UNDERSTANDING THE NATURE OF MENTORING RELATIONSHIPS DURING AN UNDERGRADUATE RESEARCH EXPERIENCE

by

Bethany Anne Butson Crowell

A Thesis

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Doctor of Philosophy

Department of Educational Studies

West Lafayette, Indiana

August 2021

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. Ala Samarapungavan, Chair

Department of Educational Studies

Dr. Audeen Fentiman

Department of Engineering Education

Dr. Nielsen Pereira

Department of Educational Studies

Dr. Aman Yadav

Michigan State University

Dr. Mike Yough

Oklahoma State University

Approved by:

Dr. Ayşe Çiftçi

It is hard to start writing this dedication without my eyes filling with tears. I am proud of myself for my resolve and persistence in making my dream come true.

This accomplishment is the culmination of years of hard work and is dedicated to my family. Thank you to my parents and siblings for being my foundation.

This accomplishment is also for my children, Sterling and Hazel. You probably will not remember the Sundays you spent with Daddy while I worked on this project, but I hope as you grow older you understand that you can do anything, and everything, you set your mind to.

And finally, this accomplishment is for my husband, Gunnar. Thank you for listening, thank you for helping with the kids, and thank you for supporting this dream. I love you, I appreciate you, and I am blessed to have you as my partner in life.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Ala Samarapungavan, for her continued support over the last nine years. Ala guided me every step of the way and held me to a high standard of excellence from start to finish. On a personal level, she was always understanding of life events including my move across the country, starting a new job, getting married, and having two children. Ala kept me on track but also provided flexibility so that I would not have to sacrifice my educational goals for my professional and personal goals. I will be forever proud of this accomplishment and grateful for her help in making this dream a reality. I would also like to thank my committee members for sticking with me on this journey: Dr. Audeen Fentiman, Dr. Nielsen Pereira, Dr. Aman Yadav, and Dr. Mike Yough. I would not be here today without this wonderful group of faculty. Special thanks to Jacque Frost who encouraged me to start this journey.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

This qualitative study examined how university students learn to engage in the practices of scientific inquiry via research apprenticeships and how such experiences prepare them to be STEM literate. Surveys and interviews addressed two primary research questions: 1. What is the nature of interaction between student participant and faculty mentor? Subsidiary question: What is the role of technology in the mentoring relationship? 2. How do students and faculty describe the development of STEM literacies in the undergraduate research experience? Subsidiary question: How does the mentoring process contribute to the development of STEM literacies? Results demonstrated the importance of learning by engaging in authentic activity under the guidance of mentor experts, the undergraduate research experience helps enable acquisition of STEM literacies but mere participation in research experiences does not always lead to high quality learning, mentoring relationships are not all the same, and the use of technology in undergraduate research experiences varies. Overall the study concludes that students find undergraduate research experiences beneficial as compared to other experiences. Research afforded them the opportunity to understand how research can be applied and gain knowledge that they would not have gained in the classroom.

CHAPTER 1. INTRODUCTION

Statement of Problem

As the United States strives to continue leading the global economy, it is essential that students are equipped with the knowledge and skills necessary to lead the country into the future. The 2014 report by the National Academy of Sciences addresses the call for college and workplace readiness in STEM fields. To that end, this project proposed to examine the nature of mentoring relationships during an undergraduate research experience. Informed by literature in cognitive apprenticeship and STEM education, this study examined how university students learn to engage in the practices of scientific inquiry via research apprenticeships, and how such experiences prepare them for their future careers.

Universities value and strive to provide authentic research experiences for undergraduates as a way to enhance their disciplinary learning (Boyer Commission, 1998). Learning science and engineering may be achieved through participation in authentic learning experiences (Kolikant et al., 2006; Murray et al., 2003; Stewart & Lagowski, 2003) and the cognitive apprenticeship model provides a framework examining and analyzing the effects of participation in authentic research experiences on students' STEM learning.

While traditional apprenticeships focus on acquiring skills in a specific setting, cognitive apprenticeship expands that idea by also helping learners acquire transferrable cognitive skills that are applicable in diverse settings (Collins & Kapur, 2014). Cognitive apprenticeship theory emphasizes the importance of learning broadly transferable cognitive skills. In the context of engineering education, STEM literacy is a term that is used to define such skills.

STEM literacies have been defined in various ways: posing and solving problems applicable to a broader context; identifying, organizing, and integrating information across multiple sources; creating representational; communicating information appropriate to specific audiences; and documenting making processes (Tucker-Raymond et al., 2017); able to maneuver as they go, expand their knowledge, demonstrate resilience to problems that are difficult or hard to deal with, and deal creatively with the unexpected (Roth & Van Eijck, 2010); and the Engineer of 2020 Initiative which outlined STEM literacies in three pillars: abilities, knowledge areas, and qualities (Appendix G). As noted above, the hope is that these skills will translate more broadly, in terms of transdisciplinary thinking.

In the cognitive apprenticeship model it would be impossible for these literacies to be acquired without a mentor. Samarapungavan et al. (2006) asserted that mere participation is not enough and that the experience and role of mentorship matters. However, mentorship in the context of undergraduate research experiences has not been fully studied. Many studies have discussed mentorship as an outcome of undergraduate research experiences but do not take a deeper look into the facets of the mentoring relationship during the experience. This dissertation addresses the nature and outcomes of the mentoring relationship.

