life outside of research. Although she was a graduate student, she also participated in roles outside of her research.

Sam's choice of conversations when working in the laboratory also suggested that he placed value in balancing academic responsibilities with other aspects of life. On the first day of observations, Sam told me about a trip he was planning to take during the semester.

> I'm actually going to New Orleans for Mardi Gras. I only have two lecture classes on Friday and I figured you know I can just skip those two just and you know <u>don't miss anymore—I usually don't miss any</u>. (Round 1, Observation 1)

Sam was going to stay with his girlfriend who had recently moved to area. Because he lived extremely far from New Orleans, it was a unique opportunity to be able not only to visit, but visit during the city's largest cultural event. In Sam's description of his plans, he spoke about how he balanced these two values, his interest in travel and in succeeding in school. As he ended his turn, he used a change in intonation to emphasize the importance he placed on his classes.

4.3.2.6 Attending Medical School

When Sam spoke about himself, he primarily communicated about the personal values he held. He placed a high value on scientific knowledge, demonstrated by his many conversations with Rachael about a variety of related and unrelated scientific topics. Accompanying his desire to gain knowledge was Sam ambition to become a doctor. When speaking about his goals during interview, Sam said, "The thing I want to do the most right now is . . . go to medical school"

(Pilot study, Interview). When talking about his personal life, Sam often referenced how his desire to go to medical school shaped the decisions he made, for example where he would live his junior year.

> Like part of me wants to [live at my fraternity] because it'd be fun but part of me is just like it would be a hassle. . . . [J]unior year is the biggest time for med school cause you have to study for the MCAT . . . that when like your hardest classes. . . . I'm probably not going to live [there]. (Round 1, Observation 2)

While Sam valued life balance, he also considered his academic goals when planning what he would participate in outside of school. He was a member of a fraternity and would normally have been expected to live in the house at some point. However, because he believed living at the house would distract him from his ultimate goal of attending medical school, he had asked for permission to continue living off-campus.

4.3.2.7 Responsible Citizenship

Many of the conversations Sam and Mary engaged in centered around ways Sam participated as a citizen of his communities outside of course-work. As discussed in the introduction, Sam often took part in activities that supported or promoted the university. Participating in these activities was one way that he helped students who were new to the university. When Sam spoke about these activities, he highlighted altruistic reasons for volunteering. His discourse suggested he desired to be helpful and promote success within his communities.

Sam's discourse suggested he held similar feelings about his responsibilities to the laboratory in which he worked. One clear example of Sam's helpful nature, mobilized through discourse, was in an offer he made to Mary on his last day of the semester. Sam chose to go home for the summer, instead of working in the laboratory for pay or academic credit. After

discussing that it was his last day, Sam said, “but no, seriously . . . if you ever need some [help], if you need me to come in one day and just do tips or something [let me know]." With his comment, Sam communicated not only a desire to help Mary and the laboratory, but a level of commitment that extended beyond pay or academic credit.

4.4 Summary

In this chapter, I described the two types of conversation Mary and Sam engaged in during Sam’s research experience: conversations about research and conversations about personal lives. My description of Mary and Sam’s conversations about research included a discussion of their primary pattern of communication, Assign-Report-Interpret. I detected this pattern of communication within each day that Sam worked in the laboratory. Mary initiated the pattern by assigning Sam tasks for the day. At some point in Sam’s progress, either when he encountered a problem with his task or had completed it, he would report his results to Mary. Upon receiving the results, Mary would provide an interpretation to determine future steps that should be taken.

Mary and Sam mobilized specific discursive features through the actions they took while participating in the Assign-Report-Interpret pattern. During their discourse, Mary contributed the majority of content while assigning tasks and interpreting results. As Mary assigned tasks she provided Sam intellectual support (Thiry & Laursen, 2011) by explaining foundational ideas he had not learned in his courses and by describing how to carry out procedures. Mary also provided Sam with personal support (Dolan & Johnson, 2010; Thiry & Laursen, 2011) by communicating her availability. When Mary interpreted results, she tended to reduce the intellectual support she provided Sam. Mary’s interpretations lacked the scaffolding present in

her assignments. I interpreted this silence (Huckin, 2002) to suggest that she believed Sam could fill in (Gee, 2011) her intentions within the context. Through interview excerpts, I provided successful and unsuccessful attempts of Sam's interpreting Mary's meanings.

Sam contributed to the conversation most often when reporting results; however, his contributions were usually brief. When reporting, Sam sought disciplinary anchoring (Thiry & Laursen, 2011) from Mary to help communicate effectively. He did demonstrate competence and confidence in reporting observations made while working. A large portion Sam's discourse when reporting to Mary involved observations. This is an aspect of the undergraduate research experience I have yet to observe in literature.

When Mary and Sam spoke about their personal lives, their pattern of communication changed drastically. I attributed this change in pattern mainly to an increase in Sam's contribution to conversations. Unlike when speaking about research, Sam selected topics for conversations, asked questions, and provided extended responses to questions. I presented excerpts from these personal conversations to demonstrate the ideas Mary and Sam communicated through subtext. Through personal conversations, Mary designated Sam's contributions to the research group as valid social currency (Bourdieu, 1986). She provided Sam with personal support (Thiry & Laursen, 2011) by including him in conversations and activities that involved the research group. Mary provided Sam with an example of the graduate student experience (Dolan & Johnson, 2010). Many of Mary's conversations focused on aspects of her experience which introduced Sam to standard practices in her field (Thiry & Laursen, 2011) like attending conferences and journal clubs.

Finally, both Mary and Sam communicated information through their personal conversations about their values. As Mary and Sam engaged in conversation, they demonstrated

a number of shared values. For example, both Mary and Sam aspired to academic success; at the same time, they also placed value in life balance. By sharing about her personal life, Mary provided Sam with the opportunity to gain new information about the characteristics of a successful graduate student (Dolan & Johnson, 2010).

CHAPTER 5. CASE TWO

5.1 Introduction

The second case I observed included an experienced undergraduate student, Serena, working with a faculty mentor, Merrill. The pair had worked together in a biochemistry research laboratory for a year. I chose pseudonyms for both participants and other members of the research team with whom Serena and Merrill collaborated. To help clarify Serena and Merrill's identities when discussing their case, I assigned Serena, the student, a name beginning with 's'; Merrill, the mentor, was assigned a name beginning with 'm.' To provide context for my interpretation of the case, I begin by introducing Serene and Merrill. I provide details about how they came to do research together and describe what a typical day looked like when they worked in the laboratory. Serena's experience working with Merrill did not have a high degree of structure in conversations. However, I noted a distinction in the conversations where Serena made decisions about their research versus those where Merrill was asked to decide. I chose to organize my discussion about their discourse around this feature.

I recruited Serena and Merrill to participate in my study during Serena's third semester of undergraduate research. Serena was a senior undergraduate chemistry major. Merrill was an associate professor. I chose pseudonyms for both participants; I selected a first name for Merrill because Serena regularly referred to him in this manner. Serena and Merrill approved their pseudonyms before use.

Serena was a traditional, domestic student. She was from out-of-state, although many of her family members had attended Purdue previously. Serena rarely travelled home to her family, who lived across the country. She had relatives who lived in the area with whom she was close

and regularly visited. Outside of academics, Serena spent much of her time involved in university athletics. She was a walk-on athlete and participated all four years of her undergraduate career. Her athletic responsibilities meant that she regularly needed to travel out of town to compete. At the same time, she was expected to maintain a minimum grade-point average (GPA) to stay on her team. Serena balanced these obligations well; she received an award her final year for maintaining a GPA of 3.7 or higher for the previous academic year. She was also on the Dean's List the year before. Serena considered maintaining a high GPA as one way she could contribute to the success of her team.

Serena began college as a biology major. She changed her major to chemistry during her freshman year because she, "liked it better than biology and . . . was doing better in it" (Round 1, Interview). After volunteering in a hospital, and realizing she did not enjoy it, she decided she needed to gain research experience in preparation to attend graduate school. Serena spoke to me about her choice in our first interview.

> I was like okay, I'm probably going to go to grad school then, so then I decided that I needed to try and get some undergraduate research experience. Because it . . . looks good to have that. That's something grad schools look for. (Round 1, Interview)

Serena decided to consider graduate school during her junior year, leaving her only a limited amount of time to gain research experience before applying to graduate school. Her participation in athletics complicated her situation because it limited her ability to keep a regular schedule. Serena's situation guided her selection of research experiences.

> [T]here's not a lot of free time for me to go like shopping around for professors. . . . My advisor . . . periodically sends out emails . . . [of] professors looking for people to research with and one of them, one of the emails had Merrill's name in it. . . . And so then I emailed him and started talking to him and the project seemed relatively interesting enough so I decided to just to. And also it helped that I told him that I was really busy. Like I might have to either remote into work or just like, there's going to be some weeks where I may not be able to come in at all or on this one day because of traveling for practice. He seemed fine with that, so it really worked out. (Round 1, Interview)

Serena expressed an interest in her research with Merrill both during our interviews and observations. However, she also chose to pursue an experience with Merrill because it fit with her limitations. Serena described Merrill as, “more than willing to work around [her] schedule”, which meant she could continue to participate in athletics while also pursuing research to support her goal of attending graduate school.

During the semester I observed Serena, she was in the process of applying for graduate school. Serena wanted to be close to her family and applied primarily to schools that would allow her to live near them. When speaking about how she chose graduate schools she said, “I wasn’t opposed to applying to schools on the East Coast, but I definitely thought . . . geographically, what are the best schools that I think I can get into that are a little bit further west” (Round 1, Observation 3). Serena applied to multiple universities and received both acceptances and rejections. When talking about being rejected, she showed an attitude of hardiness and perseverance.

> I didn’t get into the University of Washington. I was a little bummed but my mom was a little more upset because that’s where she went to school (*Serena laughs.*). . . . I expected to get some rejections just cause . . . it’s so competitive everywhere. (Round 1, Observation 3)

Serena was ultimately accepted into two chemistry graduate programs at public Doctoral universities. Both programs were closer to her family. Serena had to choose between attending graduate school at a less reputable program in the same state as her family, or a more reputable program farther away. She ultimately chose to attend the program that was higher ranked but in a different state. Although Serena’s undergraduate research was in the area of biochemistry, in our last interview, Serena indicated she was not considering biochemistry research but “leaning more towards analytical.”

Merrill was a tenured professor with thirteen years of experience; he had moved to the university two years prior. His academic background included training in both chemistry and biochemistry, in the United States and abroad. Merrill attended a combined Bachelor's and Master's degree before earning his doctorate degree. It was during this combined program that he had his first research experience in a laboratory. He spoke with me about his memory of the experience during our interview.

> You paired up . . . in your third or fourth year if I remember it correctly with a Ph.D. student to do a practicum in a lab where you were working on a research project. But you were always under the guidance of that PhD student. So you weren't making any decisions or anything like that, you were just learning things and got to witness it. And those things they lasted for about four to six weeks. Usually full time. . . . They were usually done over the summer or during semester breaks. (Round 1, Interview)

Merrill distinguished between his first experience in the laboratory and what he participated in while earning his doctorate.

> I wouldn't call [my first experience], well, you got your hands wet a little bit. But again, it was just sort of easing you into the whole research philosophy I guess. Then, my . . . thesis that was real research. I had to learn a few things then. . . . [I]t was quite a different experience, so there was quite a bit of a transition to do real research versus all this sort of mentored or guided experience. (Round 1, Interview)

When Merrill spoke about his two experiences, he appeared to differentiate them by the amount of guidance or mentoring he received. When earning his master's degree, Merrill described the research as "always under guidance" and an experience where "you got your hands wet a little bit." He did not call it research. Merrill referred to the work he did towards his dissertation as "real research." As part of this experience, he included the observations that there was less guidance and an increased need to "learn a few things."

During Merrill's time as a professor, he estimated he had mentored more than thirty undergraduate students. Merrill considered this to be a low number when he spoke with me in interview about his mentoring experience.

> [Other professors] were able to . . . accommodate a lot more students, there were groups that had ten to twelve undergrads at one time. I never had more than 6 at the most, because I wanted to be able to really have a close relationship with them and then time becomes an issue, if you have too many . . . it's hard if the numbers go up so high. (Round 1, Interview)

Merrill preferred to mentor fewer students, so that he had more time to spend with each student. One difference he identified between himself and his colleagues was that, by mentoring less students, he could put his students on publishable projects.

> I always made it a point that the work that they would do would be publishable in a journal. Some of my colleagues didn't want to deal with that, they said as long as they can have a poster show at a local meeting that's good enough. (Round 1, Interview)

Merrill's dedication to having students publish was reflected in his curriculum vitae, which listed thirty-one undergraduate students as contributing authors on thirteen publications.

Merrill described himself as a "self-taught" mentor. He did not receive any formal training in how to work with undergraduate students, but had developed his own approach to mentorship which he described during interview.

> At the beginning there's a lot more interaction between [the student] and me but the goal is to get them to a self-sufficient stage as soon as possible so they—not just to take the burden off of me—but also they have to learn that. That that's for their own benefit. That's part of their training, that they learn how to figure out things on their own. (Round 1, Interview)

While Merrill's ultimate goal was for a student to engage independently in research, his approach to mentoring had changed over the years. He had improved his mentoring skills through informal conversations with colleagues and, as he describes below, trial and error.

> [T]he mistake many people made, including myself, is that you ask for too much, if you have like a third-year student someone who doesn't have much experience. So you have to be careful what you're asking for, is it within their capabilities, is their background good enough, and then of course their personality factors in too. I've had outstanding students that were second year students that could do amazing things. And then others were seniors that had all the background that would screw up left and right. (Round 1, Interview)

Merrill treated each mentoring opportunity as an individual and personal experience. When possible, he considered the characteristics of a student and how those could match specific projects he had available. He also reevaluated their progress as they continued to work with him. During these reassessments, Merrill considered if a project should be made simpler for the student.

When Merrill spoke about mentoring, he focused on the importance of finding a good fit between student and project. In his approach, he described how he responded if a student was struggling with the project he had assigned. He did not speak about his actions in situations where a student proved themselves as competent. However, he did indicate that Serena was one of these students. When I asked Merrill about Serena, he readily placed her in "at least [the] top ten percent" of students he had mentored during his career.

> With [Serena] I'm . . . somebody who sets the general guidelines because she's very good at what she's doing. And she can work independently . . . she's quick learning and very self-sufficient and responsible. So you can just talk about general strategies with her and she will find a way to do them. (Round 1, Interview)

Merrill described the process of training Serena as lasting only "a few weeks" at which point he provided her with resources to help her train herself. While Serena's character and personality contributed to her transition to independence, additional supporting factors included the context in which she performed her research.

When Serena joined Merrill's laboratory, he placed her on a computational project. Serena's research was part of one of Merrill's collaborations in computer-aided drug discovery. Her role was to model the binding of a ligand to potential inhibitors, identified by his collaborators through a high-throughput screening assay. Serena's work helped Merrill and his collaborators compare experimental and computational results. Merrill considered this to be one of his more challenging assignments.

> Let's say you have two students that are equally talented with similar backgrounds, the one that's doing computational stuff needs more help in the beginning because . . . there's no classes that formally teach them that kind of stuff. It also makes it a little bit harder to check the reliability of the results and computer simulations almost always look pretty and beautiful. Somebody screws up an assay I can usually tell. (*Merrill laughs.*) (Round 1, Interview)

The project Merrill assigned Serena required her to learn computational skills she had not previously learned in any class. The nature of the work also made it difficult for Merrill to identify when she made a mistake because "computer simulations almost always look pretty and beautiful." Finally, Merrill's own experience with the supercomputers that Serena needed to use for molecular dynamics (MD) simulations was limited, meaning that he was not able to answer many of the questions she had when working. Because Serena's project required expertise outside of Merrill's experience, many of her daily laboratory interactions involved getting guidance from additional resources.

Two additional resources Serena used in her research were instructional videos and guidance from John, one of Merrill's collaborators. The instructional videos were available through a YouTube® channel maintained by the software company that created the modeling suite the laboratory used. These videos provided step-by-step guidance in how to use specific features of the software. Serena regularly played these videos while working in the laboratory. Merrill had recommended the videos to Serena, while John tended to also reference them when speaking with her. John was a computational expert from outside the department. He did not work in the laboratory, but visited regularly and was available by e-mail when Serena had questions. Merrill considered John's role in the project to be as a technical expert.

> I paired her up with [John] because I do not have a lot of experience on my own, particularly not in using supercomputers. . . . So [John] has taken her under his wing, so to speak, and taught her how to do that. And I'm involved in the interpretation of the results and what compounds to study, but the technical details it's the two of them.

> His chemical background is actually—I shouldn't say limited—but he doesn't . . . want to be the one then making the final call. (Round 1, Interview)

John provided Serena with advice on how to set up MD simulations. He would participate in discussions about Merrill and Serena's research, but did not make decisions about which compounds they would investigate, how to improve approaches or what results meant. These decisions were left up to Serena and Merrill.

Serena worked mainly in a small laboratory space made up of two rooms. During my observations, she shared this space with three other undergraduate students. Serena was the most senior of the three students. These students were on experimental projects requiring wet laboratory work. One student, Alex, was working on a project involving experimental validation of Serena's MD results; however, Serena and Alex did not work together while in the laboratory. The only interactions Serena shared with these students during my observations were social conversations and answering their questions about the locations of items. Because Serena's experience in the laboratory was mainly computational, she usually did not know where items were located, although she did often help them look.

Merrill worked mainly from his office, which was down the hall from the main laboratory space. During my observations, he came in regularly to check on the progress of his students. He did not tend to stay long, unless he was asked a question or observed that a student was having trouble. This was rarely the case with Serena and he usually spent only a couple of minutes at a time, talking with her. Serena tended to spend most of her time working alone, either quietly or as she watched instructional videos. The only times this changed were when John visited the laboratory or she showed Merrill results from her work.

When I observed Serena and Merrill working together, Serena was taking a full-time course load and planning to graduate. She received academic credit to do research and worked in

the laboratory twice a week for a total of six hours. Because Serena was a student athlete, she regularly had to go out of town to compete. This meant that her research schedule often changed. She kept Merrill informed about when she would not be coming to the laboratory. She also reported working outside of the laboratory when her athletic responsibilities kept her out of town; however, I did not observe her during these times.

5.2 Typical Day

A typical day in the laboratory began with Serena entering the laboratory and setting up her workspace. She usually spoke casually with any other labmates that were in the laboratory as she prepared to work. Serena's workspace included her laboratory notebook; her personal laptop, which she used to access e-mail and YouTube®; and the laboratory's desktop, where she accessed the MD software and supercomputer. Serena started most of her days without consulting Merrill. She usually picked up in her work from where she left off last time. She typically began by logging into the laboratory desktop and loading the MD software, including any projects that were in progress.

Each day that Serena worked, she referenced both her laboratory notebook and YouTube® videos for guidance. For tasks she had done before, she referred to her laboratory notebook. In her notebook, Serena kept a variety of information including technical details John gave her about how to set up simulations. She also documented her daily tasks, such as file names, simulation settings, and observations. For some tasks, Serena referred to the YouTube® videos recommended by Merrill and John. Serena often watched parts of these videos multiple times in a single day. During my observations, she never watched a video in its entirety. She usually skipped around within videos, watching portions relevant to her current task in brief

segments, lasting less than five minutes. She then paused and worked on her own project until she had progressed to the same point as the video's progress. As she worked, Serena would record information in her notebook about steps she had taken. She also referenced emails from Merrill, John, and additional collaborators when working, although this was not a regular occurrence.

Serena rarely approached Merrill to ask questions. Instead, she tended to ask questions when he approached her to check in on her progress. Merrill checked in on Serena every day that she was in the laboratory, although his visits were sporadically timed. When Merrill checked on Serena, he began by asking some form of the question, "how are we doing?" at which point Serena would provide Merrill with an update of her progress and ask any questions she had. It was during these conversations that he would bring up any new information he had about the project. This included discussions of how they planned to move forward with her research and plans for dissemination. Merrill brought up these longer-term conversations every day of my observations.

The simulations that Serena worked on in her research required hours and sometimes days to finish. In the laboratory, she focused on setting up these simulations so that they could run while she was away. Serena had shared access to a supercomputer, meaning that she could only run a few simulations at a time. Because of this shared access, there were times when Serena was left without work. When she described her research to me she said, "there's a lot of waiting." (Round 1, Observation 1) Merrill trusted Serena to do her research when and as she needed, so when she determined she was finished for the day she was free to leave. However, during my observations, Serena usually had enough work that she stayed until the time she was scheduled to leave.

5.2.1 John's Visits to the Laboratory

Approximately once a week John visited the laboratory. On days that he visited, Serena's routine changed discernibly. His visits usually lasted one to two hours and took up the majority of those days for Serena. When John visited, Serena was usually ready with her laboratory notebook and a list of questions she had collected since his last visit. Serena's questions were of a technical nature and appeared to be the result of her trying tasks first on her own. When Serena asked John questions, she began by showing her progress then identifying where she encountered difficulties. Her questions were direct and specific in nature. John tended to answer Serena's questions in the same direct manner. In some cases, he would also provide insight behind his answers in the form of explaining how supercomputers worked or the limitations of MD software. Serena contributed to these conversation with observations she had made while working with the software or with chemistry content knowledge. Merrill was sometimes present during parts of John and Serena's conversations. When Merrill was present, he tended to either listen to John's computational explanations or offer his own explanations, grounded in chemistry content.

5.3 Norms of Discourse

Serena and Merrill had limited conversations when she was working in the laboratory. All their discussions related directly to Serena's research. Conversations were generally collaborative, with both Serena and Merrill contributing unique content and participating equally (Roschelle, 1992). I observed that Serena and Merrill's conversations about research could be organized into two categories: conversations where Serena was comfortable making decisions and conversations where she deferred to Merrill. A third type of conversation I observed involved Serena, John, and Merrill. In these conversations, all three spoke about research and

participated in the decision-making process. For these different forms of conversation, their turns while speaking were distinct and illustrated the roles they each played in the research relationship. I provide an analysis of these norms of discourse in the sections below.

5.3.1 Conversations Where Serena Decided

Serena regularly made decisions and communicated her previous actions and plans for daily activities with Merrill. Merrill usually initiated these conversations by asking a question.

> Merrill: I haven't really talked to you much last week. . . . So you were doing some more docking, right? Or did you?
> Serena: We had. So we had docked a bunch of the barbiturates and the cinnamic acids, you know, the ones that we got from. Looked at the scores . . . then after we kind of looked at our old results, we did it again but at like 120 nanosecond.
> Merrill: How long was the one that you did before?
> Serena: I want to, it was like 1.2. . . . It was very very sh—we just kind of wanted to like you know make sure it worked and stuff. (Round 1, Observation 1)

Merrill regularly led conversations with Serena through questions. He asked both polar (yes-no) and non-polar questions (Grimes, 1975), but tended more towards non-polar questions. Most of Merrill's questions prompted Serena to provide descriptions about the details of her project. Consider the following example.

> Merrill: How does this work, making those video clips where you can—can you do that or?
> Serena: Mm-hmm. I can make movies of stuff. This, we can watch this real quick. . . . So I'm like playing around with the controls because you can, you know, superimpose it on a specific atom and stuff. (Round 2, Observation 1)

During our interview, I asked Merrill to reflect on his role in these conversations after we observed a video recording of the above discussion together. He said,

> Oh, we were just making the plan for the day. Exchanging ideas with her, trying to not be the one telling her to do this, and that, and that, and that. Because at her stage she should be able to get that on her own. . . . [A]nd she knows usually. (Round 1, Interview)

Merrill did not speak directly about his choice to use questions when planning with Serena; however, he did communicate a desire to limit how much *direct instruction* he provided. This goal echoed reports by Laursen and colleagues (2010) on the working styles of research advisors in summer undergraduate research experiences (UREs). It is possible that Merrill used questions to negotiate the tension between Serena's need to be mentored with his desire to foster her independence as a researcher (Laursen et al., 2010).

Merrill also asked Serena questions out of necessaity, because he was unfamiliar with the technical aspects of the programs she used in her research. He had allowed Serena to take responsibility for this aspect of her work with John's guidance. Since Serena regularly worked without Merrill, the details she provided were often information of which he was unaware. When Serena spoke, Merrill actively listened and provided brief statements as responses. Merrill's responses were usually backchannel confirmations (e.g. okay) (Wennerstrom, 2001) or dialogical repetitions (Bazzanella, 2011). He rarely modified what Serena said; I interpreted this as a form of speech-act silence (Huckin, 2002) communicating that he accepted or agreed with Serena's statements. In some cases, Merrill provided disciplinary anchoring (Thiry & Laursen, 2011) by contributing biochemistry content knowledge to the conversation. Merrill's treatment of Serena's turns at talking suggested that he considered Serena to be a knowledgeable researcher from whom he could learn. It appeared that one way Serena engaged in *legitimate peripheral participation* in the *community of practice* (Lave & Wenger, 1991) was through accepting responsibility for the technical aspects of her own research.

Serena reflected on her knowledge, and the nature of the relationship with Merrill during our first interview.

> It does seem like collaborating because a lot of the software I'm using, if you don't use it all the time, you don't really know how to use it. So I feel like, right now, I might know more about the software than [Merrill] at this point. (Round 1, Interview)

Serena had learned to use the software for her research independent of any contribution from Merrill through watching YouTube® videos and working with John. By asking questions, Merrill created space for Serena to demonstrate the expertise she had gained. During these conversations, Serena had the opportunity to share in the possession of information about the project (Wiley, 2009). I interpreted her discourse to suggest Serena had taken on a form of ownership described by Wiley (2009) as *ownership as right and responsibility*. As the more experienced person in these conversations, Serena was accountable for the information she presented. This accountability translated into sharing in responsibility for the overall success of the project.