The nature of mentoring relationships was examined by surveying and interviewing (1) students and faculty participating in the Summer Undergraduate Research Fellowship (SURF) program at Purdue University and (2) students and faculty participating in semester-length undergraduate research experience in the College of Engineering at Purdue University. The role of technology in facilitating the mentoring relationship is also explored. This study demonstrates how participation in undergraduate research experiences may contribute to a more scientifically literate adult population and increase the STEM pipeline.

CHAPTER 2. REVIEW OF LITERATURE AND THEORETICAL FRAMEWORK

A National Academy of Sciences report highlights the importance of STEM education and STEM literacy to innovation and successful employment both in and outside of STEM fields (Honey et al., 2014). The report notes that even young people who are not pursuing STEM careers should have STEM literacy to lead productive lives (Honey et al., 2014). Reform documents such as "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas" have advocated engaging students in authentic scientific investigations as a way of helping them learn and understand the practices of science and how these are leveraged to generate new knowledge and solve novel problems in K-12 education (National Research Council, 2012). Similarly, the Boyer Commission advocated for change in undergraduate education in their publication "Reinventing Undergraduate Education: A Blueprint for America's Research Universities (1998). Cognitive Apprenticeship Theory provides a framework for examining and analyzing the effects of participation in authentic research experiences on students' STEM learning.

This section begins with discussion of cognitive apprenticeship as a theoretical framework and its application to the study of students' undergraduate research experiences. STEM learning is explored in the context of contributing to the workforce and a scientifically literate population and the review continues by exploring undergraduate research experiences as an example of STEM learning. Undergraduate research experiences and the accompanying mentoring relationship is explored using the cognitive apprenticeship model. The final section of this review explores the role of technology in facilitating the mentoring relationship.

Cognitive Apprenticeship Theory

Cognitive apprenticeship theory was initially developed as a framework for situating learning in authentic real world contexts and for making the processes of cognition (thinking and reasoning) visible to learners. Brown et al. (1989) discussed the importance of situated knowledge and learning. They asserted that learning that takes place in the appropriate context is more useful and cited the example of a traditional apprentice learning their trade. Drawing from traditional models of apprenticeship learning for trades or crafts, they contended that cognitive apprenticeship should help students observe experts performing authentic complex cognitive tasks (for problem solving), and to practice these skills themselves in authentic contexts with guidance, support, and feedback from expert mentors. The cognitive apprenticeship model draws upon key elements of traditional apprenticeship: Experts introduce a new task to learners in an authentic real-world context and model key skills or components of task performance that are instrumental to succeeding at the task (Collins & Kapur, 2014; Lave & Wenger, 1991). Students move through gradients of participation in task performance as they acquire skills and expertise, starting by observing experts, and gradually moving practice parts or elements of task performance with coaching and feedback from experts. As learners become more skilled and fluent in performing components of complex tasks, the expert mentors cede more responsibility and control to the learners until they are eventually able to perform the tasks on their own.

Additionally, students become immersed in and members of a subculture of work, by participating in a community of practice. These social dimensions of learning allow students to informally observe and pick up important heuristics of practice that may not be formally taught. However, the cognitive apprenticeship model departs from traditional apprenticeship in two important ways. In traditional apprenticeships, in which tasks assigned to learners arise simply from the demands of the workplace, while cognitive apprenticeship emphasizes the need to carefully select learner tasks that that afford the opportunity to acquire cognitive heuristics and skills. Traditional apprenticeships focus on acquiring skills in their contexts of application, while cognitive apprenticeship is also focused on helping learners acquire transferrable cognitive skills that are applicable in diverse settings (Collins & Kapur, 2014).

Collins et al. (1991) described four dimensions that are critical to the design of successful cognitive apprenticeship:

1. *Content* refers to the disciplinary knowledge as well as patterns of thinking and reasoning, heuristics for accomplishing tasks, self-regulation and learning strategies that constitute expert performance. In the context of undergraduate research apprenticeships (UREs), *Content* includes disciplinary knowledge including knowledge of core concepts and laboratory techniques as well as more general knowledge of inquiry practices. In the context of engineering UREs which are the

focus of the current study, *Content* also encompasses STEM literacies which will be discussed below.

2. *Method* refers to the pedagogical techniques used to promote students' acquisition of expertise, for example modeling, coaching, scaffolding, giving students opportunities to explore on their own, and to articulate and reflect upon their learning. In the context of UREs, it is critical for programs to identify what kinds of knowledge and skills will be foregrounded for students as they engage in their research apprenticeships.
3. *Sequencing* refers to the ordering of learning activities to facilitate learning. Cognitive apprenticeships emphasize the importance of providing students with a global overview of the entire task and its components so that they have a conceptual map to scaffold their learning of task components and a sense of how each component activity serves the task goals and fits with other activities. Further, cognitive apprenticeship models design activity sequences of increasing complexity and diversity over the duration of learning so that the difficulty and variety of knowledge and skills that a learner must use expands systematically. *Sequencing* is critical to the design of a successful URE.
4. *Sociology* refers to the idea that learning should be embedded in communities of practice rather than decontextualized. In other words, care must be taken to situate learning experiences in authentic contexts. UREs should facilitate students' participation in a community of practice, by engaging them in communication and learning about skills in collaboration with other members of the community including their mentors and peers.

The features of cognitive apprenticeship theory described above make it a particularly useful framework for the study of student learning through apprenticeship in research experiences. Consistent with the tenets of cognitive apprenticeship, research apprenticeships can provide authentic real-world contexts for the meaningful learning of STEM literacies and inquiry practices (Stewart & Lagowski, 2003; NGSS, 2013). Further, the social characteristics of the research teams in which students participate can help learn patterns of communication and collaboration that are important to participation in communities of practice in science (Barab et al., 1999; Barab & Plucker, 2002) Stewart & Lagowski (2003) have described how cognitive apprenticeship theory can serve as a productive framework for structuring graduate chemistry education as well as to reform undergraduate chemistry laboratory experiences.

Kolikant et al. (2006) described their use of cognitive apprenticeship theory to guide the redesign of an undergraduate science course in biology, to foster the development of scientific writing and reading in students. They used the cognitive apprenticeship approach to help students learn to read, write, and understand scientific literature through the methods of modeling, coaching, articulation, reflection, and exploration. Students were assigned to developing a research proposal and identifying and reading authentic research papers as part of their proposal writing. To ensure that students received proper scaffolding, the researchers conducted a task analysis to identify what was needed from the expert during each step to help the students learn. For example, the instructor modeled the thinking process he followed to analyze and synthesize literature when reading by describing some practical questions he asked himself and then guided students' discussion of the norms of a scientific paper. By modeling his or her thinking process to the students, coaching students and providing feedback, and giving instructions and criteria, the instructor demonstrated the importance of these skills in a professional setting.

The cognitive apprenticeship methods were successful as results showed that students performed well with an average grade of 91.88 on the scientific writing task. Students earned their grade based on instructor evaluation criteria that included content of the introduction, content of the literature review, content of discussion, organization, and mechanics. The researchers' analyzed the students' grades on their final written artifacts (as evaluated by the course instructor) and concluded the students had acquired substantial mastery of scientific writing. They also noted that while a small subsection of students lost points on the literature review component of their proposal, they were able to accurately synthesize the papers they read to answer their research questions suggesting that they were able to understand their research readings, but had not yet mastered ways of communicating this tacit knowledge in their literature reviews. However, the problem with this study is that there was no baseline data for comparing student performance on a scientific writing task prior to receiving instruction using the cognitive apprenticeship instructional model. Their results would be more compelling with such a comparison. The researchers also analyze student feedback and noted that while students found the instructional scaffolding for writing to be valuable for assignment completion, many students did not believe that scientific writing was a skill they would use in their future professional life. In contrast, most students felt that reading scientific papers was a skill they would use in their future careers (Kolikant et al., 2006).

Murray et al. (2003) explored the cognitive apprenticeship model for online education in a database engineering course. The researchers used lectures, tutorials, labs, and self-assessment methods to help students learn the knowledge and skills needed to learn database engineering. In addition, the researchers noted the importance of working with an expert in an authentic setting. Scaffolding was provided through software and used to help students progress through each stage.

The apprenticeship model was evaluated by looking at behavior, performance, and student opinion. For example, as the number of requests for help from students decreased, the researchers suggested this could be attributed to an increase in self-reliance. Performance was measured in terms of improvement in coursework and exams, and finally student opinion was used to assess the traditional teaching model with the virtual model. The researchers concluded that their online course instruction model went beyond the classic delivery of online education and was successful because of the authentic activity and constructivist learning approach which support active participation. They demonstrated the success of the virtual tool-mediated apprenticeship model but this model lacks the human interaction component. As a result students may be missing out on the opportunity to develop a mentoring relationship which may be available in traditional cognitive apprenticeship models of instruction (Murray et al., 2003).

The research above illustrates the potential and challenges of using cognitive apprenticeship in the context of course-based undergraduate instruction in STEM courses. In the next section I will discuss the research on student learning from undergraduate research experiences (UREs).

Student Learning From Undergraduate Research Experiences

Undergraduate research experiences have been a longstanding model in higher education and provide an opportunity to use the cognitive apprenticeship theory to understand learning at a deeper level. In 1998 the Boyer Commission Report stated that research-based learning should become the standard, where undergraduate students are active participants in developing their own research capabilities. At present the National Science Foundation provides research opportunities for undergraduates through their Research Experiences for Undergraduates (REU) program. These National Science Foundation (NSF) projects give students meaningful experience in research projects and programs. For example, Boston University is an REU site for integrated nano manufacturing, Duke University is an REU site for research related to meeting the grand challenges in engineering, and the State University of New York at Buffalo is an REU site for studying environmental engineering solutions for pollution prevention (National Science Foundation, n.d.). In 2010 the Association of American Colleges & Universities considered undergraduate research experiences to be a high-impact experience, one which has demonstrated a significant impact on student success, because of the positive effects for students both personally and professionally (Lopatto, 2006).

Undergraduate research experiences may help promote general scientific literacy among participants. The Boyer Commission (1998) supported undergraduate research experiences and stated, “It is that kind of individual that will provide the scientific, technological, academic, political, and creative leadership for the next century.” In addition, undergraduate research projects are often credited retrospectively as launching scientists on the path to a scientific career (Laursen et al., 2012). Kendricks and Arment (2011) found that students ranked participation in undergraduate research as having the most impact in preparing them for a STEM career.

Several national organizations have supported undergraduate research including the National Science Foundation (NSF), the Council of Undergraduate Research (CUR), and the National Conferences on Undergraduate Research (Hunter et al., 2007; Laursen et al., 2012; Pacifici & Thomson, 2011). For example, participation helps students think and work like a scientist, personal-professional development, clarification or refinement of career plans, graduate school preparation, communication skills (Hunter et al., 2007); increased awareness of career options including networking, relationships, and community support; career clarification including enhanced research and confidence in skills, and development of research identity; and enhancement of students’ professional credentials including recommendation techniques, presentations, publications, awards, and fellowships (Adedokun et al., 2012); gain knowledge, gain skills, obtain a letter of recommendation, increase grade point average, help clarify career goals, make peer connections, make faculty connections, publish research, help in applying to graduate school (Pacifici & Thomson, 2011).