While Merrill initiated conversations with Serena to discuss her plans for the day, it was common for the role of lead in the conversation to transition as they continued speaking. As Serena and Merrill spoke, Serena's turns-at-talk would begin to dominate with Merrill taking on the role of listener. She would introduce new topics to the conversation, like her plans for how she would proceed. Consider the following excerpt where Merrill asked Serena about data she had provided to their collaborator, David. After running a short docking-simulation for David, Serena had set up a longer one that required days to complete.

> Merrill: That's the thing you had for [David], right?
> Serena: Yeah, the little . . . PDF file.
> Merrill: Okay, and now we have a longer one. That should be—
> Serena: Yeah, so it should be done by now and what I was planning on doing today is, you know, trying to figure out how to get it off from the supercomputer. You know by myself or whatever. (Round 1, Observation 1)

Serena tended to present her plans to Merrill spontaneously, without prompting, although her responses did appear to be related. In the example above, Serena responded to Merrill's statement of the status of the project "now we have a longer one" with a turn which transitions from the current situation to what comes next. Her introduction of future plans appeared to be accepted by Merrill, who did not interrupt but continued to listen.

When Serena discussed her plans, she usually included information both about what she could do on her own and parts of her plans where she would need assistance.

We can see an example of Serena engaging in this self-regulated learning (Zimmerman, 1990) as she identified a gap in her own abilities to work with the interface in the continued description of her plans for the day.

> But I'll probably still need [John] to help me get that PDF file because I can save it no problem . . . but I just don't have the skills to get it off . . . their interface or whatever. (Round 1, Observation 1)

When Serena spoke about getting help from John she tended to be exact in her descriptions, as demonstrated in the above excerpt. She identified specific information or skills which she lacked and strategies for how he would assist her (Zimmerman, 1990).

Merrill offered personal support (Thiry & Laursen, 2011) by inquiring about Serena's comfort in executing her plans, particularly when she planned to work without John on something she had not done alone before, as in the following example.

Serena:	I think I already docked it, so I could honestly probably just start working on the MD stuff.
Merrill:	Are you comfortable enough without [John] or?
Serena:	I think it would be good practice for me to at least try by myself.
Merrill:	Absolutely. Have him look it over at least before you . . . ask for computer time for a week of simulation (*Merrill laughs.*). . . . But no, I think as long as you're comfortable.

Merrill's reply highlighted a second concern he had, that Serena might make a mistake resulting in a week of wasted simulation time. He negotiated this concern by instructing her to use John as a resource to check the work. Serena responded both with confirmation that she understood Merrill's instruction and a statement of confidence identifying the ways she planned to make sure that her work was accurate (Zimmerman, 1990).

> The only part I'm a little iffy about is figuring out how I do some of it on the lab computer . . . but then like I have to do the rest of it on my computer and it's just a matter of saving it somewhere where I can find it easily and stuff. I've taken some notes when he's been here and I know some of the shortcuts and stuff (*Serena laughs.*). . . .So I'll give it my best shot at trying to set it up by myself and hopefully [John] will come by so I can just be like, 'Hey, look at this'. . . . I've gotten—there's a bunch of tutorials and stuff online, too. So that's not the big issue cause, you know, it's kind of hard to remember every single step. But since I do have the tutorials that's not a big deal. It's trying to make sure everything get on the supercomputer correctly. (Round 1, Observation 1)

In Serena's response, she spoke confidently about which aspects of her plan she believed she could do without help from John. To support her claim, she mentioned her laboratory notebook and the instructional YouTube® videos.

When Serena worked alone, I regularly observed her referring to her laboratory notebook and YouTube® videos. This often occurred after she displayed what I interpreted to be signs of experiencing difficulties (e.g. sighing) (Hoey, 2013). Serena rarely asked Merrill for assistance when she encountered problems during her daily activities. Instead, she would re-read notes in her laboratory notebook or re-watch parts of YouTube® videos multiple times. It appeared that having these resources allowed Serena to work more independently by providing her places to seek answers when she needed them in a self-directed manner (Knowles, 1975).

Serena spoke confidently about her plans for how to move forward in her research independently. When discussing her research with Merrill, she even indicated decisions and actions she made without Merrill's input or knowledge. Consider the following excerpt where

Merrill asked Serena about the next inhibitor David would like for them to work on, based on his experimental findings.

Merrill:	Did [David] e-mail us the structure of that thing, that we know which one it is?
Serena:	Yes. . . . He did. And I docked it already.
Merrill:	Oh, you did already?
Serena:	Uh-huh.
Merrill:	Excellent.
Serena:	I was just looking through scores. It does have a lower score than a lot of the one ones, but I guess—
Merrill:	That's okay.
Serena:	I mean, if it works, it works. (*Serena laughs.*) (Round 1, Observation 1)

Instead of waiting for Merrill's confirmation, Serena had taken the initiative to move forward with the next inhibitor as soon as their collaborator, David, had provided her with the file. I interpreted Serena's actions to indicate she was comfortable taking ownership as responsibility for her research decisions (Wiley, 2009). In addition to docking the inhibitor, her conversation indicated she had further engaged in thinking about and interpreting the results on her own. As expected, based on Merrill's goals for Serena to become an independent researcher, he responded positively to Serena's actions. His intonation also suggested he may have been surprised by her level of independence (Wennerstrom, 2001).

After Serena finished giving her opinion about the docking score and its meaning, Merrill added his own interpretation. He agreed with Serena and explained, "We know for sure from the experiments that this is an active inhibitor. And I really don't care so much about the docking score at that point. We know it works, let's analyze it and see what it does." (Round 1, Observation 1) Merrill's contribution supported Serena's ideas with explicit reasons for the decision. His explanation appeared to be an effort in professional socialization, containing both a discussion about disciplinary knowledge and norms of the profession (Thiry & Laursen, 2011). He also expanded the conversation to include a discussion of the relative importance of

experimental findings and theoretical findings (i.e. the docking score). This comparison introduced information into the conversation which may have been present in Serena's understanding, but was only explicit through Merrill's discourse. To further illustrate the importance of experimental findings, Merrill continued with an example from Serena's past work when her computation results conflicted with findings in the laboratory.

> Because remember with the pure, with cinnamic acid scaffold . . . it's a beautiful docking and then . . . it didn't do much. Which is still surprising because they should all do something, because they all have been picked high-throughput screen, showing that they do something . . . at higher concentrations. (Round 1, Observation 1)

Merrill's example highlighted some of the underlying assumptions Serena's research. In his example, he asserted that results could differ between experimental and theoretical findings. At the same time, he added that experimental results are expected to stay consistent, if found under the same conditions. Merrill's action of contributing "big picture" ideas to the research conversations is consistent with previous findings on the positive influences of faculty mentors on undergraduate researchers (Dolan & Johnson, 2010).

5.3.2 Conversations Where Merrill Decided

While Merrill often provided Serena guidance, I rarely observed him making decisions for her. When Merrill made a decision, it was prompted by a direct question. Consider the following excerpt where Serena, having completed her analysis of one molecule, asked Merrill what molecule to analyze next.

> Serena: Should the next one we think about doing, should it be like you know like the real one we've been using or should I pick the top barbiturate?
> Merrill: No, the real one. . . . [W]e want to avoid a scenario—because you know these things they take time—and if you end up with another dud that is time . . . wasted essentially. To show how it doesn't inhibit (*Merrill laughs.*) and highlight the discrepancy between experimentation and computation. (Round 1, Observation 1)

Serena asked Merrill how to proceed by providing him with a choice of two options. She had already narrowed her plan of action based on her own knowledge. It was only after she identified the gaps in her own knowledge (Knowles, 1975) that she chose to consult Merrill. Demonstrated in the quote above, Merrill first answered Serena's question, then provided her with an explanation of his decision.

Merrill's discourse indicated that he took into consideration both the goals of their research and Serena's experience when making the decision. As a mentor, Merrill was mindful of how he negotiated these two needs (Laursen et al., 2010). Investigating either molecule would have been useful for Merrill's work, since the "top barbiturate" had scored well enough to suggest it may be successful in further testing. However, as Merrill explained, selecting the "top barbiturate" also carried risk. It was possible that the "top barbiturate" would not work and Serena could "end up with another dud." If this happened, Serena would only have negative findings to report at an upcoming research symposium.

Serena also sought Merrill's guidance at the end of the semester, when she had finished her work with two weeks left. Consider the following excerpt.

Serena:	So, would you want me to start on more jobs? Cause right now the ones I just finished running were the experimental barbiturate with the second run with no modifications and then the first run of the het state one. . . . Or, if there's anything else you would want me to do.
Merrill:	No, I just want to plan accordingly so we're not having a scenario where you have to leave and things are still going on that. Did you make that table or list of systems that—
Serena:	Not yet. I can do that.
Merrill:	Do that. And then we look at that and see if anything else is needed for those. And the rest of the time, I would say analyze what you have. And maybe organize everything so we can find stuff once you are no longer here. But that has been historically sometimes problematic that somebody is gone and, "Oh, where do I find this? Where's that?" I forget. So, let's sort of plan to reach a conclusion rather than starting new things. Unless there's something that really needs to be done. (Round 2, Observation 1)

Because this was Serena's first time doing research, she had no previous experience to help her determine when to begin wrapping up her work before leaving permanently. She was also not familiar with the process of checking out of a laboratory. When Serena sought advice from Merrill on what to do, he chose to intervene (Laursen et al., 2010). Instead of continuing with more jobs as she suggested, Merrill decided it was time to begin wrapping up her work. He also introduced a disciplinary norm in his conversation about the importance of Serena taking the appropriate steps to leave the laboratory with the resources to move on without her (Thiry & Laursen, 2011).

In both instances where Serena sought Merrill's advice, his decisions were based on more than knowledge about her research. Similar to the research advisors who participated in Laursen and colleague's (2010) study, Merrill's decisions were rooted in his values and experiences. When deciding how Serena should proceed, Merrill considered what findings would be most useful for her. Based on his discourse, it appeared that Merrill preferred for Serena to have positive findings before she graduated. He also kept in mind that, once Serena moved, the knowledge she had about the project would need to be preserved. With Merrill's decisions, he balanced his need for his research to be productive and successful with his desire for Serena to have a positive experience (Laursen et al., 2010). These were the "big picture" decisions about Serena's research experience (Dolan & Johnson, 2010) that she was not equipped to make herself.

5.3.3 Conversations Where the Group Decided

Merrill used his discourse to regularly encourage Serena's independence as a researcher (Laursen et al., 2010). He suggested she make decisions on her own or with help from John or

himself when possible. Serena usually made decisions alone or with John's assistance. In certain cases, I observed that Serena and John would both be unwilling to make a decision, at which point Merrill was sought out as the ultimate decision-maker (Dolan & Johnson, 2010). These were usually situations where a high amount of biochemistry content knowledge was needed to determine how to proceed.

One example where Merrill played the role of biochemistry content expert occurred early in my observations, when Serena and John asked him to help them decide which of a set of three tautomers should be used for a future simulation of the ligand. Tautomers are molecules with the same molecular formula but different bonding patterns and atomic organization. The difference between these structures came down to the placement of a single hydrogen atom. When Serena and John approached Merrill, all three of them appeared hesitant to decide. John initiated the conversation by saying, "I have no idea about the ligand." (Round 1, Observation 1) To reach a conclusion, the three participated in a 25-minute collaborative discussion (Roschelle, 1992). Merrill provided chemistry content knowledge while John contributed computational information about how the structures were generated. Serena supplied both her knowledge of chemistry content and the information she had learned through working with the software.

Serena, John, and Merrill each contributed knowledge to the conversation based on their own expertise (Roschelle, 1992). Serena began the conversation by showing Merrill the structures in question.

Serena:	Yeah, so we have . . . three different options.
Merrill:	Okay.
Serena:	Originally like— (*Serena displays one of the structures on her screen.*)
Merrill:	This is how you . . . is that protonated on that?
Serena:	This is un-protonated and then it like, swings the double bond over (*Serena displays an alternant structure of the screen.*).
Merrill:	Oh, it's a tautomer then. Okay. (Round 1, Observation 1)

Serena was familiar with how to handle the computer and software used for her work. While John was also familiar with the computer and software, he allowed Serena to take charge in presenting their problem. After Serena showed Merrill their choices, his first action was to anchor the conversation in disciplinary language (Thiry & Laursen, 2011). He noted that the structures were tautomers, structural isomers which readily interconvert, although he did not provide the definition. I interpreted his silence to suggest he either believed this was presupposed knowledge (Huckin, 2002), or that Serena and John could determine a definition through context clues.

After Merrill had seen all three structures, he began by stating the limitations of his knowledge. In his explanation, he cited content knowledge (Thiry & Laursen, 2011). He explained, "I don't know which one is more relevant here. And even if you know it for a ligand, how it behaves in bulk, things . . . biologically can be different." He then asked Serena questions about the process she used to arrive at these structures, again suggesting that Serena shared in ownership of the project through the right and responsibility of intellectual contribution (Wiley, 2009).

Merrill:	So, does this docking—it's been docked, right?
Serena:	Yeah. This is one of the experimental docked. This is the best experimental docked pose.
Merrill:	But does the pose give you the tautomer?
Serena:	Um.
John:	No. (*John speaks to Serena.*) Go ahead.
Serena:	I don't know. It gave me three poses and they might all be the different tautomers.

John began to answer Merrill's question for Serena when she first hesitated. After he commented, he quickly followed up that Serena should continue with her explanation. Serena began by using the new disciplinary terminology (i.e. tautomer) Merrill introduced; however, it is unclear if she understood the meaning of the term.

As the conversation continued, Merrill asked more questions about how the structures were created. Both Serena and John answered these questions, contributing their own knowledge and individual expertise (Roschelle, 1992). While viewing the structures, Merrill began to talk aloud as he tried to decide which one to use.

Merrill: There's something not right here. Because there needs to be a hydrogen on that nitrogen.
Serena: Over there? (*Serena points to screen.*)
Merrill: Yeah, yeah. And then show me some others. (*Serena shows a different structure on screen.*) See that's what I meant. That has both those blue nitrogens protonated, that's sort of how I would draw it. But that doesn't mean—you can take one of those white hydrogens and move it to a neighboring oxygen making that an OH single bond. And then you have a double bond between the carbon and the nitrogen. See what I?
Serena: Mm-hmm.
Merrill: So you would have a double bond here, and single bond there and that hops from over here to there. What you have previously just looked like this but it lost the proton. That would I think it would be a negatively charged species which I would be suspicious about. (Round 1, Observation 1)

Merrill described specific features of each structure that suggested to him that it was a likely or unlikely candidate. As he spoke, he cited disciplinary knowledge (Thiry & Laursen, 2011) and his own personal intuition as a chemist. John and Serena listened and contributed brief backchannel statements (Wennerstrom, 2001) or dialogical repetitions (Bazzanella, 2011) which were interpreted as acknowledgment that they understood what he was saying. After reviewing all three, Merrill concluded, "So I do not know which one is the correct, or not the correct . . . the lucky one."

While Serena, John, and Merrill worked together to reach a conclusion, none of them was willing to make a final decision. During out interview, Merrill reflected on this incident.

> [John] likes to discuss things, but he doesn't want to be the one then making the final call. . . . I think [Serena] doesn't want to do that either, even though she participate in those discussions. I didn't want to make it either because I simply don't know. (*Merrill laughs.*) (Round 1, Interview)

Eventually Merrill had to leave for another meeting and concluded the conversation with his thoughts.

> We have to somehow pick one (*Merrill laughs.*) and have some reasonable criteria . . . if it's as dumb as saying this is what the docking program spits out, no questions further being asked. Maybe because if you now do the pKa then you have to pick and you have nothing to base your selection on. You have no docking score or anything like that. . . . You can think about it, if you guys want. Nothing better comes to me at the moment. (Round 1, Observation 1)

A few days later, I observed John explaining to Merrill which structure he and Serena had decided to use. After narrowing their choice down to two, John had suggested they proceed with both structures and use the outcome of the simulation to determine which is a more likely candidate. Merrill was surprised to learn that it was possible to proceed with more than one option. It appeared that the decision was made collaboratively, through contributions by all three members of the conversation (Roschelle, 1992).

Similar to Serena and Merrill's conversations, I observed that conversations that involved Serena, John, and Merrill also included participation by all members (Roschelle, 1992). When discussing the research, each member possessed distinct information about the project. While John and Merrill represented expert knowledge in their respective fields, Serena spent the most time working on the project. Serena's work in the project was legitimate peripheral participation (Lave & Wenger, 1991). As she worked on the project, she gained expertise that she shared with the group. She kept up with the details of their work and was the one to whom both John and Merrill directed questions.

5.4 Summary

In this chapter, I have described the three types of conversations Serena and Merrill engaged in during Serena's research experience. I differentiated between these conversations on the basis of which members were responsible for making decisions. Two of these types of conversations involved Serena and Merrill speaking together; a third type involved Serena and Merrill speaking with their collaborator, John.

Most of the conversations between Serena and Merrill involved Serena updating him on her progress and informing him about her plans for the future. Serena's discourse when engaging in conversation with Merrill suggested she regularly engaged in self-regulated learning practices (Zimmerman, 1990). Serena thought about her research. She participated in the planning of her research, she monitored her progress, identified gaps in her knowledge, and sought out resources that could help her fill in those gaps. The actions Serena took through her discourse suggested she had taken responsibility for her research (Wiley, 2009). This responsibility appeared similar to one form of project ownership identified by Hanauer and colleagues (2012) in the linguistic analysis of undergraduate student's discussions about their research. Furthermore, Serena's discourse suggested that beyond responsibility, Serena's experience in research had provided her agency. I observed Serena regularly opting to figure out her problems alone, with the help of resources like YouTube® and her research notebook. She also made decisions on her own, before seeking guidance from Merrill.

Merrill's treatment of Serena when she worked in the laboratory appeared to contribute to her self-regulation (Zimmerman, 1990) and responsibility (Wiley, 2009). Merrill had placed Serena on a project that required her to learn about software he knew little about. He provided her with resources to help, but placed the responsibility of learning in her hands. Serena's

resources included John, a collaborator, and a YouTube® channel designed by the software company for training. While John visited regularly, Serena's access to YouTube® videos was continuous. During my observations, she regularly used these videos to help direct her learning (Knowles, 1975).

Merrill regularly mobilized specific discursive features to encourage Serena's independence during their conversations. When discussing plans for the day, Merrill tended to begin the conversations with questions. His non-polar questions (Grimes, 1975) provided Serena with opportunities to discuss her research, which often led to her talking about ideas for future research. When Serena demonstrated this type of initiative, Merrill encouraged her actions by actively listening and allowing Serena to lead the conversation. Merrill contributed with backchannel confirmations (Wennerstrom, 2001) and dialogical repetitions (Bazzanella, 2011) to indicate he was listening. He also provided disciplinary anchoring (Thiry & Laursen, 2011) to support Serena's content-knowledge. Merrill sometimes expressed explicit verbal approval when Serena demonstrated initiative in her research.

Merrill rarely made decisions for Serena. The contexts in which he made decisions suggested that he trusted Serena to identify when she needed his intervention (Laursen et al., 2010). Merrill only made decisions for Serena when she asked him direct questions. Serena's questions involved "big picture" aspects of her research (Dolan & Johnson, 2010). When Merrill answered Serena's questions, his responses attended to his goals for her experience, disciplinary knowledge, and personal experiences mentoring (Laursen et al., 2010). To answer the questions required Merrill to access personal knowledge and negotiate priorities. As a person new to research, Serena would not have been able to consider these ideas on her own.

When Merrill and Serena spoke with their collaborator, John, I observed that all three members of the research team participated and contributed knowledge to the conversation (Roschelle, 1992). While John and Serena sought out Merrill to make decisions when they were unsure how to proceed, Merrill used his discourse to position himself as knowledgeable but not omniscient. Merrill contributed disciplinary knowledge to the conversations (Thiry & Laursen, 2011); however, he deferred to John and Serena when the conversation began to explain how the modeling software worked or what tasks had been completed before. Merrill asked John and Serena questions about the research. His discourse suggested that he considered the three of them to each share in the possession of the project (Wiley, 2009). When Serena answered questions and contributed her ideas, both John and Merrill used backchannel confirmations (Wennerstrom, 2001) and dialogical repetitions (Bazzanella, 2011) to communicate they were listening to her. Their treatment of Serena suggested that her research activities were a form of legitimate peripheral participation (Lave & Wenger, 1991).

CHAPTER 6. CASE THREE

6.1 Introduction

The third case I observed included a novice student, Simon, working with a postdoctoral-associate mentor, Mia. The pair had worked together in a biochemistry research laboratory for about two months. I chose pseudonyms for both participants and other members of the research laboratory. To help clarify Simon and Mia's identities when discussing their case, I assigned Simon, the student, a name beginning with 's'; Mia, the mentor, was assigned a name beginning with 'm.' To provide context for my interpretation of the case, I begin by introducing Simon and Mia. I provide details about how they came to do research together and describe what a typical day looked like when they worked in the laboratory. I noted that Simon's experience working with Mia carried a high degree of structure in conversations. Therefore, I chose to organize my discussion about their discourse using the same structure I observed.

I recruited Simon and Mia from a biochemistry department in Simon's first semester of undergraduate research during his freshman year as a biochemistry major. Mia was a postdoctoral associate who held a Ph.D. in Chemistry. She was in her first year in the position. I chose pseudonyms for both participants; Mia and Simon approved their pseudonyms before use.

Simon was a biochemistry major. He was driven and academically successful. Although he was in his first semester of college, Simon was a sophomore based on academic credits. He was enrolled in a full load of classes, including organic chemistry, which was normally taken by biochemistry majors in their second year. Simon was one of two students awarded a prestigious scholarship in his department based on academic merit. He was not sure of his future professional plans. He spoke about his aspirations in interview.

> I might want to go to medical school, but the other one is I might want to go to graduate school for either biochemistry or for like business school. . . . Because I think working for a company like Eli Lilly or another biopharmaceutical company would be really cool. (Round 1, Interview)

During our interview, he spoke about both medical school and graduate school in biochemistry. It was clear that he had a strong interest in medicine and pharmaceuticals.

Simon was a traditional, domestic student. He grew up approximately two hours from the university and enrolled the fall after graduating high school. He maintained relationships with his friends from high school. During our observations, Simon spoke with Mia about attending friends' weddings and planning vacations together. He was also active on his campus. He was a member of a club for his major and played a variety of sports. The semester I observed Simon, he was rushing a cooperative. He had chosen the cooperative he was most interested in and was regularly attending social events in preparation to join. His plans were to live in cooperative housing the following year.

Simon sought out a research opportunity in his first semester of college at the encouragement of his department.

> The Biochemistry Department encourages undergrads to get into research as soon as possible and a couple of my friends had gotten research already. And so I . . . felt kind of the pressure to like, geez, I need to get into a lab. (Round 1, Interview)

When Simon began looking at professors to work with, he started with those he already knew. On a campus visit, he sat in on a class with Dr. Tyler, Mia's boss. Simon decided Dr. Tyler's research looked interesting, based on the description online. He contacted them in the fall semester to ask for a position in his laboratory. Simon noted that he was willing to do any work available in the laboratory. He described how he sought out an opportunity in our interview.

> I looked [them] up and I read about what [their] research is about and I really liked what I read on the internet. So then I emailed [them] and asked [them] like, hey, I'm an

> undergrad and I'll be willing to do anything like wash dishes or whatever you need, I just want to get into a lab. (Round 1, Interview)

Dr. Tyler initially told Simon that they were not able to take on an undergraduate researcher, but they later offered Simon the opportunity to work with their postdoctoral associate, Mia.

During observations, Simon appeared to be a responsible and cautious student. He had worked at a chocolate shop before coming to the university. Simon had also chosen to rush a cooperative instead of a fraternity. Although similar, joining a cooperative meant he would take on additional responsibilities like cooking meals and cleaning the house as part of membership. When working with Mia, Simon listened carefully and regularly clarified instructions to make sure that he was doing tasks correctly. He spoke about his approach to research during interview saying, "I'm always really careful to not mess something up because I really . . . hate disappointing." (Round 1, Interview) Simon was motivated to please Mia with his work.

> I'm not getting graded on it. So I don't feel—like I feel pressure to do good, but at the same time I know that like if I mess up I'm more scared of disappointing her than getting a bad grade. (Round 1, Interview)

Simon was also a curious student. Mia commented on how Simon approached working in the laboratory during her interview saying, "he really is active in like learning. And so in research and in regular life and so I've noticed that he would ask . . . questions." (Round 1, Interview) Simon demonstrated interest in learning more about Mia's research. He also regularly asked Mia questions about topics unrelated to her research, including questions about politics and scientific research. Mia commented on his interest in learning from her.

> He'll actively bring me things that he notices or learns or he'll do things . . . I suggest. And so he is like—he is actually—he is one of the first [students] that I've actually seen implement things that I've suggested or done or wants me to know something. (Round 1, Interview)

In addition to bringing new topics of conversation to the laboratory, Simon would also text Mia with information about topics they discussed in the laboratory.

Mia was originally from a city approximately 90 minutes from the university. She had moved out-of-state for her bachelor's degree, but returned to the university for her doctoral work. Mia had taken a couple of years out of school between her bachelors and doctorate. She was working as a postdoctoral associate at Purdue University, where she also received her Ph.D. Her new research was in a separate department and unrelated to her doctoral work.

As an undergraduate, Mia had participated in one year of undergraduate research in her senior year. She had experienced difficulties finding a research opportunity at her university because funding was earmarked for minority students and she was not a minority.

> I had one guy who was super kind . . . he said I could work with him. I just wouldn't get any credit. . . . At that point I was a senior and I wanted to graduate also and so I agreed. And so I worked with him . . . for a year and he showed me and introduced me to nothing biochemistry, but I took anything I could get. . . . So I worked with the surfactants and single-walled carbon nanotubes. (Round 1, Interview)

In addition to participating in research on campus, Mia was an intern in industry over two summers while an undergraduate.

> And I had an experience at GlaxoSmithKline. I had a 12-week internship in the R&D drug discovery and then I did research in the lab there. . . . I think I was a sophomore. And then I don't consider it lab research, but I was researching intellectually. I worked in U.S. Regulatory Affairs and I had to research – I had a lot of research projects for them. (Round 1, Interview)

Mia did not mention her own research experiences in undergraduate as informing how she mentored students. As a graduate student, Mia had worked with three undergraduate students. During the semester I observed her working with Simon, she was mentoring one other undergraduate. When I asked Mia about how she learned to mentor, she mentioned multiple resources.

> I don't know. . . . I taught two years of organic chemistry in the chemistry department as a TA. . . . And so from that experience, from teaching them, I didn't think it was that much of a leap. . . . I teach them how I would have liked to be taught. And so when I went to grad school I was like, this sucks, nobody is teaching me, I have to learn everything and I didn't have that much experience. And so I was like if I were an undergrad, how would I want to be taught to be prepared for graduate school like I wanted to? (Round 1, Interview)

Instead of drawing on her own experiences being mentored, Mia shaped her mentoring by considering what she was lacking when she entered graduate school. She also communicated that her approach to mentoring had evolved.

> I was more obstinate about like I had to go through it this way so they can which I'm totally not anymore. . . . [T]hat has totally changed. I think I only was that way for maybe a year in the beginning. . . . [I]t was stupid for the fact that like how I learned wasn't the best and so why do I want to continue to like promote that, or I don't want to be the same as who I learned from. . . . And so I just kind of – like I kept refining it over trial and error. (Round 1, Interview)

Mia regularly reflected on her mentoring practices. During our interview, she spoke to me about her experiences mentoring students besides Simon. Cases where Mia struggled to mentor a student encouraged her to try "a ton of different approaches." (Round 1, Interview) She continually sought out ways to improve her mentoring. After our interview ended, she even approached me for advice on mentoring a student with whom she had experienced difficulties.

When Mia spoke with me about mentoring, I observed key features that made up her philosophy of mentoring. Mia considered each student to be unique and require a different approach. In interview she said, "They're all totally different. . . . I kind of don't know what to expect when one comes in." While she considered each student to be different, she also observed similarities in how they began working with her.

> [T]hey always come in really fearful, like oh, my gosh, if I don't do this right or I mess this up and I'm – I honestly make them do stuff that I just don't care. . . . I think that's the only thing that I can maintain the whole time is I don't have higher expectations. It will be nice if it worked, but if they mess it up, it doesn't mean they're destroying like a whole week's worth of something that I'm doing or it's not like they can't redo it. And so I make sure to give them something that they can fail, but I'm sure that they can succeed

> at the same time. And I really try to give them something that I know what's going wrong so that I can help them as opposite to like we're both like, what the hell with this. (Round 1, Interview)

Mia's experience with undergraduates had been that they were scared when they first began working with her. She used a direct approach to address their fear. Mia chose to expose her students to what she considered were safe situations where they had the opportunity to make mistakes.

Mia learned about Simon's interest in undergraduate research from Dr. Tyler during a group meeting. At the time, she was working with one student whom she had "inherited . . . from another postdoc." (Round 1, Interview) She decided to take on Simon, in part, because she had never worked with a freshman.

> He is still a freshman. . . . I've had experience in the past with undergrads who are in their last year or coming up to their last year. And I never had experience with one who is just starting. And I've heard . . . it may be a lot more work to have one that's just starting. But if they continue to keep working with you, you have an investment and so then it can be mutually beneficial. So he can learn and then if I can convince him to stay for few years then I could have him, who's experienced, and keep working with the project to help me. (Round 1, Interview)

As a freshman, Mia viewed mentoring Simon as a long-term opportunity. She expected that it would take more time initially to train him. However, if she was successful in creating a positive experience, Simon might work with her until either he or she left.

Mia and Simon worked mainly in a large, open-space laboratory. Each student and postdoctoral associate in the research group had a bench in the space. The students worked on separate projects, although all their projects related to the Principle Investigator's (PI) work in enzymology. Communal equipment was located both on the periphery of the laboratory space and in adjacent rooms. The laboratory shared some resources (e.g. ice makers) with additional research groups in the building; these were located in separate rooms. During my observations,

the laboratory members generally worked quietly and independently. Simon rarely engaged with them. When he did speak with group members, it was to ask questions about the location of supplies.

The PI, Dr. Tyler, did not work in the laboratory during any of my observations. They did stop in to chat briefly with groups members. Dr. Tyler usually worked in an office down the hall from the laboratory. Mia and Dr. Tyler interacted most often in individual and group meetings. Mia shared a separate office with two members of the group down the hall from Dr. Tyler. This space was also usually quiet, with group members working individually.

The semester I observed Mia and Simon working together, he was taking a full-time course load. He received academic credit to do research and worked in the laboratory three days a week for a total of six hours. Simon's schedule sometimes changed; he and Mia regularly texted to keep up with both of their availabilities.

6.2 Typical Day

A typical day in the laboratory began with Simon meeting Mia in her office. They would walk together to the laboratory, located across the building. When Simon entered the laboratory, he was careful to get safety glasses from a designated space in the laboratory. Mia was prepared with a specific task she and Simon would be completing for the day and would begin explaining once he came to her bench. Mia and Simon usually worked together; however, there were some tasks that he completed alone. For example, Simon would load a protein gel by himself. Once loaded, Mia would check his work and help set up the gel box before running the gel.

Mia began each day by telling Simon what they would be doing. If she had already worked on a task, she would first bring Simon up-to-date with her progress while he was out of the

laboratory. For tasks Simon was doing the first time, Mia gave an overview of how the experiment worked. This overview included showing Simon pieces of equipment and explaining scientific content Simon had not covered; Simon tended to ask many questions during these conversations. When Simon had worked on an experiment previously, Mia began by asking what he remembered of the task. Mia critiqued Simon's explanations and encouraged him to continue speaking. During both types of conversations, Mia would begin to pull out printed protocols that she referenced or encouraged Simon to reference.

When working on a task with which Simon was unfamiliar, Mia took the lead in collecting and setting up new materials. She regularly instructed Simon to obtain supplies he had used in previous experiments (e.g. 200-milliliter beakers) on his own as she set up experiments. For familiar tasks, Mia instructed Simon to take the lead using specific discursive strategies, described in detail below. When Simon was in charge, Mia regularly directed his attention to printed protocols and checked work behind him. Both Simon and Mia asked questions during this process. They continued working in this manner until Simon left for the day.

Mia generally planned tasks that had convenient stopping points when either she or Simon needed to leave. Sometimes Simon would leave the laboratory while Mia finished an experiment. I also observed Mia leaving one day when the experiment was complete but Simon was cleaning glassware.

6.3 Norms of Discourse

Mia and Simon's conversations centered around three broad topics: Mia's research, the nature of science and scientific research, and personal lives. Conversations about these topics

were often interwoven. I present an analysis of the norms of discourse for each topic in separate sections below.

6.3.1 Conversations About Research

I observed two distinct types of conversation that occurred when Mia and Simon spoke about research. These were conversations where Mia made decisions and discussions where she invited Simon to take charge of decision-making. Mia generally made decisions when Simon was working on a task for the first time. After Simon had worked with Mia once on a task, I observed that she encouraged him to begin making decisions.

Both types of conversations were present as Mia and Simon worked together in the laboratory. Their work tended to follow a pattern of movements, guided by Mia. She initiated the sequence by introducing what she and Simon would do for the day. After introduction, they would execute the given tasks together, while Mia evaluated Simon's work. When a task was complete, they would interpret any data they had collected; in some instances this data was in the form of observations. I provide descriptions of each movement in the sections below. For each movement, I include discussion and examples from both types of conversations when I observed their presence.

6.3.1.1 Introducing the Day

6.3.1.1.1 Mia's Role in Introductions

Mia began her introduction of the day's tasks by updating Simon on any relevant work she had completed while he was not in the laboratory. These were often tasks she had completed with another undergraduate researcher, Martha. She described tasks Simon was not present for in

detail, explaining each step that was taken. Simon often contributed to the conversation by asking questions or explaining his own reasoning.

Mia tended toward less technical language when first explaining experiments. As she introduced new technical language and disciplinary ideas (Thiry & Laursen, 2011), she made regular use of analogies to help explain the concepts being discussed (Orgill & Bodner, 2004). Mia's use of analogies is demonstrated in the example below where she described the work she and Martha had completed on a Western blot.

Mia:	[Martha and I] ran a gel and then you have your proteins in the gel. And you want to transfer them to the membrane that has a bunch of holes in it. It's like a sponge. . . . And then you send an electrical current through there and then the proteins transfer and they go into the membrane. And so, then that's called a transfer. . . . [W]hen that's done, you have to block. . . . And so imagine you have your sponge and you have your proteins in there, but then there's still all these open holes. And if you stick your antibody in there, your antibody is just another protein. It's gonna go and get stuck into the holes.
Simon:	The ones that aren't already filled?
Mia:	Yeah. You have to fill all the holes with protein.
Simon:	Okay. That makes sense.
Mia:	We use non-fat milk because it's because it's a pretty inert type of substance with tons of protein and there's no fat. . . . And then we let that sit overnight or until we're ready to do the next step. And then this is where we are. We've got the membrane. (Round 1, Observation 3)

After Mia updated Simon on their progress, she verbally summarized the tasks they would be working on together. She used a similar level of detail for steps he would be executing as she used when she explained previous work. Mia regularly rooted these conversations in language from the discipline (Thiry & Laursen, 2011). She mixed analogical language (i.e. "a sponge") with terminology used by scientists (i.e. "the membrane") to both explain how a technique worked but also establish how scientists spoke about the technique.

As Mia spoke about what Simon would be working on, she often began to introduce more practical concerns that he would need to consider while using a technique (Thiry & Laursen,

2011). For example, after showing Simon the membrane they would be working with, Mia added, "You want to be mindful that the membrane holds proteins. . . . [Y]ou have proteins on your finger." (Round 1, Observation 3) She regularly constructed arguments to make sense (Berland & Reiser, 2009) of her instructions. She supported these arguments with disciplinary concepts, as demonstrated in the excerpt below. After showing Simon a 1-liter bottle of liquid, Mia explained how she prepared the liquid for the experiment. The buffer, which was kept in the refrigerator, needed to be warmed for optimal enzymatic activity. Since Mia only needed a small amount of the buffer, she poured the aliquot into a new container so that it could warm up faster. She explained,

Mia:	This is 1X [buffer]. Normally I like to let it warm up, but it's gonna be in such a thin layer of liquid, it will warm faster [in a smaller volume]. Because you have to remember that there are proteins on there and your proteins are gonna interact. The cooler it is
Simon:	The better.
Mia:	The slower
Simon:	Oh, the slower.
Mia:	your proteins are gonna react. The warmer it is, the faster the proteins are gonna interact because enzymes and stuff work faster when they're warm. . . . I'm just gonna get a container to dump that in. (Round 1, Observation 3)

Mia's explanation contained two movements. First, she explained why she transferred a small volume of the buffer to a new container (i.e. "such a thin layer of liquid, it will warm faster"). While Simon listened to Mia's explanation, he also began to participate in the explanation to make sense of the technique (Berland & Reiser, 2009). Simon joined in the explanation by asserting that the cooler the buffer was, "the better." After his contribution, Mia provided her second explanation that the buffer should be warm because, "enzymes and stuff work faster when they're warm."

Although incorrect, Simon's comment demonstrated his active participation in the conversation. By voicing his own ideas, Simon provided Mia with feedback about his understanding. Mia responded by correcting Simon's comment. However, instead of responding with the opposite form of Simon's subjective answer (i.e. the worse), Mia shifted the conversation to be about an objective idea (i.e. the slower . . . proteins react). With her comment, Mia modified Simon's idea and reconnected it to concepts in their discipline (Thiry & Laursen, 2011), further establishing the disciplinary root of the conversation.

For each new task, Mia made sure that Simon had his own protocols and notes on what to do. I interpreted this action as a way that Mia encouraged Simon's ownership of the project through responsibility (Hanauer et al., 2012; Wiley, 2009). Simon's protocols were kept in a notebook at Mia's laboratory bench that he was responsible for regularly updating. When talking about new experiments with Simon, Mia regularly referenced printed protocols, as demonstrated in the example below. Capitalized words indicate direct reading from the protocol.

> Do you have your Abcam [protocol]? . . . [I]t will be easier to follow along. . . . All of this (*Mia gesture to notes.*) is part of the Western Blotting Experiment. The Western blot, literally, is just this part (*Mia points to specific place on the page.*). TRANSFER PROTEINS AND STAINING. The other part is just in preparation for that. . . . We did this and now we're here (*Mia points to specific places on the page.*). . . . blocked it. (*Mia points to specific place on page.*) Now we're incubating it with the primary antibody (*Mia points to specific place on page.*). (Round 1, Observation 3)

In the example given above, Mia used a printed protocol to help explain what Simon and she would be doing for the day. Although Simon had the protocol in his notebook, it was Mia that guided the decision of when to reference it. She acted as a "knowledgeable other" (Vygotsky, 1978) who assessed Simon's level of understanding and determined when an outside resource would be useful. Her actions in the example above demonstrate how Mia regularly led Simon to reference resources besides herself. I interpreted this encouragement to use references as Mia

shifting ownership of the work (Hanauer, et al., 2012; Wiley, 2009) away from herself. Further examples of Mia's guidance are provided in the following section.

6.3.1.1.2 Simon's Role in Introductions

Mia began her introduction of tasks Simon had worked on previously in a similar manner, by first explaining what had been completed when he was not in the laboratory. She then stated the tasks they would be working on for the day. In contrast to new tasks, Mia would then lead this conversation by asking Simon questions. For example, in the following conversation, Mia asked Simon what he remembered of the protocol to lyse a sample of cells.

Mia:	So it's going to be the same as remember this time (*Mia pulls a protocol from her notebook and points to one page.*) when we lysed it?
Simon:	Yeah. With a buffer? Yeah.
Mia:	Uh-huh. And so, do you remember what we did?
Simon:	First we made the buffer. Or, we got our ice and put the pellet on the ice to thaw it
Mia:	Mm-hmm.
Simon:	and then we made the buffer while it was thawing. And we had to get the, I think some of this was already made (*Simon points to the top of the protocol.*).
Mia:	Yep.
Simon:	Yeah. And then we had to add the lysozyme, DNAse and DTT.
Mia:	Alright. So we can do that and this time I'll let you lead the way . . . and I'll just follow you and watch you, and if you need help, then I'll tell you what to do.
Simon:	You won't let me mess something up real bad? (*Simon laughs.*)
Mia:	No, not at all. This is important to me. (*Mia laughs.*)
Simon:	Okay, cool. Awesome. (Round 1, Observation 1)

While Simon had performed cell lysis before, this was the first time he was in charge. Mia used her discourse as a tool to transfer ownership (Hanauer, et al., 2012; Wiley, 2009) of the day's tasks to Simon by asking questions rather than giving instructions. She also provided Simon with a resource to reference if he struggled with his explanation in the form of a protocol.

As Simon explained the plan for the day, he referenced the protocol Mia had placed in front of him. Mia contributed to the conversation using backchannel confirmations (e.g. okay) (Wennerstrom, 2001) to indicate when he was correct in his explanation. Once Simon had summarized what he would be doing for the day, Mia explicitly communicated his role as leader in the task saying, "I'll let you lead the way." She also explained that she would support him if he needed help, demonstrating personal support (Thiry & Laursen, 2011). Simon's discourse suggested he needed this support, when he reconfirmed that Mia would not let him "mess something up real bad."

Simon reflected on the experience of leading tasks during our interview. He was aware of the transition that was occurring in the laboratory. He said,

> She used to just explain to me everything but now I'll ask a question and she'll like throw it right back at me. She's like, why do you think? Well, I don't know and then she forces me to think through it and that helps me get better. Which it kind of stinks sometimes because I don't know the answers. But . . . it helps me learn when she's tough on me like that. (Round 1, Interview)

Simon communicated that it was difficult being in charge because he did not always know the answers. It appeared that he was encountering the experience of being uncertain, a common aspect of science (Lederman, 2007). This discomfort was perhaps increased in part because of the situation and his own nature. Simon described himself as a "people pleaser." He did not want to disappoint Mia or mess up her research. In his description of the transition, Simon indicated that he was aware of the change in Mia's discourse. She had started to respond with questions instead of answers. When I asked Simon about this change in responsibility he said,

> She's trying to get me more independent. . . . [T]hat way this summer and in the future I can be on my own and she can do her own thing and I can assist her more without having her to hold my hand. (Round 1, Interview)

Simon communicated that Mia had spoken with him about her ultimate goals for him in the laboratory. While learning to work independently was "tough" in the moment, it carried the potential for long-term benefits both for him and Mia.

In the example of Simon explaining the tasks for the day, we also see him modifying when he explained the task out of sequence. He began, "First we made the buffer" then modified to "Or, we get our ice and put the pellet on the ice to thaw it . . . and then we made the buffer while it was thawing." This modification suggested that Simon was able to pay attention to the details of his project; he was taking responsibility (Hanauer et al., 2012; Wiley, 2009) not just for what he would do but also how. Simon's explanation of the task resembled the level of detail Mia provided in her descriptions. Not only did he remember what tasks he would be completing, but he also recalled the order that would be most efficient (i.e. "we made the buffer while [the pellet] was thawing." Mia encouraged this level of detail throughout Simon's time working in the laboratory using discursive strategies that shifted responsibility onto him.

One example occurred during my second round of observations. I completed my second round of observations with Simon and Mia when Simon had been working in the laboratory for approximately four months. At the beginning of a conversation from her introduction, Mia informed Simon that he would be running a protein gel. He had completed this task before, so she asked if he remembered the procedure. She planned to make preparation of the samples completely Simon's responsibility.

Mia:	Do you remember how to prepare samples to run a gel?
Simon:	Not really.
Mia:	Okay. Let's see if you can find it in your notebook. (*Mia hands Simon his notebook.*)
Simon:	Okay. . . . Is it adding the DTT and? (*Simon looks at a page in his notebook.*)
Mia:	Mm-hmm. . . . Yay! You found it! Okay, so read the instructions and see if that helps you. (Round 2, Observation 2)

When Simon was not able to remember the procedure, Mia suggested that he consult his protocol. With her comment, Mia reemphasized that Simon was responsible was completing this task (Hanauer et al., 2012; Wiley, 2009). At the same time, she provided a form of support (Thiry & Laursen, 2011) by suggesting a resource he could use to find the information. Mia worked on a separate project beside Simon as he began to look at the protocol. While he read, she provided support and guidance (Thiry & Laursen, 2011) in how to read the protocol to see if the information was there.

Mia:	I'll tell you the volumes to add, but does it help you with what you need to do.
Simon:	Yeah.
Mia:	So if you read those directions, you could follow them and prepare your samples and run a gel?
Simon:	No. (*Simon looks at protocol.*)
Mia:	Okay, well what do you need other than that?
Simon:	I would need . . . I don't really know how to heat it to 95 degrees for one minute. (*Simon looks at protocol.*)
Mia:	What's else? (8.0) It's not a trick question. (*Mia laughs.*)
Simon:	(*Simon laughs.*) Besides that I'm not really . . . I just would need to be able to find DTT and the gel dye.
Mia:	Then go through the whole process in your head and see if there's anything else. I know you've done it a few times, so just try to imagine it. (Round 2, Observation 2)

While Mia was strict in removing her responsibility (Hanauer et al., 2012; Wiley, 2009) from the task, she also provided support (Thiry & Laursen, 2011) by suggesting a protocol and teaching Simon how to use it. She taught Simon about this practice by asking questions. Her questions served as a model (Thiry & Laursen, 2011) for how scientists engage with a protocol and how Simon should as well. After Simon answered her questions, Mia provided further support by instructing him to "try to imagine" working through the process.

As Simon complied with her instructions, he began to engage in self-regulated learning (Zimmerman, 1990) by identifying the gaps in his knowledge about the technique.

Simon: Do I put the 100 microliters of gel dye, loading buffer . . . is that?
Mia: That's your stock. So you'll just have it in this tube then you'll take some of that and put it into your sample.
Simon: Oh okay. . . . Then setting up the whole gel contraption.
Mia: You just need a refresher?
Simon: Yeah, I think so. I might be able to figure it out, but yeah I probably need a refresher.
Mia: Okay, so those few things are good things to add to your notes. So when you keep notes, you want to write everything that you may need to use sometime in the future. So DTT is at a 1 molar stock in the minus 20 in one of my boxes. . . . I guess maybe take a picture of what the gel setup looks like. You could do that. . . . That's how you have really solid notes. (Round 2, Observation 2)

When Simon identified a piece of the protocol he had forgotten to include a note about or did not understand, Mia helped by explaining and clarifying his notes. Once he has finished identifying these gaps, Mia again used her discourse to direct ownership (Hanauer et al., 2009; Wiley, 2009) of the work and notebook to Simon. In her final response, she provided ways that Simon should improve his notes so that he does not need her help in the future.

6.3.1.2 Executing a Task

6.3.1.2.1 Mia's Role in Execution

When they worked on tasks that were new to Simon, Mia tended to perform most tasks while Simon observed. Simon was an active participant in the task by regularly asking questions. Consider the following example where Mia began to use a serological pipette and an automatic pipetter to measure out a solution of buffer and dry milk. She explained,

> This (*Mia gestures to the pipette in her hand.*) *is* a serological pipette and this is the automatic pipette. . . . This is more accurate . . . and easier than a graduated cylinder. . . . They're called serological pipettes I think because they're mostly used for medical stuff. (Round 1, Observation 3)

When Mia used tools or techniques with which Simon was unfamiliar, like the serological pipette, she regularly explained what the tool was and why she was using it. This discourse

provided Simon with knowledge of disciplinary knowledge and terminology (Thiry & Laursen, 2011). She often included additional information, as in the example above when she began to explain the origin of the name.

After measuring out the solution, Mia began to thaw and prepare a 10-microliter aliquot of antibody to be added to the solution. As it thawed, she flicked the tube back and forth to mix its contents. This was not the technique she usually used to mix solutions with Simon. Normally, Mia used the vortexer to agitate liquids. She explained to Simon why it was important to mix solutions after they have thawed.

Mia:	Anytime you thaw something, you want to make sure you mix it because it might not have . . . frozen in a homogenous mixture. If you don't mix it and then you take some, it may not be . . . the concentration you thought you were taking.
Simon:	Do you do that (*Simon gestures to Mia mixing.*) instead of that (*Simon gestures to the vortex mixer.*) to prevent bubbles or is that?
Mia:	Yeah. . . . Also, it's such a tiny amount. And then sometimes you want to be gentle because maybe the protein. It's not gonna affect the protein. (Round 1, Observation 3)

This was not the first time I observed Mia explaining the importance of mixing a sample once thawed. I interpreted her continued emphasis on this point to suggest she considered it essential that Simon learn this laboratory technique (Thiry & Laursen, 2011).

Simon actively participated in the conversation again by asking questions. In addition to a question, Simon's contribution provided his own prediction for an answer. It appeared that he was trying to make sense (Berland & Reiser, 2009) of her technique on his own. He suggested that Mia could be flicking the tube instead of using the vortex mixer because she did not want to create bubbles. Simon's question communicated that he possessed some level of disciplinary knowledge (Thiry & Laursen, 2011) about the benefits and limitations of using specific equipment in the laboratory. Mia confirmed Simon's idea and then extended the conversation to

include additional reasons why flicking was the preferred technique. After Mia finished the answer, Simon followed up on Mia's explanation by asking, "Is an antibody technically a protein?" Simon's question involved a fundamental understanding of the biochemistry research. With the question, he communicated to Mia part of what he currently understood about antibodies and proteins. This initiated a new disciplinary discussion (Thiry & Laursen, 2011) where Mia explained how proteins of different sizes are classified.

6.3.1.2.2 Simon's Role in Execution

Once Simon had observed Mia performing a task, Mia began to transition how she mentored him to lessen the instruction she gave and increase his responsibility (Hanauer et al., 2012; Wiley, 2009). These modifications were present both when she introduced the tasks he would be completing for the day and when he was working in the laboratory. During her interview, Mia reflected on the process of reducing guidance when Simon was working in the laboratory.

> Well he is still trying to make sure he is doing everything right. So even though I know he knows what to do, he'll still ask me, "I should do this, right?" And so trying to get him away from getting the reassurance. . . . I'll ask him what does he think. . . . And then now I've got to, "You tell me" and then, "I will let you do it and then if you mess up, you start over again." So I'm trying to wean him off the reassurance. Except on the important things like making sure the centrifuge is screwed down properly. (Round 1, Interview)

Mia had identified ways to modify her discourse to encourage Simon's independence (Thiry & Laursen, 2011). These involved responding to Simon's question with a new question, a quip, and finally, a direct denial instruction. She described these responses as a progression to "wean him off the reassurance." Mia's discourse removed personal support (Thiry & Laursen, 2011) from Simon. This removal generally increased the chances that Simon might make a mistake. However, Mia was mindful to only allow errors that would not result in a safety hazard (i.e. the

case of working with the centrifuge). Mia also intervened when mistakes were large enough to affect the outcome of an experiment. While Mia was partially removing her support, aspects of it remained. Mia would make sure that Simon caused no permanent damage.

I observed Mia negotiating the balance between Simon's independence and a mistake he had made (Laursen et al., 2010) on our first day. While Simon led the preparations for cell lysis, Mia realized that he had selected a glass beaker for sonication when he needed to use a metal one. A glass beaker would not be sturdy enough to withstand sonication and may break during the process. It additionally would not allow for efficient transfer of heat. Mia intervened at the point when Simon returned to the bench with the beaker, which he would use in the next step.