The longstanding model of undergraduate research experience has demonstrated a significant impact on student success, because of the positive effects for students both personally and professionally (Lopatto, 2006), promoted general scientific literacy that has been helpful in future careers (Laursen et al., 2012; Kendricks & Arment, 2011), and provided students with a wide range of benefits (Adedokun et al., 2012; Hunter et al., 2007; Pacifici & Thomson, 2011).

Despite the many benefits, limitations to undergraduate research experiences should also be considered. For example, student expectations of the undergraduate research experience may not align with outcomes (Pacifici & Thomson, 2011), undergraduate research experiences are not offered in the same format (Wang, 2017), institutions may be limiting these opportunities to high achieving students (SURF program GPA criteria), and the nature of participation on the research and the nature of mentoring may affect the quality of the experience and what is learned.

One limitation of UREs is that that student expectations of the undergraduate research experience may not align with outcomes. Pacifici and Thomson (2011) studied this specifically when they compared student expectations and outcomes of undergraduate research experiences. Results demonstrated that expectations exceeded outcomes in the areas of faculty connections and publications. When students began their undergraduate research experiences they did so with the expectation of publishing their research. However undergraduate participants learned that it is difficult to publish work in the time frame of a single semester. In addition, although students expressed gratitude for the support they received from graduate students and post docs, their expectations for developing a connection with faculty were not met because of the demands on faculty members' time.

There is great variability in the structure and duration of undergraduate research experiences as well as in the affordances for learning that they provide to student participants. For example, some undergraduate research experiences are course-based whereas others are offered via the apprenticeship model. Wang (2017) conducted a mini-review of course-based undergraduate research experiences asserting that this format is the most scalable version currently available in literature since it is embedded with undergraduate coursework and provides more students an opportunity to participate. Wang discussed how students may learn scientific practices in course-based undergraduate research experiences but also noted limitations such as obstacles to implementation for faculty members. The main concern with course-based undergraduate research experiences that is relevant to the present dissertation is that they lack the opportunity for students to have a research mentor.

Another limitation of undergraduate research experiences is that they are only offered to high achieving students. For example, the Summer Undergraduate Research Fellowship (SURF) program at Purdue University has eligibility criteria including a minimum cumulative GPA of 2.8 on a 4.0 scale. It is recommended that a student's GPA be even higher with the average SURF participant GPA standing at 3.5. Although course-based undergraduate experiences may not provide a mentoring relationship they do provide an opportunity for more students to participate. This dissertation collected data from two different models (SURF program and spring semester-length research experience in the College of Engineering).

Finally, the nature of mentoring may affect the quality of the experience and what is learned. Mentorship in the context of undergraduate research experiences has not been fully studied which will be discussed in the following section. Many studies have discussed mentorship as an outcome of undergraduate research experiences but do not take a deeper look into the facets of the mentoring relationship during the experience. This dissertation addresses the nature and outcomes of the mentoring relationship.

Despite the limitations, it has been shown that undergraduate research experiences provide a means for students to develop cognitively, socially, and emotionally. This dissertation focuses on the benefits of participation in undergraduate research experiences as related to acquisition of general scientific knowledge and increasing the STEM pipeline. Specifically, the dissertation contributes to the body of literature by exploring the mentoring relationship between students and faculty during undergraduate research experiences and how that relationship facilitates knowledge gain.

The cognitive apprenticeship model has also been applied to the study of undergraduate research experiences. Laursen et al. (2012) conducted qualitative research using interviews to study research apprenticeships for undergraduates. Faculty members who were interviewed for their research, reported positive outcomes such as greater student interest and engagement in science learning and building stronger student-instructor relationships through the research collaborations. Pacifici and Thomson (2011) interviewed undergraduate students engaged in authentic research about their experience. Students reported that they found mentorship supports provided by other research group members such as post-doctoral fellows to be valuable their learning. Students felt supported because they were provided with background readings on the research and received contextual explanations and assistance on ongoing research tasks. Although some students expressed gratitude for the support they received from graduate students and post docs their expectations for developing a connection with faculty were not met. Pacifici and Thomson stated this finding should be of concern.

Overall they stressed the importance of the congruence between expectations and outcomes as a result of discrepancies in other outcome areas as well such as the expectation to publish research. When expectations are different than outcomes it may impact how students behave in the future in terms of pursuing additional research experiences (Pacifici & Thomson, 2011). Their study was based on a small sample size at a single institution and therefore further research is needed before results can be considered generalizable but nonetheless shows support that expectations should be considered.

Hunter et al. (2006) used an apprenticeship model to help faculty scaffold for undergraduate participation in research. The study was conducted at four liberal arts colleges. Faculty mentors in the study began the undergraduate research experience by orienting students to their laboratory and research project. They provided students with background knowledge, and taught students skills necessary to complete the work. Faculty worked closely with students guiding them when needed until the student was able to work independently. They reported that through the apprenticeship paradigm, undergraduate researchers learned how to complete their own research studies, participated in poster presentations at conferences, and shared their work with others. The design of this study was effective because in addition to measuring how faculty felt about the experience they also obtained feedback from the students. Students' perceptions of their experience supported the faculty reported gains in this study. This dissertation study expanded on this research by exploring undergraduate research experiences at a research university.

The studies above suggest that cognitive apprenticeship may serve as an effective instructional framework for understanding UREs and the nature of student learning in UREs. However the literature also shows gaps that should be addressed in future research. This dissertation contributes to cognitive apprenticeship literature by addressing some of these concerns.