Mia:	So, what are we going to use to sonicate? Do you remember? To actually do the sonication?
Simon:	Oh. The metal beaker, which is in [the cabinet] as well. (Round 1, Observation 1)

Mia chose to point out Simon's mistake with a question instead of correcting his choice. While Mia's question possibly communicated to Simon that he had made a mistake, it did not provide him with how to correct the error. By asking Simon what beaker he was going to use, Mia made it necessary for Simon to reconsider the options he had for beaker choice. Her question placed the responsibility (Thiry & Laursen, 2011) on Simon to find an answer.

Later in the day, Mia brought up the topic of using a metal beaker for sonication again. After explaining that the sonicator would be warm, Mia asked Simon, "Why do you think we use a metal beaker?"

Simon:	Is it because it transfers heat better? Or keeps cool longer?
Mia:	Uhh
Simon:	Doesn't break when rattled?
Mia:	Uh-huh. So, yeah, it transfers heat and so it's not an insulator. So it's a [conductor], so when you have the heat in the inside, it will quickly transfer to the outside and the ice will be able to cool it faster. As opposed to glass because glass is an insulator. (Round 1, Observation 1)

When Mia revisited the topic of using a metal beaker, her purpose appeared to be to make sense (Berland & Reiser, 2009) of why the metal beaker would work better than a glass one and anchor it in disciplinary concepts (Thiry & Laursen, 2011). By asking a question, Mia allowed Simon to demonstrate his current understanding. He suggested a few theories, but struggled to provide an answer Mia found acceptable.

I interpreted Simon's form of answering Mia's question with questions to suggest that he was unsure why they used a metal beaker. Parts of his reasoning were correct, but he did not provide any evidence or reasoning (Berland & Reiser, 2009) to support his ideas. Mia appeared to recognize that Simon would be unable to answer her question. After he suggested a few options, she began to answer her own question. She started by acknowledging a part of his answer that was correct (i.e. "it transfers heat"). Mia then scaffolded Simon's learning (Vygtosky, 1978) by using the the information Simon supplied to begin constructing her explanation. With this explanation, she addressed the same concerns she demonstrated when using techniques that were new to Simon. She explained why metal worked better for sonicating than glass. She also anchored her explanation in disciplinary language (Thiry & Laursen, 2011).

6.3.1.3 Interpreting Results

Mia tended to make all decisions involving the interpretation of results. This included both interpreting data from experiments and making observations about individual steps in an experiment. Although Mia made decisions, I observed that her discourse changed based on whether Simon had previous experience with a specific type of data.

In the following excerpt, Mia showed Simon a print out of fast protein liquid chromatography (FPLC) data for the first time. Mia used FPLC to purify her protein. Her data

was a plot of 5 milliliter fractions versus absorbance units. The fractions containing protein registered as increases in absorbance units. She had previously provided Simon with background information about FPLC, including the purpose of the technique and a summary of a variety of foundational concepts (Thiry & Laursen, 2011). This was a lengthy conversation, since the technique is entirely new to Simon. Mia began the conversation by showing Simon the data.

Mia:	So, here we see (*Mia shows Simon the printout.*) this is where I washed it with water (*Mia draws a line under fractions where there is no absorbance.*), and then this is where I injected my protein (*Mia points to a fraction number.*), and then this is where it started taking fraction (*Mia points to an increase in absorbance on the plot.*). So, these are the numbered fraction: 1, 2, 3, 4, 5, each one has 5 mLs. So, here you can see in (*Mia places a second piece of paper on top of the plot for a straight line.*) fraction 28 and say 32. . . . Okay, so you see there? (*Mia gestures to a peak between fractions 28 and 32.*)
Student:	Yeah.
Mentor:	So fractions 28, 29, 30, and 31. . . . Will have our protein—a protein in there. We don't know what it is yet. We just know that based on this peak. (Round 2, Observation 2)

Mia took full responsibility (Hanauer et al., 2012; Wiley, 2009) for the interpretation of the FPLC. Instead of guiding the discussion with questions, I observed that Mia's discourse appeared more instructional. She showed Simon key features of the FPLC plot and explained their meaning (Thiry & Laursen, 2011). She also modeled how she interpreted the data for Simon to observe (Thiry & Laursen, 2011). This included identifying specific parts of her plot that were significant to interpretation and speaking to Simon about the meaning of those pieces.

While Mia was responsible for interpreting results, she often invited Simon to take part in the practice. She encouraged Simon to make observations and to pose hypotheses, both common scientific practices (NGSS Lead State, 2013). She did this by asking questions. The following excerpt occurred after Simon had removed the sample from the sonicator. Mia and Simon had

used new settings on the sonicator to try and disrupt the cell membranes better. Mia held the sample while Simon cleaned the instrument and began the conversation.

> Mia: So, does it look like a color difference to you?
> Simon: It looks lighter I think, a little bit.
> Mia: Okay . . . so we're going to judge beige. So originally it looks like a pinky, beige I want to say. (Round 1, Observation 1)

Mia began by asking Simon to make an open judgement about the difference in color. After he answered, she used her own response to set a framework (Thiry & Laursen, 2011) around which Simon should base his observations (i.e. "we're going to judge beige"). She then modeled (Thiry & Laursen, 2011) how she would describe the sample before it went into the sonicator. She continued the conversation by explaining the difference in how she now believed the sample appeared.

> Mia: And this looks more like it looks darker and maybe not as opaque. It feels a little more watery.
> Simon: Yeah.
> Mia: Does it to you?
> Simon: Yeah.
> Mia: Okay. And so you'll be able to see it better. But I think this is a better lysis, just by looking at the color. (Round 1, Observation 1)

Mia regularly practiced giving Simon opportunities to make engage in scientific practices related to his work. Simon viewed her efforts as another way Mia was encouraging him to become independent (Thiry & Laursen, 2011).

> She tries to get me to see what I'm supposed to see and she wants me to be able to look at it if I was by myself. I could see that it was lysed well. So she wants me to be able to recognize that I think. . . . She's trying to get me to the point where I can be independent. (Round 1, Interview)

In the future, Simon would be sonicating samples by himself. Rather than showing Mia the product, he understood that he would be responsible (Hanauer et al., 2012; Wiley, 2009) for

making judgements himself on how to proceed. By asking Simon to begin make those judgements in her presence first, Mia was scaffolding Simon's learning (Vygotsky, 1978).

6.3.2 Conversations About the Nature of Science

As demonstrated in the conversations about research, Simon tended to ask many questions when working with Mia. His questions communicated a level of comfort he felt in working with Mia. During our interview, Simon described himself as a "question asker."

> I'm a question asker in the first place. So, if she doesn't mind answering them, like I can tell what mood she's in. So if she's in a bad mood I don't ask as much, but if she's in a willing-to-explain mood then I'll ask more questions. (Round 1, Interview)

Most of the questions Simon asked related to the research he was working on with Mia. However, he would also come to Mia with questions outside of her expertise. He appeared comfortable asking Mia questions. Their conversations regularly transformed into broader discussions about the nature of science (Lederman, 2007) and scientific research. Mia attributed these conversations to Simon's skill in asking questions.

> He asks me really good questions and some of them like, I don't know. I forgot, it's been so long ago. So I can see him getting more and more interested. . . . And so it may go off to why do we have research, like the research we do has to be with reviewed. And then it goes back to what does the review board do and then something. (Round 1, Interview)

I observed that these conversations were created both by Simon asking questions and by the way Mia responded to those questions.

Consider the following example of a conversation Simon initiated as he and Mia homogenized samples, a task he had completed many times before.

> Simon: Do you think if there's ever like a super virus or something like a lot of labs in Purdue would stop what they're doing and start trying to research that? Or does that not happen?

Mia: That's interesting you ask because I've wondered the same thing. Like, would you just continue researching you know whatever you're doing because you have funding? (Round 1, Observation 2)

Simon's question addressed the topic of how human need impacted the scientific community, an aspect of the social nature of science (Lederman, 2007). Could human need become great enough to change the course of researchers' work? I interpreted the fact that he directed this question to Mia to suggest he considered her an expert on how scientific research operated. Mia began her answer by acknowledging the common ground she shared with Simon; she too had considered the same hypothetical setting. With Mia's response, she introduced her own knowledge into the conversation, that funding played a role in guiding research. She continued to speak to Simon about her thoughts related to his question.

Mia: Sometimes there's some leeway with how you do your research. Cause when you ask for funding, there's a few ways you can go about it. Most of the way is through government funding like the National Institute of Health, NIH. So when you ask for funding from them, you . . . have your plan laid out and it's very, "We're going to do this and this and this." You have to have results. It's really hard to go off script.
Simon: Cause they're paying you to do that specific one?
Mia: Yeah. . . . [A]nd sometimes . . . if you do something and you can do something else on the side with the same supplies. (Round 1, Observation 2)

While answering, Mia demonstrated her expertise in research and her own views about how scientific research worked. She asserted that funding, more than human need, directed what research a scientist would do. However, she also provided insight into how scientists engaged in research (Lederman, 2007; Thiry & Laursen, 2011) when she explained there were ways that scientists worked around those limitations to do the research they wanted.

Mia demonstrated developed opinions and a clear interest in the nature of science (Lederman, 2007) when speaking with Simon. When answering Simon's questions, she would regularly offer commentary related to how scientists know information, disseminate findings,

and defend ideas. Simon encouraged Mia to speak about these topics with his questions. In the following excerpt, Simon asked Mia where she got the strategies they were using in the laboratory. Her answer provides not only an answer to his question, but also a model for how techniques are created and modified in science (Thiry & Laursen, 2011). In the follow excerpt, Jenna discussed how she optimized homogenization of a cell pellet, a process that required physical effort to break up and mix an insoluble sample in buffer using a glass tube and metal rod.

Simon:	Were you given the strategy that you use for all this, or did you have to like develop it?
Mia:	I made it all up.
Simon:	Really? Oh, was it hard to do?
Mia:	No, it kind of came one thing after another. . . . [T]he first time [I homogenized a sample], all the skin here (*Mia points to her hand holding the metal rod.*) was cut. . . . [T]hat's when I started using the paper towel. . . . Then doing a huge pellet wouldn't work, cause it was too hard. So then it was like, "Okay do a smaller one." . . . A lot of the stuff I've been doing, nobody has done . . . so it's like, you just make it up as you go. . . . You start talking to people in here about other stuff and every single person does something different. It's like, you guys are all doing the same thing
Simon:	Just in a different way.
Mia:	Yeah. So I'm like, "Well, who the hell should I believe?" So then I'll take what everybody says and I'll compare it, and see what's consistent or what's different and then make up my own judgement. . . . That is critical thinking. (Round 1, Observation 2)

Mia often used storytelling from her own experiences in research to demonstrate how science worked. As in the example above, she would begin by speaking about her own experience. These conversations usually led to her providing overarching ideas about how scientists worked (e.g. scientists thinking critically) (Thiry & Laursen, 2011).

In addition to answering Simon's questions about science, Mia often brought up scientific topics in which she was interested. These were from news stories she had read or involved the research projects of scientists she knew. Mia was interested in a variety of topics and spoke

knowledgeably about them. She provided the same detail in her explanation of these topics as she did when explaining her own research. As with other conversations, Simon regularly asked questions during these conversations and Mia used her discourse to anchor the conversation in the discipline (Thiry & Laursen, 2011).

6.3.3 Conversations about Personal Lives

When they worked on tasks that were repetitive or more familiar to Simon, it was common for Mia to initiate conversations about either his or her life. Mia paid attention to Simon's stories and tended to keep up with developments in his life. I interpreted Mia's actions to communicate that Simon's experiences and input were valid social currency (Bourdieu, 1986). Mia reflected on this aspect of their relationship during interview.

> He is really different and so it's really—it's kind of fun working with him because it's like a different experience totally. But it's a nice experience. . . . [I]t's really interesting because a lot of times he'll come in and he'll tell me, "I got a 98 on my organic exam" and so I'm like, "Yeah, good job." And so in the beginning it was more like he'd come in, learn and then leave. And now it's like more—he tells me more and more about his academic stuff. (Round 1, Interview)

Mia considered the relationship she had with Simon was one of student and mentor, as opposed to boss or instructor. This appeared to be, in part, because of the conversations they had about topics besides her research. She communicated that this was her first time playing this role when working with an undergraduate.

As a student, Simon's personal life mainly involved friends and family, campus social events, and academic pursuits. In addition to these conversations, Mia would speak about the experience of working in the laboratory with Simon. From these conversations, I identified themes and underlying ideas which Mia and Simon communicated about each other and themselves.

6.3.3.1 Working in the Laboratory

When Mia and Simon spoke about working in the laboratory, Mia provided Simon with a perspective of what it was like to work in a laboratory as a postdoctoral associate (Dolan and Johnson, 2010). She used discourse that conveyed a positive opinion of the experience. For example, when getting ready to view the FPLC results Mia told Simon, "I'm kind of excited to go see my results." (Round 2, Observation 2) She would also describe equipment to him in positive ways, as in the example below.

> These are really cool tips because they have a low liquid retention, and so actually the liquid, since it's viscous and kind of thick, it will continue to fall to the bottom. When I was in the old lab, we didn't have this type of tip. And so I worked with red blood cells, we would pull out the red blood cells, and then a lot of the sample would get stuck to the side of the wall. Which is a problem because you're not actually pipetting what you think you are because they're stuck to the side of the wall. So these are very neat pipette tips. It's the little things. (Round 1, Observation 1)

Simon was less vocal about his opinions concerning working in the laboratory. He did not volunteer his thoughts on this topic when speaking with Mia. However, he had asked if it would be possible for him to continue working in the summer. I interpreted this action to suggest he had enjoyed his experience. At the end of the semester, as they made plans for Simon to continue working in the summer on his own project, Mia brought up the idea of him continuing in the fall.

> Mia: Well, and then, next semester. . . . Are you going to come back?
> Simon: Yeah! (*Simon laughs.*) . . . Are you still going to be here?
> Mia: Yeah. (*Mia laughs.*) . . . I hope you enjoyed it enough to come back.
> Simon: (*Simon laughs.*) Oh yeah. I'll be back. (Round 2, Observation 2)

Simon also communicated his enthusiasm to work in the summer during our interview. He said, "I am excited . . . I wanted to do something that was good for my future and I'm really excited to have my own project and make money doing something I actually want to do."

6.3.3.2 Importance of Life Balance

Mia and Simon both spoke about their lives outside of the laboratory. They shared a common value in maintaining close connections with their family and friends who lived in other towns. They each lived within a few hours of their home towns and drove back for events like weddings and birthdays. Simon also tried to maintain connections with friends from home that were now at college in other towns, though he found this difficult because of conflicting schedules. He spoke about these difficulties during our first observation saying, "All my friends are going to Florida . . . my friends that I was going to go with go to a different college and their Spring Break is like a week before ours."

In town, Mia spent much of her time with her boyfriend and dog. Simon was active in his cooperative on campus; this organization was a significant social outlet for Simon.

> Friday they just had me over, because it was really nice out, and they had a few of the pledges over and we hung out . . . and then Saturday night they had us over to our first party there, or function, that was pretty fun. . . . [T]hey had a dance floor and everything . . . which was pretty cool. I like everybody there so far. (Round 1, Observation 1)

The cooperative valued diversity, leadership, and academic excellence. It was a unique organization in that high school students were also allowed to join, although they could not participate in social events.

6.3.3.3 Encouraging Academic Success

Simon rarely spoke to Mia about his classes during my observations; his comments usually involved what he was doing in class that day. However, both Mia and Simon commented during their interviews about the ways that Mia helped guide Simon academically (Thiry & Laursen, 2011). The most predominant way Mia encouraged Simon's academic success was through helping him apply for summer undergraduate research programs. When Simon asked to

work with Mia over the summer, she recommended that he apply for a program that would pay him to do research. Simon had never experienced applying for such a program and the process was unfamiliar to him. From Mia's comment, it appeared that she did not realize the process was new to Simon.

> With this letter of recommendation, he . . . kept bugging me like, "Do I submit it, do I submit it?" and I'm like, "Okay, kid, this is how letters of recommendation work" and he is like, "Oh, I didn't know any of that." (Round 1, Interview)

Mia served as an expert that could help Simon learn to engage in academia. This was perhaps in part because Simon felt comfortable asking her questions. It appeared that Simon viewed Mia as approachable, similarly to reports by Dolan & Johnson (2010) on the influence of postgraduates on undergraduate students in research. When I asked Simon about this aspect of working with Mia he said, "she's really helpful with guiding me based on her past experiences."

6.4 Summary

In this chapter, I have described the three types of conversations Mia and Simon engaged in during Simon's undergraduate research experience: conversations about research, conversations about the nature of science, and conversations about personal lives. My description of how Mia and Simon's spoke about research included a discussion of the primary pattern of their conversations, Introduce-Execute-Interpret. I observed this pattern of communication on every day that Simon did experiments in the laboratory. Mia initiated the pattern by introducing what she and Simon would be doing for the day; they would then execute Mia's plan together.

While Mia guided the conversations when introducing and executing tasks, she used two separate discursive approaches, depending on whether Simon had previous experience with task. When a task was new for Simon, Mia focused her discourse in helping him to understand the

disciplinary concepts behind a technique (Thiry & Laursen, 2011). She also emphasized practical considerations (Thiry & Laursen, 2011) of which he should be aware. Simon tended to ask many questions during these conversations. If Simon had worked on an experiment with Mia before, Mia guided the conversation through questions. She encouraged Simon to take ownership (Hanauer et al., 2012; Wiley, 2009) of the work they were doing by asking him to speak about the steps he would be taking. Mia reduced the support she provided Simon (Thiry & Laursen, 2011), intending her silence to help Simon become more accustomed to having less guidance. In the future, he would need to be able to work independently. It also provided Simon the opportunity to practice speaking about research (Laursen et al., 2010).

Mia took charge of the interpretation of data that she and Simon produced. When she analyzed this data, she used her discourse to model how she thought about the data and its meaning for future work (Thiry & Laursen, 2011). Mia encouraged Simon to practice making observations (NGSS Lead States, 2013) about the work that he did. She treated these observations as a form of formative data-in-progress, helping them both to make claims about the effectiveness of a technique before making the next step. They also provided her with feedback on Simon's current understanding of the experiment, which she could then build on to scaffold his understanding (Vygotsky, 1978).

In addition to questions about research, Simon also asked Mia more general questions about science. His questions often resulted in broader conversations about the nature of science and scientific research. I observed that Simon treated Mia as a scientific expert who could speak on a variety of scientific topics, including the nature of science (Lederman, 2007). Mia perhaps encouraged this perception by regularly bringing up conversations about scientific stories she heard on the news or the research of colleagues.

Mia and Simon spent the majority of their time talking about research or science. In limited cases, usually when Simon was working with something with which he was familiar, Mia and Simon would begin to talk about their personal lives. As they spoke, they both communicated information about their values. Mia and Simon demonstrated that they both enjoyed working in the laboratory; at the same time, they also valued life balance and made time for family and friends. While Mia did not speak about her own desire for academic success, she did demonstrate that she placed a high value on academic success by encouraging Simon and providing guidance as he applied for summer research programs.

CHAPTER 7. DISCUSSION

7.1 Introduction

The purpose of my study was to explore the nature of the conversations students and their mentors engaged in during undergraduate biochemistry research experiences as a model to understand the phenomenon of undergraduate research. As a step toward this goal, I investigated the experiences of three cases of undergraduate students working with research mentors, each of which has been summarized in a separate chapter.

As I began to write up my third case study, it became evident that similarities between my cases necessitated the addition of a cross-case analysis to my research approach. By mobilizing the knowledge from individual cases across all cases, I could examine the similarities and differences between cases (Miles & Huberman, 1994). This analysis provided me with a deeper understanding of the individual experiences in each of my cases and served to strengthen my findings (Miles & Huberman, 1994).

7.2 Findings from Cross-case Analysis

I used a case-oriented strategy to approach my cross-case analysis (Miles & Huberman, 1994). This strategy was rooted in the conversation analysis of observational data for individual cases presented in chapters four through six, and the construction of critical incident charts, described in detail in chapter three, Section 3.5. From this cross-case analysis, I identified eleven distinct activities that made up the conversations of my cases' experiences, presented in Table 7.1. I refer to these as conversational activities because the categories represent both activities that made up the experiences of students, and conversations that occurred while mentors and student participated in these activities.

Table 7.1 Conversational activities

Conversational Activities
Monitoring
Collaborative planning
Collaborative working
Demonstrating
Documenting
Explaining
Instructing
Introducing
Locating
Personal sharing
Updating

Based on the characteristics of these eleven activities, I drew two assertions. First, that undergraduate biochemistry research experiences exhibited norms of discourse that were shared across all experiences. Second, that discursive differences divided undergraduate biochemistry research experiences into two categories: holistic and targeted experiences. In the following sections I provide a discussion of the eleven activities and the roles they played in each case.

I refer to participants by the same pseudonyms in this cross-case analysis as in their individual cases. To help clarify identities when discussing cases, names selected for students began with ‘s’; mentors were assigned names beginning with ‘m.’ The second letter in each name was used to indicate participants in the same case (e.g. the student and mentor in case one were assigned names Sa— and Ma—).

I present simplified forms of my critical incident charts to aid in the discussion. I organized these activities based on their shared or unshared nature and the two identified categories of research experience. I discuss at the end of each section how my findings relate to reviewed literature.

7.2.1 Shared Norms of Discourse

Two conversational activities were universal to the three cases in my study. These were conversations during which the mentors checked-on or monitored their students, and conversations where the student and mentor worked collaboratively. For these two types of conversation, I observed a high level of similarity both in the activity and in specific discursive practices and features that characterized individuals' turns-at-talk. Table 7.2 compares patterns of conversations where the mentors monitored their students' progress for each case.

Table 7.2 Cross-case analysis of turns-at-talk during monitoring conversations

	Speaker	Action	Example
Case 1	Mentor	Question	Were you able to find everything okay?
	Student	Answer	Yep! …I forgot to get the primers out, so I just got 'em.
	Mentor	Approval or Modification	Cool. No, you don't need those, you need the ones I diluted.
	Student	Acknowledgement	Oh! Okay.
Case 2	Mentor	Question	So, you're making a list, or?
	Student	Answer	Yeah...I kind of came up with a checklist of the different ones we've done MDs on and then I have lists of other ones that they could do in the future…so I'm going to start some of the simulation diagrams on here and [John's] gonna start the other ones so hopefully it'll get done faster.
	Mentor	Approval or Modification	Right. It would be nice if we could sort of inspect them before you finish.
	Student	Acknowledgement	Yeah. . . . Okay, sounds good.
Case 3	Mentor	Question	Do you feel the pellet or anything?
	Student	Answer	Yeah, I still feel it rattling around. It's just one little chunk.
	Mentor	Information	It might just be too much liquid.
	Student	Acknowledgement	Okay. [I'll] dump a little out.

Mentors began all conversations that involved monitoring their students. In each case, these conversations were initiated with a question posed to the student by the mentor. For Mary and Mia, the mentors in cases one and three, these conversations were opportunities for the mentors to determine if their students needed additional intellectual support with daily tasks.

During these conversations, they not only spoke with the students, but also visually inspected the students' work and progress. Mary and Mia regularly provided their students additional information on the "next steps" they should take or assisted with problem-solving during these conversations. In addition to intellectual support, Mary used these opportunities to verify the accuracy of Sam's work since he was now at the point of working independently from Mary. When Sam's work appeared to be correct, she would give a form of verbal approval (e.g. "Looks good!"). If Mary detected that Sam had missed a step or selected the wrong reagent, as in the example in Table 7.2, she provided instructions on how he should modify his approach. Sam and Simon, the students in cases one and three, participated in these conversations mainly by answering questions and acknowledging instructions.

When Merrill, my mentor in case two, introduced conversations to check on Serena, he tended to ask questions that established what task Serena was currently working on. Serena responded to these questions by describing her progress since they last spoke, including any work she had completed with John when Merrill was not around. It appeared that Merrill used these conversations to keep up-to-date on Serena's progress. He usually provided personal support with comments approving of Serena's work. Merrill also used these conversations to modify her tasks by identifying specific points at which he wanted her to report back to him, demonstrated in the example above. During my observations, Merrill did not use these conversations to identify aspects of Serena's daily work that needed to be corrected. When I

made this observation during interview, Merrill explained he had outsourced that role of intellectual support to John. He said, “I trust [John] that he makes sure that things work okay. . . . I don’t have the expertise to fact check her on that.”

The second type of conversation I observed in all three of my cases were conversations about research occurring when students and mentors worked in the laboratory together. The nature of these conversations was unique to each case and to the specific research they were working on during the observations. For example, Mary and Sam, my participants in case one, spent most of their time working separately. However, during Sam’s fourth semester, he began encountering challenges with a step in his PCR. Although he had successfully produced products with PCR in the past, he was no longer getting positive results. This was a long-term problem that Mary responded to by increasing the amount of time she worked directly with Sam. The conversation appearing in Table 7.3 demonstrates the patterns of dialogue that occurred when Mary and Sam were working together.

Table 7.3 Case one's turns-at-talk during collaborative working

	Speaker	Action	Example
Case 1	Mentor	Information	I'm just making sure everything's good with these samples.
	Student	Acknowledgement	Yeah, you should.
	Mentor	Question or Check	You added the membrane binding, then spin down . . . two washes . . . did the elution.
	Student	Answer	Yeah . . . I did . . . the two washes and then put it into the tube and then put nuclease free water.
	Mentor	Explanation or Hypothesis	I was trying to think of all the possible steps that something weird could've happened. . . . [A]nd honestly sometimes when you're like I have no idea what I did wrong, but you do it again and it works!
	Student	Acknowledgement	(*Sam laughs.*)

When Mary worked with Sam, her initial turn-at-talk suggested her purpose to be providing intellectual support by verifying that Sam was making the correct steps in his protocol. Mary was extremely familiar with the protocol that Sam was using. Based on her initiation and dominant role in these discussions, I concluded that she was in charge during these conversations. Sam assisted by verbally going through each step he had completed in the task. However, as Mary and Sam continued to speak, I concluded her later contributions to these conversations to suggest Mary used her turns to also provide personal support. For example, in the conversation in Table 7.3, it appeared that Mary confirmed Sam's work and sought to provide an explanation to support Sam during what may have been a difficult time (i.e. experiencing his first failed experiment). When Mary ran out of possible explanations, she changed her approach to one of empathy, citing the mercurial nature of research.

In much the same way as Mary and Sam, Merrill and Serena, my participants in case two, mainly worked together when Serena encountered a problem or decision she did not appear to be able to make alone or with help from John. An example of this pattern of conversation appears in Table 7.4.

Table 7.4 Case two's turns-at-talk during collaborative working

	Speaker	Action	Example
Case 2	Student	Information	So we have . . . three different options.
	Mentor	Question	Okay. . . . [I]s that protonated on the right?
	Student	Answer	This is un-protonated and then it . . . swings the double bond over. . . . [O]r we could do (*Serena displays second structure on screen*). And then this other one is like it's just the opposite. . . . So, pick one! Laughs
	Mentor	Information and Question	I don't know which one is more relevant here. And even if you know it for a ligand, how it behaves in bulk, things have a different— So . . . it's been docked right?
	Student	Answer	Yeah. . . . [T]his is the best experimental docked pose. [22 minute question-answer sequence]
	Mentor	Instruction	Let's just stick with the top docking score I would say. . . We have to somehow pick one . . . and have some reasonable criteria . . . think about it, if you guys want. Nothing better comes to . . . me at the moment.
	Student	Acknowledgement	We'll pick something.

When I observed Serena, she was usually working alone with the help of YouTube® videos, her notebook, or e-mails from Merrill or John. In contrast to Mary and Sam's interactions, it was Serena that identified when she had reached the points of needing Merrill to work with her.

Serena initiated these conversations by approaching Merrill and providing him with her problem. When Merrill responded to Serena, I interpreted his turns-at-talk to serve two purposes. First, when Merrill spoke, the content in his turns-at-talk focused mainly on providing Serena intellectual support by understanding and solving Serena's problem. Second, as Merrill helped Serena he provided information about the values and norms of their profession. Serena's research was novel, meaning that Merrill often encountered situations where there was not a clear path and he did not appear to have the answer. In these moments, Merrill used his turns-at-talk to emphasize that it was a norm of their research field to not have a single answer, but to decide on a best answer based on specific guidelines.

Simon, my student in case three, was in his first semester of research and spent most of his time working directly with his mentor, Mia. When working together, I noticed that Mia used her turns-at-talk both to provide intellectual support and to explicitly encourage Simon's independence as demonstrated in Table 7.5.

Table 7.5 Case three's turns-at-talk during collaborative working

	Speaker	Action	Example
Case 3	Mentor	Information	I'm just going to 'em. I'm putting them in the containers that are labelled in in the front. We lysed it on this day and this is what it is.
	Student	Acknowledgement	Yeah, okay.
	Mentor	Question	Okay, now what?
	Student	Answer	We need to get the Tris and the N.A.—sodium chloride.
	Mentor	Question or Check	Yep. And you . . . where you're going to get it?
	Student	Answer or Acknowledgement	Yeah. It's in the cold room.

I observed Simon and Mia working together at the point where Simon was starting to repeat tasks he had done previously. When this occurred, as in the above example, it was common for Mia to ask more questions than she answered. Mia emphasized the importance of Simon being able to do his work independently from her. At times, these conversations did not appear comfortable. Simon did not always have the answers or understand the question Mia was asking. I also observed that Mia sometimes struggled to keep herself from providing Simon the answers. However, Mia was steadfast in her use of language and actions to encourage Simon's independence. When Simon did not understand a question, she rephrased or modified. When Simon could not provide an answer, Mia referred him back to his laboratory notebook which included his protocols and notes.

Previous literature on undergraduate research experiences supports the findings I report here on the different roles research mentors played across these shared norms of discourse. In a study of undergraduate-postgraduate-faculty triads, Dolan and Johnson (2010) reported that undergraduate participants considered their postgraduate mentors as helpful, specifically for technical and day-to-day aspects of projects, while a faculty mentor provided "big picture"

direction. I identified this difference in my participants through the types of questions mentors asked when monitoring their students. In my cases, monitoring students involved asking questions about the students' needs at that specific moment, and providing support related to those current tasks. When monitoring their students, my postgraduate mentors focused on providing two types of support identified by Thiry and Laursen (2011) as needed by undergraduate research students: intellectual and personal support.

In my case with Merrill, a faculty member, the questions he asked Serena were directed at bringing himself up-to-date with her current work. When monitoring Serena, it appeared his focus was on providing professional socialization (Thiry & Laursen, 2011) to help introduce her to norms of research, like the appropriate point to check in with a research advisor. However, I also identified that his monitoring her work demonstrated an example of personal support (Thiry & Laursen, 2011) as it showed he was accessible and interested in her progress.

Similarly, when my postgraduate mentors worked with their students, I observed an emphasis on technical or practical aspects of the projects. When Sam began to experience problems in his research, Mary supported him intellectually (Thiry & Laursen, 2011) by working with him to verify that his technique was correct. This involved asking questions about specific steps he had taken and confirming their accuracy. Mia worked with Simon to encourage his accuracy and independence. This discourse appeared as questions she asked Simon to guide him in determining his next step. Mia's method of asking Simon questions appeared to be her way of supporting him intellectually while also modeling the scientific behaviors (Thiry & Laursen, 2011) she wanted him to exhibit, thereby supporting his professional socialization.

I interpreted Merrill's choice to work directly with Serena as also showing his personal support (Thiry & Laursen, 2011). However, Merrill's turns-at-talk in these conversations

demonstrated that through working with Serena he also provided intellectual support and professional socialization (Thiry & Laursen, 2011). When working with Serena, Merrill offered disciplinary knowledge he had about Serena's project that both she and John were lacking. This knowledge played a role in helping Serena to decide how she should move forward. At the same time, when a best single-direction could not be identified, Merrill was available to offer information about the values and norms of the profession (i.e. "We have to somehow pick one . . . and have some reasonable criteria.").

7.2.2 Distinct Norms of Discourse

My cases one and three shared a high amount of conversational activities. In contrast, I observed that many of these conversational activities were absent from the discourse observed in case two. From this difference, I concluded that the experiences observed in cases one and three were different than the experience observed in case two, perhaps in part because of the nature of the mentor. I identified the nine patterns of conversational activities in Table 7.6 that were prevalent forms of discourse in my cases but not always shared across all cases. Of these nine conversational activities, cases one and three had a total of seven activities in common. There was also a high amount of similarity in the critical incident charts constructed for each of these conversational activities for cases one and three.

Based on this evidence, and the dissimilar nature of the conversational activities observed in case two, I divided my cases into two categories of research experience. I categorized cases one and three as *holistic experiences* because they demonstrated a wide variety of conversational activities. Holistic experiences were experiences where the mentors and students participated in a variety of types of conversational activities, including both conversations about research and

personal experiences. I categorized case two as a *targeted experience*. As a targeted experience, the mentor and student in this case participated in only a few types of conversational activities that were all focused on the topic of research. Table 7.6 summarizes the conversational activities observed in each category of experience. Examples of each conversational activity appear in the following sections.

Table 7.6 Conversational activities observed in each category of research experience

	Holistic Experience	Targeted Experience
	Case 1 and Case 3	Case 2
Conversational Activities	Demonstrating Documenting* Explaining Instructing Introducing Locating Personal sharing Updating	Collaborative planning

* Unique to Case 3

In addition to shared conversational activities, I identified one activity that was distinct to case three. I provide an example of this conversational activity, and its role in the discourse of case three, at the end of the section summarizing the conversational activities of holistic experiences.

7.2.2.1 Holistic Experiences

My holistic research experiences shared seven conversational activities, listed in Table 7.6. In addition to having these activities in common, I observed that both cases often participated in conversational activities at similar points in the day or task. For example, in case

one, I observed that Mary and Sam's typical conversations about research took on a pattern of assign-report-interpret. For case three, I observed that Mia and Simon's typical conversations about research took on a pattern of introduce-execute-interpret. Additional details related to these patterns of movement can be found in the cases' respective chapters. After constructing critical incident charts for the activities in these patterns, I concluded that the activities of assigning and introducing were qualitatively the same conversational activity of introducing. I also concluded that their shared practice of interpreting was more accurately identified as two conversational activities: explaining and instructing.

My mentors in cases one and three both began each day with their student by introducing the task they would be completing for the day. Table 7.7 displays a typical pattern of turns-at-talk and example conversations for cases one and three introducing the day.

Table 7.7 Cross-case analysis of turns-at-talk during introducing conversations for holistic experiences

	Speaker	Action	Example
Case 1	Mentor	Information	I have to think what we were going to do today. . . . I'm going to have you run the Coomassie stain.
	Mentor	Question	Have you done one of those?
	Student	Answer	I'm pretty sure, yes.
	Mentor	Information and Instruction	So . . . it's the same thing except for once it's done running we just put it straight into the Coomassie stain. So you don't have to do the transfer or any of the antibodies or anything . . . if you want to get (inaudible) for the gel and a bucket of ice.
Case 3	Mentor	Information and Question	All right. So it's going to be the same as remember this time, when we lysed it?
	Student	Answer	Yeah.
	Mentor	Question	And do you remember what we did?
	Student	Answer	First we made the buffer. Or, we got our ice and put the pellet on the ice to thaw it. . . . And then we made the buffer while it was thawing . . . and then we had to add the lysozyme, DNAse and DTT.
	Mentor	Check and Instruction	All right. So we can do that and this time I'll let you lead the way and I'll just follow you . . . and if you need help then I'll tell you what to do.

When Mia and Mary introduced each days' tasks, their turns-at-talk suggested that they had already generated a plan for their students. The purpose of these conversations appeared to be communicating that plan to their students, and providing personal and intellectual support. To provide support, both Mia and Mary asked their students to think back to previous times they had worked on the same or related tasks. For Mary, introducing a task included summarizing the steps Sam would take and reminding him of any steps she considered significant. For Mia, introducing a task included asking Simon to summarize the task. As Simon summarized, Mia

confirmed or corrected the information he provided, eventually indicating that he had provided an adequate summary and could now begin.

When Simon and Sam began working each day, one of their first tasks was to locate the supplies they would be using. Identifying the supplies that were needed and finding their locations occupied a significant portion of the beginning of each day. It was Sam and Simon's responsibilities to find these supplies before beginning tasks; they often spoke to their mentors concerning where supplies were located. Table 7.8 compares patterns of conversation where Sam and Simon spoke about looking for supplies with their mentor.

Table 7.8 Cross-case analysis of turns-at-talk during locating conversations for holistic experiences

	Speaker	Action	Example
Case 1	Student	Question	Hey, [Mary], I cannot remember where the ammonium trisulfate is . . . that's the TRIS buffer right?
	Mentor	Answer	That's the APS. There's two spots. It's either in the tray thing or in the butter dish on the other wise.
	Student	Acknowledgement and Question	I saw that, yeah. . . . Ten percent APS?
	Mentor	Answer	Yep
Case 3	Mentor	Instruction	So you just need to get everything together.
	Student	Information and Question	Okay, so I need the lysozyme in the mini fridge, the DNAse from the mini fridge, and that from the freezer box (*Simon reading quietly.*). . . . Should I get them one at a time or should I just get them all at once?
	Mentor	Answer	I always get the DTT first because you have to thaw it . . . then it can start thawing and then I can get my graduated cylinder and measure out my buffer.
	Student	Question	Okay. . . . [W]hich one, do you know is there a preference?
	Mentor	Answer and Instruction	No, they're all the same. I would just take two . . . to make sure you have enough. Because sometimes it'll be exactly 250 and maybe a little water taken out and so you have 240. And you're like, 'ugh.'

When Sam forgot the identity or location of supplies, he usually asked Mary for the information. Mary demonstrated her personal support by making sure she was available for Sam's questions. She appeared to be Sam's primary resource for this type of information. When Simon located supplies, he began by using his laboratory notebook to identify what supplies he needed. Before getting supplies, Simon read his notes aloud for Mia to confirm or modify. Simon's notebook

was a continual focus during conversations related to locating supplies. With Mia's directions, he included the identities and locations of all supplies he used in his notes. Mia emphasized the importance of having detailed notes. As she discovered information during these conversations that Sam did not know, she would instruct him to include the new information in his notes for the next time it was needed.

As Simon and Sam worked, Mia and Mary would often provide additional instruction related to how tasks should be approached. Table 7.9 compares patterns of conversation where Mia and Mary provided these instructions.

Table 7.9 Cross-case analysis of turns-at-talk during instructional conversations for holistic experiences

	Speaker	Action	Example
Case 1	Mentor	Instruction	Once you put all that away you can inoculate the media.
	Student	Acknowledgement	Okay, cool.
	Mentor	Explanation	Cause I'm pretty sure the mutant's going to go pretty slow again. . . . We can start it a bit earlier in the day because I figure even by the time you're in tomorrow . . . they might still need to grow a bit more.
Case 3	Mentor	Instruction	Now you can measure these. You'll need a paper and a pen . . . you can use the little holder.
	Student	Acknowledgement	Okay.
	Student	Question	Then I write down on the tube the weight?
	Mentor	Answer and Explanation	No. You just need to weigh 'em all. Since we're gonna end up combining 'em anyway . . . you just write 'em all down and then we're gonna add them up.

When Mia and Mary told their students how to proceed, they also provided explanations for why they were instructing them in a certain way. These explanations generally related to practical considerations like the time needed to complete a task or why their instruction was more efficient than another option. Simon and Sam asked clarifying questions or acknowledged these instructions before continuing their work.

When Simon and Sam worked, they often updated their mentors about their progress. Table 7.10 displays typical patterns of turns-at-talk and example conversations for when Simon and Sam were updating their mentors.

Table 7.10 Cross-case analysis of turns-at-talk during updating conversations for holistic experiences

	Speaker	Action	Example
Case 1	Student	Information	Most of the [wild-types] are ready except for one. So maybe thirty minutes on all of them or I don't know. . . . I'm wondering if I didn't put enough culture in [the mutants].
	Mentor	Question	How much did you add?
	Student	Answer	Ten. But I meant before that when we—
	Mentor	Explanation	Oh, that wouldn't make a huge difference.
	Mentor	Instruction	Why don't you, we'll wait a half an hour and then recheck the ODs and harvest the [wild-type] . . . in this thirty minutes you can take out the mutant ones and just bleach 'em, wash 'em, and trash 'em . . . and then next week I'll have you redo that mutant.
	Student	Acknowledgement	Sure. . . . Sounds good.
Case 3	Student	Information	The scale is acting funny. I don't know—
	Mentor	Question	Oh, is it not stopping?
	Student	Answer	No. . . . I can't get to the weighing screen. It's just doing this.
	Mentor	Instruction	We're going to unplug it for a few seconds, maybe it will reset or something.
	Student	Acknowledgement	Yeah.

Sam's updates regularly involved communicating data or observations he collected while working separately from Mary. When he updated Mary, his turns-at-talk suggested that he was bringing this information to Mary so that she could decide further steps. He provided information, answered clarifying questions, and then waited for further instruction. Simon, who usually worked with his mentor, updated Mia when he encountered a problem that he could not address by himself. Like Sam, updating Mia involved providing information, answering clarifying questions, and then waiting for further instruction. For both cases, I observed that the students used the action of updating as a method to seek out intellectual support from their mentors.

Sam and Simon also sought intellectual support by asking their mentors to explain a variety of topics, both related and unrelated to their research. Table 7.11 displays typical patterns of turns-at-talk and example conversations for when Simon and Sam asked their mentors to provide explanations.

Table 7.11 Cross-case analysis of turns-at-talk during explaining conversations for holistic experiences

	Speaker	Action	Example
Case 1	Student	Question	I understood a decent amount [in journal club] . . . but it seemed like you guys really knew some specific details about the protein structures that I was just like . . . what is going on?
	Mentor	Answer	Yeah. . . . From my research, we don't know what the three-dimension structure of [our protein is]. . . . But . . . like we we're looking at a channel. So it's got to spread through a membrane, so you have those hydrophobic parts that are concealed within the membrane and you have the outside have to be
	Student	Information	Hydrophillic.
	Mentor	Question or Information	But also within the channel, the amino acids facing the lipids of the membranes? Those need to be hydrophobic, right?
Case 3	Student	Question	Why is that again [that we use an ice bath]?
	Mentor	Answer	So when you have an ice bath, when you put ice, each piece is solid and so only a portion of the piece of ice is touching your beaker. Where if you have a liquid in there to make a bath.
	Student	Answer	More of it will be touching.
	Mentor	Information and Question	Do you remember . . . when you have a melting ice solution that it stays the same temperature until all the ice melts. And then it will start [increasing] in temperature?
	Student	Acknowledgement	Yeah.
	Mentor	Information	So until all your ice is melted, it will have the same temperature, theoretically.

I observed that both Simon and Sam regularly initiated these conversations with questions about the rationale or conceptual foundation of their projects or techniques. Sam, who was in his fourth semester of working with Mary, tended to ask broad and cross-cutting questions. He was attending journal club meetings, which exposed him to a variety of new ideas and research areas.

The conversations he initiated suggested to me that he was actively trying to integrate this new knowledge into his current understanding of science and his and Mary's research. Mary assisted this process by using their research as an example when explaining different concepts. For Simon, his questions were usually about foundational concepts. As a freshman, Simon was currently learning many of the concepts on which his techniques were based. When explaining concepts, Mia appeared to be aware of this limitation. She regularly asked Simon if he was aware of specific concepts, before deciding how she would explain a technique.

When both Sam and Simon worked in the laboratory, their mentors, Mary and Mia, regularly took the opportunity to show them additional research on which they were working. An example of the patterns of conversation that occurred when Mary and Mia demonstrated additional techniques to their students can be seen in Table 7.12.

Table 7.12 Cross-case analysis of turns-at-talk during demonstrations for holistic experiences

	Speaker	Action	Example
Case 1	Mentor	Information	One thing I can show you first . . . this is our Coomassie I started destaining it. So you can see how it's starting to get . . . the background of the gel is less blue.
	Student	Acknowledgement	Yeah, Yeah, I see that.
	Mentor	Description	So . . . the paper towel absorbs the dye really well. So what I typically do is periodically if the paper towel looks . . . totally soaked through with blue . . . I just get another one. And basically I just fold it a bunch of times and then stick it in the corner. And make sure there's enough liquid that the gel can still move around. . . . I might add a little more of [the destaining solution] but it's getting close to being totally clear.
Case 3	Mentor	Information	This is what, when you plate bacteria . . . you see. . . . So I'm going to make more of these [bacteria]. So this is me taking some cells I plated and then they'll each grown individual colonies. I don't know if you can see the individual colonies?
	Student	Acknowledgement	Yeah
	Mentor	Description	So each colony is genetically similar. So you only want to take one colony because they're all exactly the same because they all come from one cell. So I want to make a lot of it and so you plate it out. So then you can isolate each colony and then grow a whole bunch. So this is me making more of the DNA.

I observed that Mary and Mia treated the times when Sam and Simon worked with them as opportunities to highlight the variety of work that was done in the laboratory and their particular

research. It appeared that they initiated these demonstrations spontaneously, rather than planning to show Simon and Sam additional techniques in the laboratory. In these conversations, Mary and Mia used their turns at talk to connect the new techniques and information they were demonstrating to previous knowledge they believed their students possessed.

Outside of their conversations about research, both cases one and three participated in conversations about their personal lives. Although the topics for these conversations varied, their structure was generally maintained. Conversations about personal lives involved question-answer and storytelling sequences. Examples of these types of conversations are presented in Table 7.13.

Table 7.13 Cross-case analysis of turns-at-talk during personal sharing conversations for holistic experiences

	Speaker	Action	Example
Case 1	Mentor	Question	How is your classes though?
	Student	Answer	Good, yeah. I had a bit more of that medical history class which was cool. We started going through . . . archive material today.
	Mentor	Question	Are they teaching you to go through the archives and stuff?
	Student	Answer	Yeah. They haven't really given us an exact, like, this is what you're doing yet . . . like a project.
Case 3	Mentor	Question	It's nearly spring break. . . . Are you doing anything?
	Student	Answer	Nope. Just going back home, but all my friends are going to Florida.
	Mentor	Question	What? You're not going?
	Student	Answer	Nope. Maybe next year, but I wanted to not spend money this year.

For cases one and three, Mary or Mia generally initiated conversations about personal lives. They both regularly asked their students about daily life and plans for future vacations. I

interpreted these practices to suggest intentional actions to make themselves accessible and provide personal support. During conversations about personal life, both Sam and Simon participated by telling stories about their lives and asking reciprocal questions of Mary and Mia. I observed that the roles mentors and students played in these conversations about personal lives differed from how they participated in conversations about research. It was during these conversations that Sam and Simon would volunteer their own opinions and ideas, without encouragement by their mentors.

My holistic experiences both involved postgraduate mentors, as defined by Dolan and Johnson (2010). Based on their shared norms of discourse, I did observe some similarities in the ways that they engaged in conversations with their students. Mia and Mary were helpful, a quality Dolan and Johnson (2010) reported undergraduates used to describe their postgraduate mentors. Mia and Mary helped by regularly discussing additional instructions about practical aspects of the work with their students. These were often tips or tricks they had learned during their time working in the laboratory. When Sam and Simon encountered a point where they did not know how to proceed, they would go to their mentors for help or, to use the language identified by Thiry and Laursen (2011), they would seek intellectual support. This discursive norm demonstrated the accessibility and approachability (Dolan & Johnson, 2010) both Mia and Mary displayed as mentors.

Mary and Mia's accessibility also provided opportunities for their students to participate in additional types of conversations. It appeared that conversations where Mary and Mia explained content or demonstrated additional techniques arose from the fact that Mary and Mia made themselves accessible, both temporally and spatially. Mary and Mia took the time to initiate conversations that exposed students to additional research (Dolan & Johnson, 2010). I

identified these conversations as providing personal support (Thiry & Laursen, 2011); however, taking this time may have also strengthened the belief that they had time for their students.

By working in the same space as their students, it is possible that Mary and Mia reduced the barriers that could prevent students from asking questions. During observations, Sam and Simon initiated conversations asking their mentors to explain a variety of scientific topics, both related and unrelated to their research. Their initiation of these conversations increased their opportunities to be exposed to new areas of research (Dolan & Johnson, 2010).

One important factor that contributed to my identification of these two cases as holistic experiences was the prevalence of discourse about personal lives in conversations. Both my mentors and their students in holistic experiences regularly initiated conversations related to each other's personal lives. I noticed that it was most often mentors that began these conversations each day. I interpreted this to be a method they used to provide personal support (Thiry & Laursen, 2011) and show interest in their students. These conversations also provided students with insight into the lives and experiences of graduate students (Dolan & Johnson, 2010) and postdoctoral associates.

I observed one key difference between the methods Mia and Mary used to engage in similar conversations with their students. This difference appeared in conversations about introducing the day and locating supplies. For Mary, introducing each day's task involved providing Sam with intellectual and personal support (Thiry & Laursen, 2011) through clear instructions about how he needed to proceed. This occurred both for new tasks and ones with which Sam had previous experience. When Sam experienced trouble locating supplies, Mary also provided intellectual support (Thiry & Laursen, 2011) by answering Sam's questions.

In contrast, if Simon had previous experience with a task, Mia introduced the day by asking Simon questions about the task. It appeared that Mia used questions as a method to encourage Simon's independence as a researcher. I also observed that Mia supported Simon's independence through constant encouragement for Simon to write in and use his laboratory notebook. While there were times that Mia offered intellectual and personal support (Thiry & Laursen, 2011) in response to Simon's questions, it was more common for her to direct him back to his laboratory notebook. From my interview with Mia, it appeared that she viewed Simon's laboratory notebook both as a source of intellectual support (Thiry & Laursen, 2011) and a method she could use as scaffolding (Vygotsky, 1978) to teach Simon how to be an independent researcher.

7.2.2.1.1 Unique Feature of Case Three

My assertion that undergraduate biochemistry research experiences could be divided into two categories by similarities in discourse originated from the preponderance of evidence collected during my observations of cases. It is important to note that this classification system did not fit the entirety of my data. In addition to common conversational activities, I identified one conversational activity that was present in the discourse of case three but absent in the conversations of case one. Unlike case one, I observed that discourse for case three included documenting as a conversational activity. I classified the documenting I observed in case three as a conversational activity because it involved Mia and Simon reading Simon's laboratory notebook, together and often aloud, while simultaneously participating in a conversation about how Simon could improve the quality of his notes. Therefore, I considered it to be both an activity and a conversation about an activity. I identified that this activity was an aspect of the

relationship between Mia and Simon that was not present in any conversations between Mary and Sam.

As I observed Mia and Simon working together, I concluded that a key feature of the experience Mia shaped for Simon was the importance she placed on his becoming an independent researcher. Mia used her turns-at-talk to continually emphasize that she expected Simon to eventually work in the laboratory without her help. For example, Mia expected Simon to participate in conversations introducing the day by explaining how he would go about doing each task. She also directed him to look in his laboratory notebook for information about where to find supplies, rather than asking her. In addition to referencing Simon's notebook in other conversational activities, Mia encouraged Simon's independence by making explicit time to teach Simon how to use his laboratory notebook as a primary resource to document and record his work.

Mia and Simon's conversations about his laboratory notebook contained unique features that I concluded were different than other instances where I observed Mia instructing Simon. Generally, these conversations took the form of either Mia or Simon reading the notes Simon had taken, while simultaneously having a conversation where Mia provided guidance in how Simon should approach documenting, using, and improving the information in his laboratory notebook. Table 7.14 displays an example of their normal pattern of conversation when discussing using laboratory notebooks.