In the following sections, I will discuss some specific aspects of learning that are important in context on the engineering UREs that are the focus of the current study. In particular, I will discuss how cognitive apprenticeship in research can influence the development of STEM literacies which have been identified as important in the context of engineering education, the role of research mentorship in supporting student learning through research apprenticeships, and the uses of technology to support mentoring in research.

Developing STEM Literacy

Cognitive apprenticeship theory emphasizes the need to foreground authentic and broadly transferable cognitive skills through instruction. In the context of engineering education, STEM literacy is a term that is used to define such skills. Tucker-Raymond et al. (2017) enumerate six STEM literacy practices including: posing and solving problems in the world and in the design process; identifying, organizing, and integrating information across sources; creating representational forms and traversing representational systems and materials; communicating information in new ways to different audiences; and documenting making processes and/or milestones.

Street (2003) characterized the changing nature in the focus of literacy as a move from a focus on acquisition of skills to thinking of literacy as a social practice. Street highlighted contemporary literacy practices as foregrounding the relationship between formal education and everyday life. His stance on literacy aligns with the present discussion of scaffolded learning in authentic settings.

Similarly, Roth and Van Eijck (2010) discussed the importance of fostering connections between students' own life experiences and their school STEM learning. People who successfully implement STEM learning in their lives are able to maneuver as they go, expand their knowledge, demonstrate resilience to problems that are difficult or hard to deal with, deal creatively with the unexpected, and possess an orientation toward motives of activities and goals of actions.

Zollman (2012) has also noted that traditional definitions of STEM literacy discuss societal and economic needs but fail to address personal needs. He asserted that STEM literacy should not be treated as a content area rather it should encompass all of the skills and abilities needed to expand learning. In this lens STEM should be viewed as a metadiscipline rather than separate silos of knowledge. The emphasis will be placed on helping a student learn rather than the content to be covered. Rather than focusing on STEM literacy to understand and use concepts from science, technology, engineering, and mathematics, Zollman desired to see STEM literacy used for continued learning where students gain skills that will help them in all aspects of their lives. Zollman's perspective is relevant to the discussion of context in the cognitive apprenticeship learning model.

Wilson-Lopez et al. (2016) studied 25 Latina/o high school students to explore how content knowledge in engineering was used to solve other problems in their lives. Data included copies of participant-generated artifacts to determine their knowledge in engineering. The researchers conducted interviews with the participants to explore how they used engineering knowledge in their day-to-day lives. Data collected for this study also included think-aloud protocols where the participants verbally articulated what they were thinking while completing a task and bimonthly group meetings where participants discussed problems in their communities and possible solutions.

The researchers found that many students helped their parents at work and used engineering-related processes that helped them with problem solving. Two of the students worked with their fathers on a small dairy farm and were able to help decrease the milk's bacteria count using elements from engineering design processes. To accomplish this the students defined the problem, made observations of current practices, proposed solutions and iteratively evaluated those solutions. All of these practices used to reduce milk's bacteria on a small dairy farm are also used in engineering. The researchers concluded by noting these results are not limited to Latina/o students. All students can benefit from engineering-related knowledge that will help them solve other problems in their everyday lives. The Wilson-Lopez et al. (2016) study highlights the importance of engaging students in problems that connect classroom learning to their lives outside of formal school contexts to support the transfer of STEM literacies beyond the classroom.

Tucker-Raymond et al. (2017) conducted a qualitative-interpretive study of 14 participants who are experienced in their respective fields to examine how people use literacies in their jobs to make something. For the purpose of this study the authors used five STEM literacy practices including: posing and solving problems in the world and in the design process; identifying, organizing, and integrating information across sources; creating representational forms and traversing representational systems and materials; communicating information in new ways to different audiences; and documenting making processes and/or milestones.

The study participants included a professor of computer science, biologist/entrepreneur, sound artist/instrument builder, woodworker, and metal sculptor. The researchers asked the participants a series of questions to obtain descriptions of the nature of their work processes. Examples of questions asked were (a) What is your planning process for a new thing, (b) Can you give me an example of how you use representations, (c) What is your fabricating/making/hacking process, (d) Can you give me an example of how you use representations, (e) How do you share your work, and (f) Can you give me an example of how you use representations (Tucker- Raymond et al., 2017)?

Results from the study demonstrated that people bring a wide web of resources to their endeavors. To successfully complete work in their respective disciplines participants discussed the importance of problem solving through communication and relying on their network of peers to help solve problems. For example, one participant discussed their network of colleagues as a group with a wide range of capabilities and abilities. This participant had established relationships with some of his/her peers and was able to call on them as friends when help is needed. This study highlighted the STEM literacy practice of communicating information in new ways to different audiences (Tucker-Raymond et al., 2017).

Participants also discussed the importance of documentation when making new things. One participant provided examples of how documentation is helpful as an educational resource to others and helpful to her in reflecting on her process. Finally, results showed that participants valued the use of representations in their work. Representations such as sketches help think through problems by asking what-if questions. Participants then used their representations to build their work such as the jeweler who uses the sketch to create a custom pair of earrings (Tucker-Raymond et al., 2017).

This study demonstrated how STEM literacies can be transferred to life beyond STEM content areas and the importance of the social network of people who help contribute to their successes. What is missing from this study is learning from the participants where they acquired their STEM literacies. It would be interesting to ask questions such as: Where did you learn how to pose and solve problems? Answers to such questions would allow educators and researchers to adjust learning models to provide for instruction for these literacies.