Table 7.14 Case three's turns-at-talk during documenting work in a laboratory notebook

	Speaker	Action	Example
Case 3	Mentor	Question	Do you remember how to prepare samples to run a gel?
	Student	Answer	Not really.
	Mentor	Instruction	Okay. Let's see if you can find it in your notebook.
	Student	Question	(*Simon reads notebook for 30 seconds*.) Is it adding the DTT?
	Mentor	Answer and Instruction	Yay, you found it! Okay, so read the instructions and see if that helps you.
	Mentor	Question	Does it help you with what you need to do . . . if you read those directions, you could follow them and prepare your samples and run a gel?
	Student	Answer	No.
	Mentor	Question	Okay, well what do you need other than that?
	Student	Answer	(*Simon reads notebook for 10 seconds*.) I don't really know how to heat it to 95 degrees or one minute. . . . (*Simon reads notebook for 20 seconds*.) I just would need to be able to find [DTT] and the gel that I had.
	Mentor	Instruction	Okay. Then go through the whole process in your head and see if there's anything else. I know you've done it a few times so just try to imagine it.

While Mia instructed Simon in how to read and write in his laboratory notebook, I observed that the patterns of these conversations were distinct from her instructional conversations. Instead of instructing Simon and then explaining her reasons, Mia provided Simon with questions he should ask himself to determine if his notes were detailed enough. It appeared that Mia may have asked these questions to model the type of behavior (Thiry & Laursen, 2011) Simon should exhibit when assessing the quality of his notes and preparedness to work independently.

Although the importance of keeping a laboratory notebook has been a feature of some literature on undergraduate research experiences, I uncovered no literature focusing on how a mentor should integrate the use of a laboratory notebook into their students' research

experiences. Previous focus on laboratory notebooks has generally been related to integrating ethics into undergraduate research experiences (Mabrouk, 2015; Schachter, 2003) or demonstrating how the practice of keeping a laboratory notebook was integrated at the programmatic level into the training of undergraduate researchers (Canaria, Schoffstall, Weiss, Henry, & Braun-Sand, 2012; Dillner, Ferrante, Fitzgerald, & Schroeder, 2011). For Simon and Mia, the laboratory notebook appeared to a key feature that helped scaffold (Vygotsky, 1978) Simon's understanding of what it took to be an independent researcher.

7.2.2.2 Targeted Experience

I categorized my second case, Merrill and Serena, as a targeted experience because their conversations focused explicitly on aspects of Serena's research. When Serena worked in Merrill's laboratory, I noted that she spent much more time working independently than the students in my other cases. The conversations that Serena and Merrill participated in were less structured than those in cases one and three. Additionally, Serena and Merrill's conversations were not easily categorized into isolated activities. They often integrated multiple activities into a single conversation.

Beyond conversations where Merrill monitored Serena's progress or worked alongside her, I identified one additional activity Merrill and Serena participated in regularly. Merrill and Serena frequently planned future steps in Serena's research through collaborative discussions. These conversations were unique to Merrill and Serena's case and a key feature of the discourse I observed in Serena's research experience. Table 7.15 provides an example of the collaborative conversations Serena and Merrill participated in together.

Table 7.15 Case two's turns-at-talk during collaborative planning

	Speaker	Action	Example
Case 2	Student	Information	What I was planning on doing today is like you know trying to figure out how to get [the PDF file] off from the super computer . . . you know by myself or whatever. . . . But I'll probably still need [John] to help me.
	Mentor	Check	So that essentially means that that compound would be . . . done from our point of view as far as the computational analysis is (inaudible).
	Student	Answer	Yeah . . . that guy should be done . . . and then I remember you said . . . the inhibitor we have been using . . . should be one of the next ones we do. . . . So yeah, we can probably start on that.
	Mentor	Question	Did [David] email us the structure of that thing that we know which one it is?
	Student	Answer and Information	Yes. . . . And I docked it already. . . . It does have a lower score than a lot of the other ones . . . the first little PDF . . . looked promising at least.
	Student	Question	Should the next one we think about doing . . . [be] the real one we've been using or should I pick the top barbiturate?
	Mentor	Answer	No. The real one. . . . See how far you get.
	Student	Information	I think I already docked it . . . so I could honestly just start working on the MD stuff. . . . I think it would be good practice for me to at least try by myself.

Unlike the students in my holistic cases, Serena tended to begin her work in the laboratory alone. She and Merrill would meet every few days to decide what she would be doing next. I observed in these meetings that Merrill and Serena shared the role of deciding next steps. Serena's future research steps were determined through deliberation. Serena, who was most familiar with the day-to-day research activity would provide input about the current status of the project. Merrill contributed a broader perspective and provided intellectual support by advising Serena on issues that required additional content knowledge or concerns she may not have considered.

Serena's undergraduate research experience echoed the reflections of students reported by Laursen and colleagues (2010) as part of their multi-university study of undergraduate research experiences. Like Serena, students in their study were working with faculty mentors. In interviews, these students reported gains in their confidence to do science (Laursen et al., 2010). I observed a similar confidence to do science in Serena's discourse when she participated in collaborative planning by providing ideas and taking steps to work independently. Laursen et al. (2010) contended that these gains were, in part, a consequence of students being taken seriously by their mentors.

Students in their study described being taken seriously as being trusted and relied on (Laursen et al., 2010). When considering Merrill and Serena's participation in planning conversations, I observed that Merrill used one distinct discursive method to indicate that he trusted and relied on Serena. Merrill asked Serena authentic questions about her research, to which he did not appear to know the answers. He also demonstrated that he trusted and relied on Serena by not attempting to answer the questions himself and instead allowing her to try. To guide Serena's process, Merrill provided intellectual support and professional socialization (Thiry & Laursen, 2010), usually in the form of disciplinary knowledge or additional resources (i.e. John and YouTube® videos).

It is possible that Merrill used the method of asking questions to communicate to Serena that she was responsible for her project. In contrast to my two holistic cases, Serena was the only participant that regularly engaged in conversations where she proposed plans for her research. Serena's turns-at-talk during planning conversations suggested that she had accepted ownership of her project, specifically in a form described by Wiley (2009) as ownership as right and

responsibility. In addition to working independently, Serena provided new ideas and modified Merrill's own suggestions for how the work should proceed.

7.2.3 Disconfirming Evidence

After synthesizing my data across cases, I determined the taxonomy I presented here to be the best fit (Merriam & Tisdell, 2016) and most useful way for me to consider my research questions. As I developed this taxonomy, I continually considered evidence that might disconfirm my conclusions. This discrepant case analysis was essential to shaping how I considered the conversations observed across my three cases. For example, my assertion that case two represented a different form of research experience than cases one and three emerged from a search for critical incident charts that contradicted the general patterns I was detecting. Those general patterns eventually became the conversational activities listed in Table 7.6 for holistic experiences.

Because the focus of this study was to uncover norms of discourse, my analysis emphasized patterns in the conversations that mentors and students engaged in during research experiences. My categorization of patterns was grounded in previous literature on undergraduate research experiences, summarized in chapter two, and my interpretation of data. It is possible that my knowledge of literature on undergraduate research experiences influenced my tendency to look for similar types of conversations in my own cases. This tendency may have overshadowed the discovery of unique patterns not previously observed in undergraduate research experiences. Existing literature did provide guidance in uncovering the types of conversations that were observed in my cases. As noted in this chapter, the previous literature on undergraduate experiences supports some of the findings revealed through cross-case analysis of

the data in this study. However, it is unlikely that this knowledge influenced my identification of specific patterns because, as noted in my literature review, there was an absence of literature in existence on the topic of norms of discourse in undergraduate research experiences.

CHAPTER 8. CONCLUSION

To summarize my study, I will revisit the original purpose of this study: To explore the nature of the conversations undergraduate students and their mentors engaged in during undergraduate biochemistry research experiences. I will discuss how findings from this analysis informed my responses to the three primary research questions that gave focus to my research. For each question, restated below, I provide a response based on both findings revealed through my individual cases and my cross-case analysis. I also refer to existing literature that strengthens my own findings in this study. After responding to my research questions, I explore how the theoretically underpinnings of my study shaped how I perceived the phenomenon of undergraduate research. I conclude by addressing the implications this study has both for future research on undergraduate research experiences and for educators serving as mentors to undergraduates working in research.

8.1 Responses to Research Questions

8.1.1 RQ 1: What Norms of Discourse Frame Conversations between Students and Mentors in Undergraduate Biochemistry Research Experiences?

I considered the norms of discourse that framed conversations at three granularities, as guided by conversation analysis theory (Clayman & Gill, 2011). At the coarsest-grain level, I observed that conversations were framed by discourse related to research in all my cases and personal lives in those cases involving postgraduate mentors. This difference in conversations led me to categorize my three cases into two types of experience: holistic and targeted. I categorized cases one and three as holistic experiences; case two was categorized as a targeted experience.

Parsing these two activity frameworks resulted in a list of eleven activities that framed the conversations of my participants. The conversations in both holistic and targeted experiences were framed by activities of mentors monitoring the progress of their students and working with their students. My holistic experiences also included the following activities: demonstrating, explaining, instructing, introducing, locating, personal sharing, and updating. I observed one additional activity in case three with Mia and Simon; they also participated in conversations about reading and writing in laboratory notebooks. I did not observe any of these distinct conversations in the targeted experience case, although I regularly observed Serena writing and reading her laboratory notebook on her own. In addition to monitoring and working together, the primary conversational activity I observed in my targeted experience was discussions featuring collaborative planning where both Merrill and Serena contributed to deciding next steps in her project. At the finest-granularity I identified individual actions and features of the turns-at-talk of my participants. To discuss these, I organize them based on the type of experience in which they were observed.

8.1.1.1 Holistic Experiences

Holistic experiences were most notably characterized by the structured nature of the experience and observed discourse. In their case-summaries, I found that the conversations about research in both cases one and three proceeded in an orderly and predictable fashion. For Mary and Sam in case one, their conversations about research appeared as daily cycles, initiated by Mary, of assign-report-interpret. For Mia and Simon, I characterized their pattern, initiated by Mia, as introduce-execute-interpret. In each case, I observed that the mentor took responsibility for determining the day's tasks. The mentors began each day by introducing the students to their

decisions. This process involved providing the student with information about each task and then asking questions. These questions appeared to serve two purposes. First, they were a way for the mentor to provide personal support by enquiring about the student's comfort in the task. Second, they were a way for the mentor to provide professional support by connecting the assigned task to previous work the student had done in the laboratory. While previous literature has not highlighted a mentor's role in taking responsibility for daily research tasks, this finding may help explain Dolan and Johnson's (2010) report that postgraduate mentors were perceived by undergraduates as accessible, helpful, and useful for transitioning to independent work.

Once students began working, I observed that the discourse they contributed in conversation generally focused on one goal: executing the assigned tasks correctly. Students asked clarifying and follow-up questions and reported back to their mentors at points when they appeared to not be sure how to proceed. Most of these questions and requests for support related to procedural and technical information. I observed that many were not true questions, but requests for the mentor to check and approve of the student's progress. Students also asked their mentors to explain concepts behind aspects of the procedure.

My mentors responded in a variety of ways to their students' needs for support. Both Mary and Mia acknowledged requests to explain background information and responded with explanations which they connected back to the student's own knowledge and understandings. In cases where the student's question was not a question, but a request for affirmation, I observed that my two mentors reacted differently. Mary offered answers in response to these types of questions. Mia took intentional steps to not answer at first. Instead, she provided Simon with a resource where he could find the answer himself (i.e. his laboratory notebook). She only answered Simon's question if the answer he sought was not in his notebooks. When this

occurred, she also had him include the new information in his laboratory notebook. This difference challenges the categorization of graduate students and postdoctoral associates who mentor into one category of postgraduate mentors. While this approach was used in my study and previous literature (Aikens et al. 2016; Dolan & Johnson, 2010), my findings suggest it may conflate distinct styles of mentoring.

In addition to conversations about research, the students and mentors in my holistic cases also participated in conversations about their personal lives. Unlike their research-discourse, I noted that these conversations were less structured. Students and mentors appeared to participate equally during these conversations. Mentors commonly initiated these conversations by asking a question about the student's life. However, students regularly reciprocated with their own questions. Students introduced new ideas to the conversations and often asked their mentors about a variety of aspects of their life, including what it was like to be a researcher. This finding may help demonstrate the discourse that led to Dolan and Johnson's (2010) report that postgraduate mentors provided undergraduate students insight into the graduate experience and offered exposure to other research.

8.1.1.2 Targeted Experience

I observed that the targeted experience displayed little evidence of a pre-defined structure. Case two's discourse suggested that the organization of Serena's research experience resulted from she and Merrill co-constructing a plan for how she would approach her problem. Serena and Merrill spoke together the least often of my cases, although Merrill did regularly check-in with Serena to make sure she had enough support. When they did make plans for Serena's research, I noted that both Merrill and Serena participated in the conversation in distinct

ways. Serena provided information about the current state of the project, including what work she had recently completed and ideas she had for how to proceed. Her details were usually encouraged by the open-ended questions Merrill asked. In addition to asking questions, Merrill listened to Serena's thoughts and offered intellectual support and perspective. He brought up considerations Serena may have missed and provided his own ideas for how to move forward.

During these conversations, I observed that both Serena and Merrill contributed ideas for how the research would proceed. These ideas developed as they shared their knowledge with each other. However, after discussion, it appeared that Merrill did make the final decision about how Serena would proceed. He gave these instructions by summarizing the relevant points from their conversation which detailed what Serena's next steps would be.

Similar to her independence when working, Serena rarely spoke to Merrill when she encountered problems in her research. I observed that Serena first turned to resources like YouTube® videos and her laboratory notebook when she appeared unsure of how to proceed. She would also look through old e-mails from John and Merrill. It was only after trying these resources that she would contact John or Merrill. When she approached either of them for help, she asked specific questions or requests. From John and Merrill's reactions to her questions, it appeared that they were often complex questions. Their answers were not usually simple. To answer her questions often required one or both of them to contribute content knowledge and integrate that with Serena's explanations of the project's current state. While these findings align with Dolan and Johnson's (2010) report that faculty mentors provided "big picture" advice, they also demonstrate that the list of influences attributed to faculty mentors in the report may be incomplete. Merrill's norms of discourse included methods that provided help and transitioned

Serene to independence, both qualities attributed by undergraduates primarily to postgraduate mentors (Dolan and Johnson, 2010).

8.1.2 RQ 2: How are the Norms of Discourse Established in Undergraduate Biochemistry Research Experiences?

I observed that both mentors and students initiated conversations about research and personal lives. The high number of times students initiated conversations suggested to me that they were generally comfortable addressing concerns they had when working in the laboratory. This comfort appeared to influence the types of conversation that they experienced, as their questions often prompted mentors to provide additional instructions or explanations. Nevertheless, when considering how students and mentors engaged in research together across cases, I identified strong evidence to suggest that it was the mentors' actions, the nature of the students' projects, and the students' length of experience in the laboratory that established the guidelines for norms of discourse in each undergraduate biochemistry research experience.

Mentors in my holistic cases may have established the organized-nature of their conversations by approaching mentorship from the position of an instructor. Both Mary and Mia acted in ways that suggested they considered it their responsibility to decide what Sam and Simon would do each day and assess their success. Sam and Simon worked on projects that were part of Mary and Mia's research. When they were in the laboratory, Mary and Mia both placed emphasis on providing them intellectual and personal support through clear instructions and explanations. These findings align with Dolan and Johnson's (2010) report of the influences of postgraduate mentors on undergraduates. They also demonstrate the types of support Thiry & Laursen (2011) highlighted as needed by undergraduate research students.

Mary commented in interview that when mentoring, she, "[tried] to avoid . . . confus[ing] them. I want to make sure I have it down for explaining it to them." In turn, I observed that students' discourse in my holistic cases emphasized the fidelity of their work compared to their mentors' instructions. This accuracy was determined by the mentor, who further encouraged this pattern of discourse by validating or correcting students' actions. During my interview with Mia, she reflected on her choice to mentor using this style. She said, "that's still something I'm struggling with. . . . [If] I give him too much uncertainty, it's too overwhelming. But then if I do too much of, 'this is how this is' and he is going to think that every single time this is how it should go." Mia's reflection suggested she was struggling with how to balance Simon's need to be mentored with her desire to foster his independence as a researcher (Laursen et al., 2010).

Merrill, the mentor in my targeted case, established the collaborative nature of the discourse in Serena's research experience by asking questions that held Serena responsible for specific aspects of the project. While Serena's research related to Merrill's, it was her own independent project. When I spoke to Merrill about Serena's research, he readily expressed that he did not know all the answers. To help Serena, Merrill provided her resources like John and YouTube® videos that she could use when she had questions. While these resources helped, Serena still needed to figure out some aspects of her project on her own. It was perhaps from this authentic nature of Serena's research that the collaborative nature of discourse arose (Laursen et al., 2010).

The amount of time dedicated to a specific conversational activity appeared to be guided in part by how long the student had been working in the laboratory. For Simon, who was in his first semester, many of his conversations involved Mia introducing or explaining how to work in the laboratory. Sam, who was in his fourth semester, often worked independently and spent more

time updating Mary on his progress and receiving additional instructions. Serena and Merrill's conversations were qualitatively different than cases one and three, demonstrated by the unique conversational activities. However, like Sam, Serena regularly worked independently. When she and Merrill spoke, it was either to update Merrill on her progress or to make plans for future steps. These findings support work by Adedokun and colleagues (2014) that asserted undergraduate research experience have developmentally distinct stages, which helps explain why students experience different gains based on their time in an experience.

I did not attribute any differences in discourse to students' current academic classifications (e.g. freshman versus senior). One explanation for this is that I did not detect these differences because all my students were participating in research involving concepts outside the scope of normal course material. For example, Serena's research into computer-aided drug discovery involved concepts and techniques usually only covered in graduate-level courses. Aspects of Sam and Simon's projects were related to their course-work; however, most of the content they needed to understand their projects was taught to them by their mentors.

8.1.3 RQ 3: How do the Conversations Students and Mentors Engage in Impact the Undergraduate Research Experiences of Students?

Based on the observations and interviews I collected over three cases, I identified three ways that conversations had an impact on the research experiences of my participants: The independence, the anxiety, and the ownership students exhibited while doing research. Most notable was the role that asking questions played in encouraging independence in students, an influence on undergraduates reported by Dolan and Johnson (2010). For my participants in case three, Mia asking Simon questions was a regular part of their daily routine. It appeared that Mia used the practice of asking questions to guide Simon while also encouraging him to think for

himself. Mia was selective about which of Simon's questions she would answer. During the interview, Mia mentioned she had increased the number of questions she asked and reduced the number she answered as Simon gained experience. In cases where Mia determined that Simon should know the answer to his question, she responded with a new question that directed him to look in his notes.

While Mia's use of questions encouraged Simon to act independently, it is also possible that it increased his anxiety. During my first observation, when Mia explained that she planned to let Simon lead her in the preparation of samples for sonication, he followed up by asking, "You won't let me mess something up real bad?" He expressed similar sentiments in our interview when he explained in the laboratory, he was, "more scared of disappointing her." In comparison, Sam, who was not expected to answer questions related to research described working with Mary as, "not necessarily relaxing but at the same time . . . it's not too intense." This may be because Mary readily supported Sam by providing answers to his questions.

Merrill's use of questions when working with Serena also appeared to encourage her independence. However, unlike Mia, Merrill's questions arose not from a desire to increase Serena's independence but from an actual need to know. Serena's project was her own independent research, and appeared to be the most authentic experience of my three cases. Merrill had given up part of his responsibility for the work, meaning he did not know the answers to the questions he asked Serena. This context that led to Merrill to ask questions appeared to not only encourage Serena's independence but also her ownership of the project. Serena was my only participant that appeared to demonstrate ownership of her project as right and responsibility (Wiley, 2009). When working with Merrill, Serena provided new ideas and even modified suggestions from Merrill about next steps in her project.

8.2 Exploring the Conversations of Undergraduate Research Experiences

When I chose to focus on the experiences of students engaging in undergraduate research, I was interested specifically in better understanding the relationship between students' participation in undergraduate research and their growth in thinking like, working like, and eventually becoming scientists. Based on work by Laursen and colleagues (2010), I anticipated that evidence of these skills could be detected in the discourse of undergraduates engaging in research experiences. My interest in discourse as a way to better understand undergraduate research experiences naturally led me to consider certain theoretical lenses, as detailed in Section 3.3.

I chose to view my undergraduate research experiences through a lens informed by hermeneutical, ethnomethodological, and conversation analysis theory. In addition to guiding methodological choices, I identified that commensurate aspects of these three ways of knowing informed how I thought about and approached using discursive data to understand undergraduate research experiences. Most prominent was the emphasis all three theories placed on the role of words in making sense of the world. When observing the conversations of mentors and students in my cases, I viewed the words they spoke not just as conversation but also as individual attempts to organize and make sense of their relationship and experiences together.

By considering words in this way, I was able to think about the methods by which both mentors and students processed working in the laboratory together. For example, I concluded that Mary, who had previous experience working as an undergraduate in two distinct environments, thought of undergraduate research as an intimidating experience. As a mentor, she considered part of her role to be lessening that intimidation. Mary attempted to reduce Sam's anxiety with words that conveyed guidance and support. This included providing Sam

instructions, explanations, and information at any point she perceived it was needed. Mary's discourse exemplified the positive influences Dolan and Johnson (2010) reported postgraduate mentors have on undergraduate students. I noted that Mary's emphasis on supporting Sam may have also influenced how Sam made sense of his research experience. Sam appeared to rely on Mary as a primary resource and approached her any time he needed guidance. Thus, Mary's support may have prevented Sam from having a more independent research experience.

Mia considered Simon's research experience as an opportunity to equip him with the skills she believed he would need to succeed in research. These were skills Mia identified by reflecting on her own experiences as a graduate student. To prepare Simon for his future in research, Mia used her words to create situations like what she expected Simon would encounter in the future. A key feature of this experience was the expectation that Simon would eventually need to work independently. To provide Simon experience in this area, Mia limited the guidance she gave Simon directly. Mia's mentoring style demonstrated a direct approach to using discourse to remove intellectual and personal support (Thiry & Laursen, 2011) in order to transition a student to independence (Dolan and Johnson, 2010). Although Simon still asked Mia questions, Mia regularly responded by suggesting he think about the question a bit longer or look in his notebook. When I asked Simon about Mia's practice in interview, he said, it "helps me get better . . . [and] learn when she's tough on me." Based on Simon's response, it appeared that he viewed his undergraduate research experience as an opportunity to learn and grow.

When I observed Merrill working with Serena, I noted that the nature of their conversations was distinct from those of my other cases. Most significant was the absence of personal conversations. I interpreted the emphasis on research conversations to suggest that Merrill made sense of Serena's research experience as an opportunity to engage in authentic

research. My interpretation was supported by the fact that, in interview, Merrill mentioned gauging the success of an undergraduate research experience by the number of presentations and papers it resulted in contributing to the field. When working with Serena, Merrill used his words to help her by providing the disciplinary knowledge she needed to further her research. Beyond this form of support, Serena sought alternative resources to help her research progress. These included John and YouTube® videos, both suggested by Merrill, and a variety of documents (i.e. her laboratory notebook and e-mails), which she appeared to keep track of and use with her own guidance. The presence of these actions, and their absence in other cases, led me to conclude that Serena was my only student to demonstrate ownership, specifically as right and responsibility (Wiley, 2009). It appeared that the authentic nature of Serena's research contributed to her participating in conversations that supported these gains (Laursen et al., 2010).

8.3 Implications for Research

While a large amount of research has been done on the topic of undergraduate research experiences (see Section 2.2), I have found no studies that focus specifically on the norms of discourse that frame the conversations between mentors and students in undergraduate research experiences. Furthermore, the current body of literature focusing on undergraduate research experiences suffers from a lack of studies using qualitative methods to explore and understand the processes that make up undergraduate research experiences (Adedokun et al., 2012, 2014; Sadler et al., 2010). Therefore, this study contributes to the limited body of articles currently in existence that investigate the processes and contexts in which undergraduate research experiences occur (Adedokun et al., 2012, 2014; Aikens et al., 2016; Dolan & Johnson, 2010).

Additionally, in this study I have identified eleven norms of discourse that mentors and students used to communicate during undergraduate research experiences. By reporting on these norms and the nature of their use in conversations, this study provides a starting point from which further research can explore aspects of both mentors' and students' discourse in undergraduate research experiences. For example, this study uncovered two ways that mentors used questions to encourage their students' autonomy and independence. However, it was unable to uncover details about the features of these questions that made them effective methods. Future studies should further investigate the role asking and answering questions plays in shaping students' independence in research.

An important feature of this study was its role in supporting and adding to findings from works by Dolan and Johnson (2010) and Aikens and colleagues (2016) that suggested the identity of a mentor (i.e. postgraduate versus faculty) and influenced the research experience of the undergraduate student. Like these researchers, I observed similarities in the experiences of my students working with postgraduate mentors. This study added to those findings by providing details into the ways postgraduate mentors' discourse differed from that of a faculty member's, thus impacting the experiences of undergraduates involved.

As evidence mounts for the consideration that undergraduates' research experiences are impacted by the identity of their mentors, the question arises whether research on evaluating undergraduate research experiences can proceed effectively without consideration for those differences. To address the potential risk of conflating unique experiences, researchers should explore the current diversity of practices that are classified as undergraduate research experiences. Without a clearer picture of what is meant by the term "undergraduate research

experiences," the evaluation and responsible funding of this educational practice will continue to be a major challenge for the field.

8.4 Implications for Practice

The results from this study have implications for mentors who are working with undergraduate students in research experiences and seeking to scaffold their students' development as independent researchers. To effectively facilitate students' development as autonomous researchers, mentors may find it helpful to replace some of the personal support they provide through conversations with their students with alternative resources. For example, mentors may consider suggesting their students diversify their support by speaking to additional researchers or looking up information on YouTube® to address questions before approaching them. They may also find it useful to encourage and explicitly educate their students in the documenting of their research progress through research notebooks, as observed in the conversations between Mia and Simon in case three.