In 2006 Samarapungavan et al. conducted a study to examine how students and professional chemists conceptualize their work. They explored the role of research apprenticeship in students' developing understanding of the nature of scientific inquiry in the context of organic chemistry research.

Interviews were conducted with high school students, undergraduate and graduate chemistry students, and professional chemists who were faculty and actively involved in chemistry research. The undergraduate students included two separate groups. One group were chemistry majors involved in research and the other group were undergraduates enrolled in a general chemistry course with a laboratory component. The purpose of the interviews was to evaluate views of science, explore whether their views vary as a function of experience, and explore whether research experience influences their beliefs. Ninety-one participants answered questions related to their beliefs about five themes including: description of their work, choice of problems and methods, models for handling empirical anomalies, criteria for evaluating their work, and addressing the "what is science" question (Samarapungavan et al., 2006).

Results found significant differences between participant groups for all themes. For example, faculty professional chemists conceptualized their inquiry practices in highly discipline-specific ways. This finding shed light on a gap in science education as it appears that descriptions of STEM literacies may be overly domain general and underrepresent important discipline-specific and contextual aspects of inquiry practices that are critical to conducting research. Additionally, the researchers found that the nature of student participation in inquiry (i.e., their research experiences) had a profound influence on their understanding of science and scientific research. The researchers found that high school and undergraduate students without research experience viewed their lab work as simple and very structured. Students were told exactly what to do and knew the expected outcome of their work. Essentially students work through step by step guidelines to achieve a desired result. They had little insight into the broader meaning or purpose of their laboratory work and also lacked effective metacognitive knowledge and heuristics for identifying and solving problems encountered during laboratory work.

Although undergraduate students who participated in research experiences showed some shared understanding about the nature of science and scientific inquiry with expert chemists and graduate students, they also showed significant gaps in their understanding. For example, URE students tended to attribute all anomalous findings to human error while research chemists distinguished between mundane error and true anomalies that lead new fruitful lines of research and exciting findings. URE students also tended to use brute force solutions such as doing an entire procedure over from scratch when they encountered problems in the laboratory. In contrast, more experienced graduate students and research chemists, used disciplinary knowledge to narrow down potential sources of anomaly such as checking the calibration or instruments or the purity of chemicals. Samarapungavan et al. (2006) suggest that mere participation in UREs does not guarantee high quality learning and that care must be taken to structure student experiences so that the tacit disciplinary heuristics used by expert chemists to guide laboratory inquiry are more visible to students.

More research is needed to explore the nature of the research experience. This in-depth look should explore how experiences are different, discipline-specific contexts, and the role of mentorship to facilitate students' understanding in these experiences and discipline-specific contexts. Future research should include methods using observations since the current study was based on interview responses. In addition the study by Samarapungavan et al. (2006) was limited to the chemistry discipline and therefore future research could contribute to this body of literature by exploring other STEM disciplines.

The studies above presented a framework for STEM literacies (Tucker-Raymond et al., 2017), characterized STEM literacy as a move from a focus on acquisition of skills to thinking of literacy as social practice (Street, 2003), described STEM literacy in terms of fostering connections between students' own life experiences and STEM learning in school (Roth & Van Eijck, 2010), and viewed STEM literacy as metadiscipline (Zollman, 2012). Research by Wilson-Lopez et al. (2016) and Tucker-Raymond et al. (2017) provided examples of how STEM literacies can be applied to life beyond the classroom. Finally, research by Samarapungavan et al. (2006) serves as a reminder that mere participation is not enough and that the experience and role of mentorship matters.

As the United States strives to continue leading the global economy, it is essential that students are equipped with the knowledge and skills necessary to lead the country into the future. The 2014 report by the National Academy of Sciences addresses the call for college and workplace readiness in STEM fields. This dissertation demonstrates how participation in undergraduate research experiences may contribute to a more scientifically literate adult population and increase the STEM pipeline. Cognitive apprenticeship is the theoretical lens used to explore STEM learning in undergraduate research experiences and the significance of a mentoring relationship. The role of technology in facilitating the mentoring relationship is also explored.

Mentoring

As introduced above, a key aspect of the cognitive apprenticeship model is modeling support and feedback from a knowledgeable expert. In the context of UREs the research mentor fulfills the role of the knowledgeable expert. The Boyer Commission Report (1998) recommended a reinvention of undergraduate education that focuses on inquiry-based learning. The report asserted that learning should be guided by a mentor and based on discovery. Drawing a comparison to graduate level education and the emphasis on the student-faculty relationship, the report used the mantra “A Mentor for Every Student” making the argument for a similar student-faculty relationship in undergraduate education. Since the publication of this report in 1998 empirical research has confirmed the benefits of improving communication skills and the mentoring relationship in undergraduate research experiences.

Mentoring relationships take many shapes and forms. Ragins and Cotton (1999) explored formal versus informal mentoring relationships. They defined informal mentoring relationships as those that develop from mutual identification where the needs of both the mentor and mentee will be satisfied. These relationships are often selected based on perceived competence and interpersonal comfort. Formal mentoring relationships on the other hand are often formed by assignment. They surveyed men and women from occupations of engineering, social work, and journalism. A total of 654 women and 500 men completed the study. Results found that informal mentoring relationships provided greater benefits than formal mentoring relationships. Mentees with informal mentors reported greater overall satisfaction, received more career development, and typically earned more money. The results from this study suggest that informal and formal mentoring relationships should be considered in undergraduate research experiences. Despite this finding the present dissertation will focus on formal mentoring relationships because of the nature of the research experience.