Conversely, mentors who think their students are struggling with the experience of doing research may consider increasing the personal support they provide by using methods like those observed in my holistic experiences, summarized in Section 7.2.2.1. For example, providing structure to a student's research experience may help them to overcome anxiety they may be experiencing. They may also consider taking time to converse openly about the personal challenges and struggles they face when doing research.

APPENDIX A. MENTOR INTERVIEW EXAMPLE

MENTOR INTERVIEW PROTOCOL
CASE 3 ROUND 1

Introduction
Thank you for agreeing to participate in this study on discourse in undergraduate research. I have two purposes for this interview. First, I would like to talk about your experiences working with your student in undergraduate research. Second, I want to play some video clips of you and your student working in the laboratory together and have you reflect on them.

1. How did you begin working with Simon?
    a. When did you begin working together?
    b. How was the experience initiated?
2. How do you see your role working with Simon?
3. Approximately how many students have you worked with before Simon?
    a. Undergraduate students?
    b. Graduate students?
4. Please tell me about your experiences doing research as an undergraduate.
    a. How does your experience in undergraduate research inform how you mentor your undergraduate student?
5. Please tell me about your experiences doing research as a graduate student and postdoc.
    a. How does your experience in graduate or postdoctoral research inform how you mentor your undergraduate student?
6. What other types of experiences guide how you shape Simon's undergraduate research experience?
7. Please tell me about your current research and the project you are working on with Simon.
8. What kinds of changes have you noticed in how you and Simon interact since she began working with you?
    a. Changes in you?
    b. Changes in Simon?

Video Clips
I have selected 8 clips that I would like to play for you of different conversations you and Simon have had in the lab since I began observing. After listening to a clip, I would like for you to reflect on the conversation you were having with Simon by answering some questions.

Clip 1 Beginning of the day
How would you describe what you and Simon are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What previous experience has Simon had with this procedure?
What did you mean by "this time, I'll let you lead the way and I'll just follow you"?
What do you think Simon meant by "you won't let me mess something up real bad"?

Clip 2 Sonication
How would you describe what you and Simon are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What previous experience has Simon had with this procedure?
What did you mean by "it didn't appear to be lysed"?
What did you mean by "there's always a chance maybe 65 for 13 minutes is too much and it's going to generate too much heat"?
What was your motivation in discussing these changes?

Clip 3 Writing in notebook
How would you describe what you and Simon are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What did you mean by "every single step in [your protocol]"?
What can you tell me about the paper Simon was writing on?

Clip 4 Western Blot membrane
How would you describe what you and Simon are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What did you mean by "my results looked kind of wavy"?
What did you mean by "some may be used a lot in this area and some may not be used a lot in this area"?

Clip 5 Mixing solutions that were frozen
How would you describe what you and Simon are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What did you mean by "it may not be the correct concentration"?
What did you mean by "you've got to make sure that it's all solubilized"?

Clip 6 Reading in the notebook together
How would you describe what you and Mia are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What can you tell me about the notebook you are reading from?

Clip 7 Looking at the sonication product
How would you describe what you and Simon are doing in this clip?
What is Simon doing?

What are you doing?
What were you and Simon talking about?
What did you mean by "we're going to judge beige"?
What did you mean by "it feels a little more watery"?
What did you mean by "I think this is a better lysis"?
Can you tell me about the events that led up to this conversation?
Why were you judging whether this was a better lysis?

Clip 8 Mia making suggestions
How would you describe what you and Simon are doing in this clip?
What is Simon doing?
What are you doing?
What were you and Simon talking about?
What did you mean by "this would be a good thing to note"?
What did you mean by "we don't have to run it for 20 minutes; 10 minutes is fine"?
What did you mean by "just to be more time efficient"?
What do you think Simon meant by "is it unlysed cells"?
Why do you respond to Simon's question with "probably"?
What did you mean by "because they're compact"?

Conclusion
1. How do you interact with Simon outside of the laboratory?
2. How often do you do an experiment parallel to Simon?
3. What effort do you make to connect back to Simon's classes and previous knowledge?
4. Is there anything I did not ask in this interview about your experience with Simon that you would like to add?
5. How often do you choose to not answer Simon's questions or answer them with a question? What is your motivation behind this method?

APPENDIX B. STUDENT INTERVIEW EXAMPLE

STUDENT INTERVIEW PROTOCOL
CASE 3 ROUND 1

Introduction
Thank you for agreeing to participate in this study on discourse in undergraduate research. I have two purposes for this interview. First, I would like to talk about your experiences working with your mentor in undergraduate research. Second, I want to play some video clips of you and your mentor working in the laboratory together and have you reflect on them.

1. Please tell me a bit about yourself.
    a. What's your major?
    b. Year in school?
    c. Where are you from?
    d. What classes are you taking this semester?
    e. What kinds of questions do you ask in class?
2. How did you begin working with Mia?
    a. When did you begin working together?
3. What previous experience have you had doing research?
4. How do you see your role working with Mia?
5. Please tell me about the current project you are working on with Mia.
6. What kinds of changes have you noticed in how you and Mia interact since you began working with her?
    a. Changes in you?
    b. Changes in Mia?

Video Clips
I have selected 8 clips that I would like to play for you of different conversations you and Simon have had in the lab since I began observing. After listening to a clip, I would like for you to reflect on the conversation you were having with Mia by answering some questions.

Clip 1 Beginning of the day
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
What previous experience have you had with this procedure?
What do you think Mia meant by "this time, I'll let you lead the way and I'll just follow you"?
What did you mean by "you won't let me mess something up real bad"?

Clip 2 Sonication
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
What previous experience have you had with this procedure?

What do you think Mia meant by “it didn’t appear to be lysed”?
What do you think Mia meant by “there’s always a chance maybe 65 for 13 minutes is too much and it’s going to generate too much heat”?
Why do you think you two discussed these changes?

Clip 3 Writing in notebook
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
Why do you think Mia writes “every single step in [her protocol]”?
What can you tell me about the paper you were writing on while talking with Mia?

Clip 4 Western Blot membrane
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
What do you think Mia meant by “my results looked kind of wavy”?
What do you think Mia meant by “some may be used a lot in this area and some may not be used a lot in this area”?

Clip 5 Mixing solutions that were frozen
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
What do you think Mia meant by “it may not be the correct concentration”?
What do you think Mia meant by “you’ve got to make sure that it’s all solubilized”?

Clip 6 Reading in the notebook together
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
What can you tell me about the notebook Mia is reading from?

Clip 7 Looking at the sonication product
How would you describe what you and Mia are doing in this clip?
What is Mia doing?
What are you doing?
What were you and Mia talking about?
What do you think Mia meant by “we’re going to judge beige”?
What do you think Mia meant by “it feels a little more watery”?
What do you think Mia meant by “I think this is a better lysis”?
Can you tell me about the events that led up to this conversation?

Why were you judging whether this was a better lysis?

Clip 8 Mia making suggestions

How would you describe what you and Mia are doing in this clip?

What is Mia doing?

What are you doing?

What were you and Mia talking about?

What do you think Mia meant by "this would be a good thing to note"?

What do you think Mia meant by "we don't have to run it for 20 minutes; 10 minutes is fine"?

What do you think Mia meant by "just to be more time efficient"?

What did you mean by "is it unlysed cells"?

Why do you think Mia responded with "probably"?

What do you think Mia meant by "because they're compact"?

CONCLUSION

1. How do you interact with Mia outside of the laboratory?
2. How often does Mia do an experiment parallel to you?
3. Is there anything I did not ask in this interview about your experience with Mia that you would like to add?
4. How often does Mia not answer your questions or answer them with a question? Why do you think she does this?

APPENDIX C. EXCERPTS FROM GEE'S 27 DISCOURSE ANALYSIS TOOLKIT

1. *The Deixis Tool*

   How are deictics being used to tie what is said to context and to make assumptions about what listeners already know or can figure out.

2. *The Fill In Tool*

   Based on what was said and the context in which it was said, what needs to be filled in here to achieve clarity?

3. *The Making Strange Tool*

   What would someone find strange here…if that person did not share the knowledge and assumptions…that render the communication so natural…?

4. *The Subject Tool*

   Why have the speakers chosen the subject/topics they have and what are they saying about the subject? What other choices could they have made and why did they not choose those?

5. *The Intonation Tool*

   How does the speaker's intonation contribute to the meaning of their words? Where did the speaker place or remove emphasis with intonation?

6. *The Frame Problem Tool*

   After completing the discourse analysis, consider if any additional information about the context in which the data occurred changes your analysis.

7. *The Doing and Not Just Saying Tool*

   Ask not just what the speaker is saying, but what he or she is trying to do with their communication.

8. *The Vocabulary Tool*

   What sort of words are being used in the communication (e.g. Germanic, Latinate, etc.) How does the use of words effect the style of communication?

9. *The Why This Way and Not That Way Tool*

   Why did the speaker build or design grammar in the way they did and not another way? How else could the speaker have built or designed their grammar? What could the speaker be trying to do by saying it how they did?

10. *The Integration Tool*

    How are clauses packaged or integrated into utterances or sentences? What was left out or included? What perspectives are being communicated by the way the information is packaged?

11. *The Topics and Themes Tool*

    What is the topic and theme for each clause? What is the theme for a set of clauses in a sentence? Why were these choices made?

12. *The Stanza Tool*

    In longer communications, look for stanzas and how stanzas cluster into larger blocks of information.

13. *The Context is Reflexive Tool*

    Specifically in reference to tools 2, 6, 7, and 9: How is what the speaker is saying, or how he or she is saying it, helping to create what listeners will consider relevant? How is what the speaker is saying, or how he or she is saying it, helping them to continue to exist through time and space? Is the speaker reproducing contexts unaware of aspects of the context that, if he or she were aware, would not want to reproduce? Is what the speaker is saying, or how he or she is saying it, replicating contexts or transforming/changing them?

14. *The Significance Building Tool*

    How are words and grammatical devices being used to build up or lessen significance for certain things and not others?

15. *The Activities Building Tool*

    What activity or activities is the communication building or enacting? What activity or activities is the communication trying to get others to recognize as being accomplished? What groups support and set the norms for these activities?

16. *The Identities Building Tool*

    What socially recognizable identity or identities is the speaker trying to enact or get others to recognize? How does the speaker's language treat other people's identities?

17. *The Relationships Building Tool*

    How are the words and grammatical devices being used to build, sustain, or change relationships among the speaker and other people?

18. *The Politics Building Tool*

    How are words and grammatical devices being used to build what counts as social goods and distribute or withhold these from listeners or others?

19. *The Connections Building Tool*

    How do the words and grammatical devices connect things, disconnect things or ignore connections? How does the words and grammatical devices make things relevant or irrelevant to other things?

20. *The Cohesion Tool*

    How does cohesion work to connect pieces of information and in what ways? How does the text fail to connect pieces of information?

21. *The Sign Systems and Knowledge Building Tool*

    How do the words and grammar privilege or de-privilege specific sign systems (e.g. Spanish vs. English) or different ways of knowing and believing?

22. *The Topic Flow or Topic Chaining Tool*

    What are the topics of all main clauses and how do these topics link to each other to create a chain that creates an overall topic? How have people signaled that they are switching topics?

23. *The Situated Meaning Tool*

    What specific meaning to listeners have to attribute to these words and phrases given the context and how the context is construed?

24. *The Social Languages Tool*

    How are words and grammatical structures used to signal and enact social language?

25. *The Intertexuality Tool*

    Ask how words and grammatical structures…are used to quote, refer to, or allude to other 'texts'.

26. *The Figured Worlds Tool*

    What typical stories or figured worlds do the words and phrases of the communication assume and invite listeners to assume? What participants, activities, people, objects, and institutions are in these figured worlds?

27. *The Big "D" Discourse Tool*

    How is the person using language, believing, valuing, various objects, tools, etc. to enact a specific socially recognizable identity and engage in one or more socially recognizable

activities? What Discourse is the language part of? What kind of person is this speaker or writer seeking to be recognized as?

APPENDIX D. IRB APPROVAL

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	GEORGE BODNER WTHR 216G
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	06/28/2016
Committee Action:	**Expedited Approval - Category**(6) (7)
IRB Approval Date	06/28/2016
IRB Protocol #	1606017883
Study Title	Student Discourse in Undergraduate Research Experiences - Phase 2
Expiration Date	06/27/2017
Subjects Approved:	40

The above-referenced protocol has been approved by the Purdue IRB. This approval permits the recruitment of subjects up to the number indicated on the application and the conduct of the research as it is approved.

The IRB approved and dated consent, assent, and information form(s) for this protocol are in the Attachments section of this protocol in CoeusLite. Subjects who sign a consent form must be given a signed copy to take home with them. Information forms should not be signed.

Record Keeping: The PI is responsible for keeping all regulated documents, including IRB correspondence such as this letter, approved study documents, and signed consent forms for at least three (3) years following protocol closure for audit purposes. Documents regulated by HIPAA, such as Authorizations, must be maintained for six (6) years. If the PI leaves Purdue during this time, a copy of the regulatory file must be left with a designated records custodian, and the identity of this custodian must be communicated to the IRB.

Change of Institutions: If the PI leaves Purdue, the study must be closed or the PI must be replaced on the study through the Amendment process. If the PI wants to transfer the study to another institution, please contact the IRB to make arrangements for the transfer.

Changes to the approved protocol: A change to any aspect of this protocol must be approved by the IRB before it is implemented, except when necessary to eliminate apparent immediate hazards to the subject. In such situations, the IRB should be notified immediately. To request a change, submit an Amendment to the IRB through CoeusLite.

Continuing Review/Study Closure: No human subject research may be conducted without IRB approval. IRB approval for this study expires on the expiration date set out above. The study must be close or re-reviewed (aka continuing review) and approved by the IRB before the expiration date passes. Both Continuing Review and Closure may be requested through CoeusLite.

Unanticipated Problems/Adverse Events: Unanticipated problems involving risks to subjects or others, serious adverse events, and serious noncompliance with the approved protocol must be reported to the IRB immediately through CoeusLite. All other adverse events and minor protocol deviations should be reported at the time of Continuing Review.

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:	05/23/2017
Committee Action:	**Expedited Approval for Renewal - Category**(6) (7)
IRB Approval Date	05/23/2017
IRB Protocol #	1606017883
Renewal Version	Renewal-001: Renewal-001:
Study Title	Student Discourse in Undergraduate Research Experiences - Phase 2
Expiration Date	05/22/2018
Subjects Approved:	40

The above-referenced protocol has been approved by the Purdue IRB. This approval permits the recruitment of subjects up to the number indicated on the application and the conduct of the research as it is approved.

The IRB approved and dated consent, assent, and information form(s) for this protocol are in the Attachments section of this protocol in CoeusLite. Subjects who sign a consent form must be given a signed copy to take home with them. Information forms should not be signed.

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Change of Institutions: If the PI leaves Purdue, the study must be closed or the PI must be replaced on the study through the Amendment process. If the PI wants to transfer the study to another institution, please contact the IRB to make arrangements for the transfer.

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APPENDIX E. MENTOR CONSENT FORM

RESEARCH PARTICIPANT CONSENT FORM

Student Discourse in Undergraduate Research Experiences

Principle Investigator: George M. Bodner
Co-Investigator: Sara L. Johnson
Department of Chemistry
Purdue University

What is the purpose of this study?

The purpose of this study is to investigate the communication practices of undergraduate students participating in research in science laboratories. Because of the nature of communication, investigation of these practices involves observation of and interview about the discussions that occur between undergraduate students and those individuals in mentor roles. I am asking you to participate in this research because of your role as a **mentor** in a research laboratory. For this project, I am hoping to recruit a minimum of 20 student/mentor pairs for participation.

What will I do if I choose to be in this study?

By choosing to participate in this study, you are agreeing to be observed and audio recorded during laboratory interactions with your undergraduate student. Additionally, you are agreeing to participate in audio-recorded interviews with the co-investigator, Sara L. Johnson. Observations will be conducted in your working space in two-hour increments, a maximum of five times per week. The co-investigator will take field notes while making observations; an audio recorder will be used to record all student-conversations. One additional day of the week, your student will be asked to wear an audio recorder while they interact with you. You will be asked to participate in a minimum of two interviews, at the beginning and end of your participation. These interviews will last about 45 minutes and will be audio recorded. You may be asked to participate in an additional three interviews. All scheduling will be based on your availability.

How long will I be in the study?

Participation in this study will last for approximately six months.

What are the possible risks or discomforts?

The risks posed by this study are no greater than the risk you experience in everyday life.

Are there any potential benefits?

There are no direct benefits to participating in this study. You may find that participation in this study provides the benefit of taking a closer look at your own research, communication and mentoring practices. Participation is anticipated to benefit general knowledge about undergraduate students' research experiences.

Will information about me and my participation be kept confidential?

All personal information is strictly confidential, and no names will be disclosed. All audio recordings will be transcribed, de-identified and coded at a later date. All data collected (audio recordings, transcriptions, field notes and interview notes) will remain confidential. 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 research records will be destroyed after completion of analysis and the end of the research project. The project's research records may be reviewed by departments at Purdue University responsible for regulatory and research oversight. 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 study?

If you have questions, comments or concerns about this research project, you should direct these to the co-investigator, Sara L. Johnson, at john1121@purdue.edu. You may also contact George M. Bodner, the research advisor, with questions at gmbodner@purdue.edu. This project and consent form have been reviewed by the Human Research Protection Program, which ensures that research projects involving human subjects follow federal regulations.

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

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

_____ _____

Participant's Signature D ate

_____

Participant's Name

_____ _____

Researcher's Signature D ate

APPENDIX F. STUDENT CONSENT FORM

RESEARCH PARTICIPANT CONSENT FORM

Student Discourse in Undergraduate Research Experiences

Principle Investigator: George M. Bodner
Co-Investigator: Sara L. Johnson
Department of Chemistry
Purdue University

What is the purpose of this study?

The purpose of this study is to investigate the communication practices of undergraduate students participating in research in science laboratories. Because of the nature of communication, investigation of these practices involves observation of and interview about the discussions that occur between undergraduate students and those individuals in mentor roles. I am asking you to participate in this research because of your role as a **student** in a research laboratory. For this project, I am hoping to recruit a minimum of 20 student/mentor pairs for participation.

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How long will I be in the study?

Participation in this study will last for approximately six months.

What are the possible risks or discomforts?

The risks posed by this study are no greater than the risk you experience in everyday life.

Are there any potential benefits?

There are no direct benefits to participating in this study. You may find that participation in this study provides the benefit of taking a closer look at your own research and communication practices. Participation is anticipated to benefit general knowledge about undergraduate students' research experiences.

Will information about me and my participation be kept confidential?

All personal information is strictly confidential, and no names will be disclosed. All audio recordings will be transcribed, de-identified and coded at a later date. All data collected (audio recordings, transcriptions, field notes and interview notes) will remain confidential. 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 research records will be destroyed after completion of analysis and the end of the research project. The project's research records may be reviewed by departments at Purdue University responsible for regulatory and research oversight. Any new information that develops during the project will be provided if that information may affect your willingness to continue participation in the project.

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_____ _____

Participant's Signature D ate

_____

Participant's Name

_____ _____

Researcher's Signature D ate

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VITA

Sara Lorraine Johnson was born in Waynesboro, Mississippi. She attended the Mississippi School for Mathematics and Science before moving to Hattiesburg, MS to earn her Bachelor's degree in Chemistry at the University of Southern Mississippi (USM). She moved to New Orleans after college to laissez les bons temps rouler, but found she grew tired of life in The Big Easy. She happily returned to Hattiesburg, MS to get her masters in Science Education and eventually become an instructor in the Department of Chemistry and Biochemistry at USM. In 2012, against the advice of every southern, snow-fearing person she knew, she decided to move to West Lafayette, IN and pursue her doctorate in Chemistry at Purdue University. She survived five Indiana winters before deciding to make her way back south after graduation. She is now a faculty member in the Department of Chemistry and Industrial Hygiene at the University of North Alabama in Florence, AL.

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Student Understanding of the Secondary Structure of Proteins Revealed by Instruction with a Physical Model

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Richard C. Garratt is the co-creator of *Protein Folder*, the physical model kit used for this project. *Protein Folder* is not currently being marketed; therefore, we declare no conflict of interest. The authors' inclusion of *Protein Folder* in this work is not intended to promote the model kit over the exclusion of similar physical model kits.

Abstract:

There is a dearth of educational research reported on student difficulties with protein structure, despite this area being a major focus of biochemistry teaching and research. Physical models, like other external representations, are commonly used to help students visualize aspects of protein structure but little is known about how useful they are for revealing evidence of student understanding and difficulties in this area. In this study, we investigated how students reason about, and visualize, certain properties of protein structure when using a physical model kit, *Protein Folder*. The study focused on 26 upper-level students enrolled in a Protein Structure and Function course, which made use of representations to teach about protein structure. Qualitative data were collected from class assessment materials and interviews. Analysis of students' physical models revealed students displayed four major types of errors when building models, including errors in the: twist, connectivity, topology, and directionality of their protein models. Classification of these difficulties and interview data using the Concept-Reasoning-Mode (CRM) model revealed student difficulties reasoning both with concepts and the physical model kit, *Protein Folder*. Findings from this work have implications for future research investigating the sources of students' reasoning difficulties with the secondary structure of proteins and additional scientific fields that make use of external representations to teach topics of interest.

INTRODUCTION

Students encounter many challenges when learning about the structures of proteins in the biochemistry classroom. One challenge is gaining a clear understanding of the relevant key concepts and principles. Another challenge is gaining the representational competence needed to decode, visualize and interpret external representations (ERs) of proteins (Schönborn and Anderson, 2010). ERs are visible representations that can be shared between people; they are distinct from internal representations, or mental models, which only exist within the mind's eye (Johnson-Laird, 1980; Seel, 2003; Gilbert, 2005; Jonassen *et al.*, 2005). Learners and scientists use ERs to construct knowledge, communicate and integrate scientific concepts, express and assess understanding, and participate in a community of knowledge builders (Kozma *et al.*, 2000; Treagust *et al.*, 2002). As such, ERs are useful for participating in the practice of modeling. Consequently, representational competence is an integral component of model-based reasoning (Harrison and Treagust, 2000; Justi and Gilbert, 2002; Van Meter and Garner, 2005; Nersessian, 2009, Quillin and Thomas, 2015).

The American Society for Biochemistry and Molecular Biology (ASBMB) includes both modeling and communicating with visual tools in its list of skills undergraduate students should have when graduating from biochemistry or molecular biology programs (White *et al.,* 2013). This consensus list, developed through focused workshops with biochemistry and molecular biology educators, demonstrates the importance educators place on students' abilities to work with ERs. While identifying threshold concepts for biochemistry, which transform a student's understanding and must be mastered to continue progress in the field, Loertscher *et al.* (2014) concluded that visual literacy skills are relevant to all threshold concepts, thus bolstering the importance of representational competence to biochemistry. Two threshold concepts Loertscher

et al. (2014) identified were the physical basis of interactions and the thermodynamics of macromolecular structure formation. These concepts play a particularly important role in helping students understand the principles that govern the structures of proteins. Therefore, one way we can investigate students' progress in these biochemistry concepts is through investigation of their visual skill development within the context of protein structure.

Although a range of reports exist on student difficulties in biochemistry (e.g., Orgill and Sutherland, 2008; Bretz and Linenberger, 2012; Offerdahl and Montplasir, 2014), limited research has been published about student difficulties with protein structure. Even fewer have chosen to include ERs as a component of their focus on student understanding. Reports focusing on conceptual and visual difficulties with protein structure primarily include works by Harle and Towns (2012a, 2012b, 2013) who investigated student understanding of protein structure within the context of the potassium ion channel. These works place a heavy emphasis on ERs and highlight the key role ERs play in student understanding of protein structure (Harle and Towns, 2013). However, more work is needed to fully understand the relationship between students' understandings of protein structure concepts and their use of ERs.

The focus of protein visualization research has been largely on three areas: (1) the development, use and effectiveness of computer visualization software (e.g. Craig *et al.*, 2013; Canning and Cox, 2001; Rudnitskaya *et al.*, 2010); (2) the development, use and effectiveness of physical models (e.g. Hageman, 2010; Herman *et al.*, 2006; Pikaart, 2011); and (3) the comparison of the effectiveness of various visualization teaching tools (e.g. Abraham *et al.*, 2010; Barak and Hussein-Farraj, 2013; Roberts *et al.*, 2005). Such works demonstrate the power educators see in ERs as tools for helping students visualize proteins. They also indicate a strong interest by educators in the use of a variety of ERs for teaching. Nevertheless, there has been a

dearth of research studies into how to incorporate molecular visualization into the classroom in the most effective manner; how to assess student understanding and related conceptual, reasoning, and visual difficulties; and how to evaluate teaching approaches in this area (Craig *et al.*, 2013). In particular, few researchers have focused on the development of classroom activities that use physical models to teach about protein structure (Hageman, 2010; Herman *et al.*, 2006; Pikaart, 2011). Activities currently reported use models of varying complexity, from simple paper (Pikaart, 2011) to detailed structures created through 3D printing techniques (Herman *et al.*, 2006). But, as with visualization software activities, researchers mainly provide anecdotal evidence. Participating students have a positive attitude toward the inclusion of physical models in biochemistry curricula, but limited data exists on the nature of student understanding and difficulties revealed by such tools.