In addition to the differences between formal and informal mentoring relationships, past literature has also explored the traditional faculty-student mentoring relationship and the emergence of the peer-to-peer mentoring relationship. Terrion and Leonard (2007) conducted a literature review to explore the type of peer best suited to act as a peer mentor. Fifty-four articles were included in the literature review and the authors used these studies to create a taxonomy of peer mentor characteristics for successful mentoring relationships. They noted five prerequisites for the student peer mentor including ability and willingness to commit time, consideration of gender and race, how to navigate the university environment, academic expertise in the field that gives the student credibility, and prior mentoring experience.

The taxonomy created by Terrion and Leonard included two characteristics related to career support and eight characteristics related to psychosocial support. The taxonomy proposed that the mentor and mentee should share the same program of study and mentors should possess self-enhancement motivation because they typically provide better career-related support. To serve the psychosocial function of the mentoring relationships peer mentors should possess skills in communication, supportiveness, trustworthiness, empathy, enthusiasm, and flexibility. They also stated the importance of personality match between the mentor and mentee and the willingness of the mentor to develop and interdependent relationship with the mentee.

Near-peer mentoring is another type in addition to faculty-student and peer mentor models. Tennebaum et al. (2014) discussed how near-peer mentoring relationships offer unique opportunities to integrate research and teaching in STEM. Near-peer mentor is an undergraduate or post-baccalaureate student who completed a research and teaching summer internship. These students acted as mentors in the "Gains in the Education of Mathematics and Science" (GEMS) program for middle school and high school students. The near-peer mentors were responsible as subject matter experts, role models, curriculum designers, lab safety officers, and technicians in the research lab. The study explored the experiences of 11 near-peer mentors as well as 475 high school participants through survey responses. In their responses, near-peer mentors described their development as professionals, teachers, and scientists. The experience of a near-peer mentor allowed students to learn the importance of accountability, adaptability, and increased their knowledge. Fifty-nine of the GEMS participants completed the survey and results found rapport and guidance were the best part of having a near-peer mentor. These students felt they were able to connect better connect with their near-peer mentor as compared to older mentors. Students also noted the guidance received by their mentor in a way where learning was fun and mentors were able to make the material understandable because they were closer in age and recently learned the subject matter (Tennebaum et al., 2014). The authors asserted that results of this study reinforces the pipeline of scientific learning and provides a continuum of training in STEM. The near-peer mentoring model may indeed have benefits but also presents the same limitation as the peer-to-peer mentoring model in terms of the missing expertise from a faculty mentor (Tennebaum et al., 2014) which is a defining characteristic of the cognitive apprenticeship model. Although this dissertation focused on the faculty-student relationship, results yielded examples of peer and near-peer mentoring relationships.

Although peer and near-peer mentorship models have documented benefits, they also carry some significant limitations. Samarapungavan et al. (2006) found significant differences in expertise among members of research groups (i.e., faculty research scientists, graduate students, and undergraduate researchers) in understanding of scientific inquiry practices and the nature of sciences, as well as in the use of heuristics o deal with problems encountered in the conduct of research. For example, the faculty professional chemists drew upon deep disciplinary knowledge to describe targeted, strategic problem solving and decision making in the context of ongoing scientific research while graduate and undergraduate students were often unable to do so an fell back on general and less effective strategies such as simply redoing an experiment from scratch when faced with problems. These findings suggest potential limitations to the benefits of peer and near-peer mentoring. Guided by the cognitive apprenticeship framework, the present dissertation focuses on the benefits and challenges of the faculty-student mentoring relationship.

In line with the cognitive apprenticeship theory, Mueller (2004) discussed mentoring as a relationship in which a more experienced individual helps someone who is less experienced. The goal of this developmental relationship is to promote growth both personally and professionally. Mueller discusses the many roles of mentors including providing performance-related feedback, emotional and moral support, and sharing sources of information.

Chesler and Chesler (2002) discussed a similar mentoring model with an experienced person giving technical and psychosocial support. Some benefits include problem solving; tips for approaching internships and jobs; how to prepare a research proposal; and learning the norms of an organization. Psychosocial issues included how to deal with people who are hard to deal with; how to obtain work-life balance; and how to grow as a person.

Linn et al. (2015) reviewed 60 studies published within the last five years to explore the impacts and opportunities of undergraduate research experiences including the benefits of a successful mentoring relationship. They asserted that mentors helped undergraduates develop and integrate knowledge and background information; how to develop an evidence-based argument; and introduced mentees to the culture of the lab.

Furthermore, they said mentors helped students form a scientific identity and learn their role in the lab, understand gaps in their knowledge, and identify ways the students can contribute to the task while also building on their current capabilities. In addition, they found that mentors provided professional socialization and emotional support. From their review, they concluded that mentors play a significant role in undergraduate research experiences (Linn et al., 2015). The review by Linn et al. demonstrates the benefits of learning under the cognitive apprenticeship model and the present dissertation corroborates these positive outcomes.

Relevant to the current study, past research has also explored the faculty-student mentoring relationship in undergraduate research experiences. Several of these studies have emphasized the benefits of establishing collegial working relationships from both faculty and student perspectives. For example, Thiry et al. (2011) compared undergraduates who participated in research experiences with those that did not and found that undergraduate participants in research experiences were more likely to experience collegial relationships with a faculty as a benefit. Seymour et al. (2004) also found that establishing a working relationship with faculty mentors was a significant benefit of undergraduate research experiences. In their qualitative study interviews were conducted with students at four different liberal arts colleges. They found that undergraduate research experiences provided many students with their first opportunity to work with a faculty mentor as a partner.