In this paper, we address the above-described gap in our knowledge by presenting students' conceptual and visual reasoning with the secondary structure of proteins and physical models. This is a portion of a larger project focusing on students' reasoning with all levels of protein structure, revealed through the use of a protein structure physical model kit, *Protein Folder* (Garratt *et al.*, 2005). We intend this work to explore some of the concepts and topics we see as directly related to the core concept "Macromolecular Structure and Function" identified by the ASBMB as essential to biochemistry and molecular biology students and the threshold concepts "physical basis of interactions" and "thermodynamics of macromolecular structure formation" identified by Loertscher and colleagues (Tansey *et al.,* 2013; Loertscher *et al.*, 2014). Likewise, because we agree with the stance held by Loertscher *et al.* (2014) concerning the relevance of visual skills to all biochemical concepts, we intend this work to investigate such skills within the context of physical model ERs. In light of these goals, we chose to view these

student experiences through the lens of the Concept-Reasoning-Mode (CRM) model (Schönborn and Anderson, 2009; Anderson *et al.*, 2013) because of its clear alignment with our own interest in students' abilities to reason with both the concepts of protein structure and the ERs used to represent those concepts. This model provided focus and structure to our analysis.

The CRM model proposes three main factors that influence a student's ability to interpret and learn from ERs: the conceptual factor (C), reasoning factor (R) and mode factor (M). In addition, these three factors interact with one another, creating a total of seven factors that influence a student's ability to learn from an ER (Schönborn and Anderson, 2009; Anderson *et al.*, 2013). Thus to learn from an ER, a student must make use of their own conceptual knowledge (RC) and use various visualization skills to interpret and make sense of the ER (RM), while also being influenced by the nature and mode of the ER (M).

We used the CRM model, and the approach described in Anderson *et al*. (2013), to classify specific difficulties, and their potential sources, that students encounter when using a physical model to learn about the secondary structure of proteins. The CRM model guided our initial classification of students' reasoning difficulties into RC and RM categories. Additionally, the model helped us identify and consider the potential sources of difficulties, which allowed for more specific identification of novel research paths.

Research Questions

The goal of this study was to gain greater insight into the nature of student understanding and difficulties related to the secondary structure of proteins. In addition, we hoped to obtain a better understanding of students' visual literacy and competence to use physical models to learn about protein structure. Towards this end we addressed the following research questions:

1. What difficulties do students display when using a physical model kit to learn about the secondary structure of proteins in a biochemistry classroom?
2. What claims about the nature and source of students' difficulties can be made using the CRM model?

METHODS

Context and Study Participants

We conducted this study at a South African university. The sample population included 26 consenting student participants from a semester-long undergraduate biochemistry course on protein structure and function. The course was designed for biochemistry majors in their 3rd year; however, it was open to enrollment by other upper-division students in science majors at the university. The course was taught by one of the authors (TA), except during the two weeks of this project when the second author (RG), the designer of *Protein Folder* (Garratt *et al.*, 2005), guest lectured.

Study Design and Data Collection Instruments

We conducted this study over a two-week period. Students received five lectures on topics and concepts considered relevant to protein structure by both the instructor (TA) and guest lecturer (RG). We focused on topics and concepts related to all levels of protein structure, including, but not limited to: chirality, connectivity, dimension and size, fold classification, geometrical packing, molecular recognition and function, representations, structural hierarchy, structural stability, symmetry, topology, and torsion. These specific topics were chosen by the instructor (TA) and lecturer (RG) based on their expertise in the area of protein structure and representation of the structures of proteins.

During the course, we made extensive use of ERs to demonstrate and explain the topics and concepts. ERs included *Protein Folder* physical models, ball-and-stick physical models, and a variety of diagrams (e.g. Ramachandran plots, ribbon diagrams, space filling diagrams). We used these and additional ERs to help communicate to students the fundamental concepts of protein structure. See Appendix A for more instructional details. We collected data in the classroom in the form of quizzes and worksheets that included model building activities (Appendix A).

Over the course of two weeks, students received five one-hour lectures on the topic of protein structure and the visualization tool *Protein Folder*. Students participated in two three-hour tutorials during which they worked in small groups (2 - 4 students) to complete worksheets on the topic of protein structure. Worksheet questions required students to become familiar with the *Protein Folder* modeling kit. The tasks required students to understand the symbolism of *Protein Folder*, the topics and concepts focused on by TA and RG, as well as how to use *Protein Folder* to build physical models of an NAD^+ binding domain from 2D diagrams. We also supplied students with the *Protein Chart* (Garratt and Orengo, 2008), a 2D visual guide to 3D protein structure, and allowed them to refer to it as needed throughout the class. The instructor (TA), guest lecturer (RG) and student demonstrators (i.e. teaching assistants) were present to address students' concerns and to aid students in the use of *Protein Folder.* We saved copies of students' worksheets and quizzes in digital format, along with digital stills of physical models built by students at two points during the building process.

After completing the two-week unit, seven students participated in 30-minute clinical interviews. We selected student volunteers who represented the full spectrum of performance and observed understanding of protein structure as demonstrated in their class performance. We

approached the interviews using the three-phrase single interview technique (3P-SIT) to elucidate student reasoning and conceptual understanding (Schönborn and Anderson, 2009; Schönborn *et al*., 2007). In brief, this technique allowed us to investigate students' abilities to interpret and reason with *Protein Folder*. We transcribed each audio-recorded interview in preparation for analysis. Before analysis, we de-identified and applied pseudonyms to all written and interview data to ensure the confidentiality of our participants.

Protein Structure Representations

The primary ER used during our two-week lesson was *Protein Folder*, a physical modeling kit developed for teaching about protein 3D structure (Garratt *et al.*, 2005). It is based on Richardson´s (1981) schematic representation of secondary structures using simple geometrical shapes. As detailed in Table 1, the modeling kit is composed of various plastic units designed to represent the key components of α-helices and β conformations of secondary structure. Pieces can be combined quickly and with ease in a variety of ways to represent such structures. This predictable and adaptable nature makes *Protein Folder* useful as a representational teaching tool in the classroom.

The CRM model asserts that the nature of an ER's mode (M) limits the quality and use of the representation (Schönborn and Anderson, 2006). We consider this to also hold true in the case of our physical model. Therefore, we outline in Table 1 how the plastic components were intentionally designed to represent certain aspects of secondary structure (e.g., β strands; hydrogen bonds; amino- and carboxyl-termini), while not depicting others (e.g., primary structure; amino acid side chains; polypeptide backbone). Table 1 provides a brief list of the components, their uses, and several limitations of *Protein Folder* as a representational tool. We

provide this table to help readers in their decoding of *Protein Folder* physical models in the provided data analysis and findings.

[Insert Table 1 about here]

In the present project, the instructors took steps in their teaching and during tutorials to ensure that students became familiar with all the concepts represented by both *Protein Folder* and any additional ERs used. This included gaining an appreciation for limitations and avoiding any potential confusing nature of the symbolism (Schönborn and Anderson, 2006).

Data Analysis

We analyzed and coded student responses using a multiphase approach informed by the list of protein structure concepts and topics identified by the instructor (RG) and the CRM model. RG first scored students' NAD^+ binding domain physical models and responses on worksheets and quizzes for accuracy. After scoring, we identified emergent themes based on the frequency of common student errors in the physical models. We used our initial list of protein structure concepts to guide naming these emergent categories. From these codes, we generated a list of concepts and topics related to the structures of proteins and protein models with which our students demonstrated difficulties reasoning.

We coded interview responses using a deductive approach. We identified and coded excerpts that related to the emergent themes observed in students' physical models (Creswell, 2013; Patton, 2002). We then applied a second code to our selected data using the CRM model to investigate the potential sources of students' difficulties (Schönborn and Anderson, 2009; Anderson *et al.*, 2013). We looked for evidence of poor- and well-developed student reasoning with protein structure concepts (RC) and reasoning with the mode (RM) of representation (i.e. *Protein Folder*). Questions and students' responses were coded first at the coarse-grain level as

either requiring or containing reasoning with concepts (RC), reasoning with representations (RM) or both. We then proceeded with fine-grain coding using the selected reasoning abilities central to expert visual literacy in biochemistry provided by Anderson *et al.* (2010).

[Insert Table 2 about here]

We triangulated data and used peer debriefing to ensure our findings represented accurate interpretations of participants' understandings (Creswell, 2009). The concepts, topics and reasoning difficulties presented herein are those appearing in both students' physical models and interviews. We excluded those observed only in student written work or only in physical models and where lack of interview data prevented our confidence in some findings. The choice of findings we present here were guided by the data and our decision, in this work, to focus on students' understanding of the secondary structure of proteins. They are a small portion selected from a larger pool of observed difficulties for their prominence, clarity and our confidence in their existence. We will use the findings from those concepts, topics and reasoning difficulties not meeting our exclusion criteria to inform future research on students' understanding of protein structure.

FINDINGS

Students' physical models of a generic NAD^+ binding domain exhibited four major types of errors. These included errors in the (a) twist, (b) connectivity, (c) topology, and (d) chain direction of their protein. We identified and documented the twist of students' protein models after they completed the first step in the building activity. All other errors were identified and documented after students had completed the model building activity. Each category below includes frequencies of students' errors with examples of both correct and incorrect student-built models. We used student-built generic NAD^+ binding domain models to guide our interviews on

the structure of proteins and *Protein Folder*. We include within each category examples from the data of students' reasoning about their errors in interview, accompanied by descriptions and CRM model analysis. These different errors relate to one another, such that some examples include multiple errors while others do not.

Twist

Of the 13 groups, four (eight students) successfully built β-sheets with the left-handed twist which results from standard L-amino acids. Five student groups (ten students) built β-sheets with an opposite twist and an additional four groups (eight students) built β-sheet structures containing either no or a mixture of both twists. We organized student groups into three categories: no twist, incorrect twist and correct twist (Figure 1).

[Insert Figure 1 about here]

We asked Vuyie, a student whose group built their β-sheet with incorrect twist, to further explore the topic of β-sheet twist by revisiting her model.

Interviewer: *When you started to build [your model], what was the first thing you did?*

Vuyie: *Ok. The first thing, I just connected the β-strands then twisted them clockwise.*

Interviewer: *Ok. Can you…do that for me?*

Vuyie's description of her actions aligned with those she was taught about building β-sheets with appropriate twist, although her model did not. To clarify her understanding, the interviewer provided Vuyie with a flat β-sheet and asked her to explain in detail and demonstrate how to build a β-sheet and determine its twist.

Vuyie: *Firstly, when you look at it, it should point that way. (Vuyie turns the model so that she is looking perpendicular to the direction of the β-strands) This strand is the one that is close to me, so I must twist the following one clockwise, and the following one*

clockwise, and clockwise again. Then the strand is gonna be like this. (Vuyie twists the strands we she talks)

Interviewer: *Ok. What's the handedness of that strand?*

Vuyie: *It's left-handed.*

Interviewer: *Left-handed?*

Vuyie: *I mean right-handed.*

Interviewer: *Ok. I'm going to…make it flat again and now I'm gonna ask you to do it the other way…what would you do if you were to look at the other way?*

The interviewer flattens the model and hands it to Vuyie so that the β-strand that was originally closest to her is now furthest away.

Vuyie: *I would do it anticlockwise.*

Interviewer: *You're gonna rotate it the other way around? Do it for me so that I can see you do it. Is that right?*

Vuyie: *(Vuyie begins manipulating the model) No, I don't think it's right.*

Interviewer: *So, what do you conclude about whether it matters if you look one way or the other way?*

Vuyie: *It doesn't matter whether it's going that way or towards me as long as the second strand is twisted clockwise…from the strand that is closest to me.*

When Vuyie spoke about her model during interview, she initially chose to not pick up or handle her model; she appeared hesitant about reasoning with her model (RM). After encouragement from the interviewer, Vuyie did handle the provided models. However, she needed this encouragement on multiple occasions, as she would again revert back to explaining in words alone. Although the words Vuyie used were correct, in the case of explaining how to

twist a β-sheet, it was through her handling of the model that she learned that the twist of a β-sheet remained the same regardless of the direction of viewing.

At a later point in the interview, we asked Vuyie why β-sheets tend to twist rather than stay flat. She readily answered, "[twists are] caused by the side chains of the amino acids, so when they are on top of each other, they must be sterically hindered." Vuyie answered with a correct but incomplete answer; she did not pick up or use the provided models in any way for her explanation, despite their availability. We considered her response to demonstrate her confidence in reasoning with the concepts (RC), and again her reticence in reasoning with *Protein Folder* (RM).

Connectivity

Two students groups (four students) built models containing all right-handed (correct) connections. The NAD^+ binding domain was built with at least one left-handed connection by 11 groups (22 students). Of these 11 groups, two groups (four students) built models containing only left-handed (incorrect) connections. These left-handed connections resulted in mirror-image protein models. We organized student groups into two categories: incorrect and correct connectivity (Figure 2).

[Insert Figure 2 about here]

We revisited Nkosinathi's group's NAD^+ binding domain and asked him to make observations about the accuracy of the model. Nkosinathi's group originally built their model with only left-handed (incorrect) connections, resulting in a mirror-image protein model.

> ***Interviewer:*** *Let me ask you to look specifically at connections. Okay. Let's look at the connections between this strand here and the one at the back…what can you tell me about that connection?*

Nkosinathi: *Which one?*

Interviewer: *Okay…this α-helix and this β-sheet (the Interviewer points to specific parts of the model) Big sheet strand here, two strands and one helix. What about that connection, what kind of chirality does it have, for example?*

Nkosinathi: *(Silent for a while) It's left-handed.*

Nkosinathi correctly identified the connections in his model as left-handed and then changes his mind.

Interviewer: *Are you sure?*

Nkosinathi: *No, it's right-handed. I think we made a mistake by the connections, because like here I can't see.*

Interviewer: *What chirality should it have?*

Nkosinathi: *A right-handed chirality.*

Interviewer: *How do you look at it in order to decide if it's left or right? Use your finger; you know you could point if you want to.*

Nkosinathi: *These two are supposed to be in the same direction I guess. You look at the beginning where the proteins start to fold. In this case, you start looking here, it folds, I think the problem is here because this one is pointing the other way.*

Although Nkosinathi's model contained exclusively left-handed connections, he answered confidently that the connections should be right-handed. We considered his confidence and accuracy to initially indicate his abilities to reason with concept of connectivity (RC). However, when Nkosinathi identified the connections in his group's NAD^+ binding domain, he was uncertain and, ultimately, wrong. Nkosinathi did not pick up or handle his model (RM), until

the interviewer encouraged him. Furthermore, he failed to identify the repeating connectivity-error in his model that resulted in a mirror-image protein.

Topology

Of the 13 NAD^+ binding domain physical models built, 11 groups (22 students) built physical models with topology similar to that assigned; two groups (four students) built models with incorrect topology. We organized these students into two categories: correct and incorrect topology (Figure 3).

[Insert Figure 3 about here]

While two groups generated NAD^+ binding domains with incorrect topology, these two groups' structures varied significantly. One group built an NAD^+ binding domain whose N- and C-termini were on opposite ends of the structure. That is, they connected pieces of their physical model in a row as if the linear sequence mirrored the spatial sequence. The second group with incorrect topology built an NAD^+ binding domain with more complicated errors. This group's structure contained internal closed loops and chains with conflicting chain orientation (more below).

We interviewed Thembi to further investigate her understanding of protein topology. Thembi's group built a model with internal closed loops, conflicting chain directionality and incorrect topology. We asked her to revisit her group's model and reflect on its accuracy.

Interviewer: *This is one of your models…what can you tell me about that?*

Thembi: *It's…wrong, because I'm looking at the loops from the upper helices to the β-strand. I think that there is a cross-connection which I don't think should be there.*

Interviewer: *Can you point to it?*

Thembi: *There. (Thembi points to an internal loop in her model)*

Although Thembi identified the internal loop in her model, she did not discuss the effects this error had on the topology of her NAD^+ binding domains. The interviewer probed deeper and guided Thembi through her model.

Interviewer: *Let's look at the following part of the structure. Here you have a β-strand connected to this helix…then it goes up the back there and joins that strand at the back. Look at the part of the structure and tell me what you think about it.*

Thembi: *Mmm. I can't see clearly, here it's joining the other strand?*

Interviewer: *It starts on this one, the second strand here and then it goes round here and then it goes and joins that one at the back. (The interviewer points as he talks)*

Thembi: *Okay. Yoh.*

Interviewer: *Do you think it's correct the way it's connected up?*

Thembi: *Yeah. I'm not sure.*

Interviewer: *Ok…do you think that this connection is right-handed or left-handed?*

Thembi: *It's left-handed..because the connection goes underneath the strand connecting to the other loop. So, to be right-handed, I think it should have gone above the strand.*

Interviewer: *So when you follow the chain, are [they] going clockwise or anticlockwise?*

Thembi: *It goes in a clockwise direction.*

Interviewer: *Is that correct? Should it be clockwise?*

Thembi: *Yes, it should be clockwise, like here it goes clockwise. But, now when I'm look at this strand (she begins investigating another part of her model), the loop here goes in an opposite direction, which is wrong.*

When the interviewer began describing the locations of strands and helices, he intended to direct Thembi towards a discussion about topology. Instead, her response led towards a

discussion on connectivity, a concept related to topology. These two concepts are closely related because incorrect connectivity can result in incorrect topology. However, Thembi did not communicate knowledge of this relationship between concepts during her interview (RC).

Thembi needed initial encouragement to begin reasoning with her model, but she continued using her model to identify errors without the interviewer further prompting her (RM). During her interview, she identified errors in the connections by handling the model. Although these errors also created topological errors in her model, even with guidance, she did not identify topological errors in her NAD^+ binding domain.

Chain Directionality

In total, six groups (12 students) created physical models with arrows changing direction along the protein chain. These chain direction errors were observed in students' physical models where they united α-helices by a β-strand. We organized these students into two categories: correct and incorrect chain direction (Figure 4).

[Insert Figure 4 about here]

While some groups with errors in chain direction created NAD^+ binding domain models that were reasonably accurate, other groups with difficulties in chain direction created models with multiple, repeating errors. Thembi's group, whose physical model included errors in topology, also exhibited errors in chain direction. Four out of five α-helices in their group's NAD^+ binding domain had arrows pointing in the opposite direction to an adjoining β-strand.

When Thembi revisited her NAD^+ binding domain model, she identified these errors related to chain direction. She observed, "the α helices and the β strands, like the arrows, here an arrow to an arrow…[that's] wrong." While Thembi identified these structural errors, she made no other comments about the errors in her model's chain directionality. During Nkosinathi's

interview, the interviewer probed directly into the topic of how *Protein Folder* represented chain directionality.

Interviewer: *Does it matter which way the arrows point or not?*

Nkosinathi: *Ok. Let's say it doesn't matter. Ish. I don't know where we made a mistake here, I can't see.*

Thembi was the only student who noticed errors in the directionality of her NAD^+ binding domain model. She made this identification while manipulating and investigating her model (RM). She made no comments about what she believed the arrows represented, or any conceptual reasoning she used to identify her error. Besides Thembi, no other student identified errors in the directionality of their chains or discussed how *Protein Folder* represented chain direction.

DISCUSSION

In this study, we investigated conceptual and visual difficulties students displayed while using *Protein Folder* to learn about protein structure in a biochemistry classroom. By including *Protein Folder* in an undergraduate biochemistry course focusing on protein structure and function, we uncovered four errors students exhibited when building physical models of the generic NAD^+ binding domain. Students' models contained errors in the twist, connectivity, topology, and chain direction of their proteins. These errors related to one another, although students did not readily make these conceptual connections during interviews. With guidance, students identified their errors in twist, connectivity and chain direction. No students identified topological errors in their models.

As a representational tool, *Protein Folder* is a simplified protein model. Shown in Table 1, some components of protein structures were intentionally not included in an effort to simplify

the representation (e.g. amino acid side chains). These simplifications were made both for the user and out of necessity; it would be impossible to represent all aspects of protein structure in one representation. However, the benefits of simplicity versus complexity are still unclear with current work surprisingly suggesting that complexity may be better in certain contexts (Jenkinson and McGill, 2012). Some of the difficulties presented in this work can be explained by the absence of key structural features from the physical model due to simplification. Perhaps the inclusion of additional visual cues would have allowed students to detect topological errors in their protein structure models. With this in mind, further work is needed to investigate whether the inclusion of these features, which would increase the complexity of the model, could help students with less representational competence to build more accurate physical models.

We explored the use of the CRM model by Anderson *et al*. (2013) to classify these difficulties and identify their potential sources as relating to either reasoning with concepts (RC) or reasoning with models (RM). We determined these difficulties to relate both to difficulties reasoning with the concepts (RC) of protein structure and reasoning with the mode (RM) of representation used in teaching about protein structure (i.e. *Protein Folder* physical models). The nature of our data prevented further fine-grain classification with the CRM model (Table 2). Nevertheless, we believe the CRM model did help us think about our data in informative ways, as demonstrated below.

When investigating their own models, students rarely made statements connecting errors to either the concepts of protein structure (RC) or their physical models (RM). Students, like Vuyie and Nkosinathi, often used the correct words while describing their errors, leading us to initially believe they had mindfully memorized the concepts with which they were reasoning (Table 2). However, as we explored their understanding of these words through interview with

models, we found their knowledge was incomplete and fragmented. Because they were novices, we were not surprised by the fragmented nature of their knowledge (diSessa, 2004). These findings echo previous work by Harle and Towns (2012b, 2013) on students' understanding of the secondary structures of proteins through 2D ERs. The fragmented nature of their understanding of the secondary structure of proteins did prevent us from further classifying their ability to reason with the concepts of protein structure. Without a sound understanding of the basic concepts, we found only two students who could participate in types of reasoning (Table 2) requiring higher cognitive load (Bloom, 1956; Anderson et al., 2001). These two students were able to integrate concepts to construct explanations (Table 2). However, these cases were not relevant to the secondary structure of proteins and, thus, not included here.

When we began looking at interviews from the perspective of students' abilities to reason with models, we first observed that few students chose to reason with their models (RM) without encouragement from the interviewer. Students like Vuyie required multiple prompts by the interviewer to pick up or handle models in any way. Other students like Thembi continued reasoning with their model after only one suggestion by the interviewer. No students began their explanations by handling their models, despite their participation in approximately six hours of worksheets focusing on *Protein Folder*. We found this reticence to align with previous work on students' use of physical models in organic chemistry by Stull *et al.* (2012), suggesting its source may not be conceptual but mode-specific. Further work is needed to explore if students' apprehensions were due to the nature of physical models as a class ERs, or if these observations are generalizable to all types of ERs.

As expected, when students handled and reasoned with their models, we found they also identified more of their own errors. By handling her model, Thembi identified her errors in

connectivity, although she was not able to see her topological errors. However, we believe our data suggests the most benefit came not from general handling, but from specific types of spatial manipulation (Table 2) suggested by the interviewer. Students who were guided to make physical changes to their models, to demonstrate and explore as they explained, appeared to gain more benefit than those who did not. For Vuyie, changing the provided models allowed her to not only identify her errors, but also prove herself wrong. By using the model to work through her explanation, she uncovered new understanding about the twist of β-sheets. This tactile advantage aligns with previous work on students' use of physical models in organic chemistry (Stull *et al.,* 2012). However, further exploration is needed into the nature of these experiences and their specific advantage. It may be that physical models alone do not help students so much as the experience of guided exploration of the ER with an expert. We believe such work would have implications for those who claim physical models, or any ERs, have innate benefits in the classroom.

CONCLUSION

This work provides a clearer picture of students' understanding of secondary protein structure and one type of physical model used to communicate about related concepts. Likewise, the findings and limitations have implications for future research in these areas. We see this work as adding support to the potential usefulness of ER construction for revealing student understanding (e.g. Harle and Towns, 2013). At the same time, we acknowledge our findings may be conflated by the known benefits of expert guidance. Regardless, we believe our work does add weight to the argument for students to revisit their constructed ERs. In interviews, revisiting ERs provided students an opportunity to reflect back on their previous understanding; transcripts indicated that this experience helped scaffold some students to a better understanding

of secondary protein structure and ERs (Vygotsky, 1978). Revisiting also allowed students to self-assess and practice metacognition. However, we again emphasize that this revisiting occurred in the presence of an expert. Further research is needed to explore whether similar results could occur with less guidance or in a classroom setting.

Finally, we found our ability to parse out students' RC and RM difficulties to be limited by the data collection methods. While we were able to narrow the list of potential difficulties from those proposed in the CRM model, we found in many cases that it was impossible to identify individual sources (Schönborn and Anderson, 2009; Anderson *et al.*, 2013). From our work, we determined student construction of an ER to require multiple skills and abilities. Likewise, the inability to construct an ER can be explained by one or a combination of those same skills and abilities. Further isolation and identification of students' difficulties working with protein ERs is needed. To complete such analyses, alternative data collection methods may need to be created or appropriated. We see task-specific interview protocols similar to those by Stieff (2011) as a promising future for this fine grain analysis of students' difficulties.

The importance of representational competence is gaining recognition from biochemists and biochemistry educators alike (White *et al.,* 2013, Loertscher *et al.,* 2014). Such increased focus requires curricular changes that support these goals. In this study, we made explicit attempts in the curriculum to explain the ERs used in both class lectures and assessments. This included consistently highlighting the components of ERs and explaining their uses and limitations during the two-week period. Nevertheless, our students continued to display a variety of difficulties when working with protein ERs. Furthermore, during interviews, they still appeared hesitant to work with models without guidance. As educators, we are concerned by the persistent nature of these difficulties with concepts and physical models. While we believe

instructors should be explicit in their use of ERs, we also see that this work suggests even stronger efforts are needed to give students support. Reasoning with physical models does present students with educational advantages, but one of the largest challenges is students' willingness to participate in these types of reasoning. Thus, we recommend the development of curricula that not only introduces and uses ERs in the classroom, but also explores novel ways educators can provide continuous support and encouragement to students. We see this development of representational confidence as a key component in the development of students' representational competence and skills in mode-based reasoning.

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Figure 1. Student groups built β-sheets with no (L), incorrect right-handed (M) and correct left-handed (R) twists.

Figure 2. Student built protein structures with incorrect (L) and correct (R) connectivity.

Figure 3. Student built protein structure with incorrect (L) and correct (R) topology.

Figure 4. Student built protein structures with incorrect (L) and correct (R) chain direction.