Laursen et al. (2012) also discussed the development of collegial relationships in their research. They examined the short and long-term benefits to students participating in an undergraduate research experience as well as the processes by which undergraduate research provides these benefits. The study included interviews of 400 students, alumni, faculty, and administrators and results identified positive benefits to students including thinking and working like a scientist, personal and professional growth, becoming a scientist, skills, career preparation, and career clarification. New collegial relationships with mentors was discussed as a positive outcome and students appreciated feeling like a peer to their professor. One student said he/she felt like a partner because they were working together with the faculty member to figure out the project. A faculty advisor talked about the rewards of having a close one-on-one relationship with students and discussed how there is as much joy in discovering a solution through as student as by him/herself. The faculty advisor said the most satisfying moments occurred when he/she gave a student a hard problem and the student came back with the solution. The advisor noted how it was particularly rewarding when the student came up with an even better solution (Laursen et al., 2012). Rogers et al. (2012) agreed that undergraduate research provides multiple educational advantages.

The role of the student-advisor relationship in undergraduate research experiences was also explored by Thiry and Laursen (2011). Seventy-three undergraduate students were interviewed as part of their qualitative study to explore professional socialization, intellectual support, and personal/emotional support. In the professional socialization realm students said mentors set guidelines and expectations, provided disciplinary anchoring, modeled and guided scientific behavior and norms. For example, one student noted the benefits of lab meetings and the opportunity to listen to everybody talk about how various aspects of the project are related. This student sentiment provided an example of a mentor providing disciplinary anchoring to introduce students to the big picture of a project and help students understand basic concepts. Mentors also helped student researchers with knowledge and comprehension, application and analysis, synthesis and evaluation. One student discussed how in the beginning they were just trying to absorb all of the information and not questioning what they were doing. As time progressed the student began to understand and question the results which demonstrates an example of scaffolded learning via the cognitive apprenticeship theory. The student believed that asking a lot of questions would help with preparation for graduate school by learning to become more independent run their own experiment. This student provided an example of how their collegial relationship with their mentor helped them apply their learning to create new knowledge and understanding (Thiry & Laursen, 2011). Finally, the study found that mentors provided personal and emotional support. Research mentors were open, accessible, friendly, patient, respectful, and committed to the work of the group. As a result of mentor support students felt comfortable and collegial relationships were developed. Their study could be enhanced by expanding the methods to include interviews of advisors and other data collection methods such as observations. The study could also include a comparison of a group of students who are not participating in an undergraduate research experience. In addition, most of the undergraduate students (42%) in this study were advised by graduate students which, as mentioned previously, may present its own set of missed opportunities for students compared to being mentored by faculty (Thiry & Laursen, 2011).

However, several studies have also suggested limitations to mentoring relationships in the context of undergraduate research experiences. Hunter et al. (2007) used a constructivist framework of "communities of practice" to study undergraduate research experiences. In the case of undergraduate research experiences, students are working with faculty to become part of the community of research.

Their qualitative study addressed questions related to undergraduate engagement in faculty-mentored, authentic research experiences of students at four liberal arts colleges. They interviewed students participating in an undergraduate research experience, faculty advisors, administrators, and a comparison group of students. Interviews focused on the nature, value, and career consequences of undergraduate research experiences.

Results found that student and faculty sentiments regarding participation in undergraduate research experiences were overwhelmingly positive. Students and faculty both discussed the opportunity to build a close, collegial relationship with faculty as a benefit of participation in undergraduate research experiences. However, the study also found limitations to learning from mentorship. For example, example, fewer respondents mentioned increases in higher order thinking skills. The omission of gains in complex epistemological understanding of science should be of concern based on the premise of students' development of STEM literacy competencies (Hunter et al., 2007).

Pacifici and Thomson (2011) conducted a study to compare student expectations and outcomes of participation in undergraduate research experiences. They also looked at expectations and outcomes for GPA, faculty connections and recommendations, publications, getting into professional or graduate school, confidence in doing research, and being a scientist. Using a mixed-methods approach with a questionnaire and interview data, Pacifici and Thomson found that the greatest expectation of students participating in a research experience was to gain skills and knowledge and that outcomes were closely aligned with expectations in this area.

Making connections with faculty was the second highest expectation of students behind the acquisition of skills and knowledge. Unfortunately the expectations and outcomes for connections with faculty had the greatest discrepancy among students. Students hoped to build a strong relationship with faculty but spent most of their time with graduate students (Pacifici &

Thomson, 2011). It is imperative for future research to address this finding. Particularly in this case where students had an expectation that was not met the outcome was disappointing. As noted by Samarapungavan et al. (2006), faculty who are professional scientists possess more knowledge and experience that students can benefit from compared to what can be provided by a graduate student.

The cognitive apprenticeship theory is based on the idea that the mentor provides help until the mentee can accomplish a task on their own. Therefore, simply having a mentor is not enough, the mentor must be available for enough time to provide sufficient support and it is important to consider how the mentoring relationships are structured and nurtured.

Several studies have described features of successful STEM mentoring relationships for undergraduates. Kendricks and Arment (2011) have emphasized the importance of creating sustained and nurturing mentoring relationships for recruiting and retaining underrepresented students in STEM. The researchers believed worked with STEM faculty advisors to create a nurturing mentorship environment to support minority students at a historically black university. Six learning activities were used to foster a nurturing environment including: participation in an academic learning community, a living and learning community, mandatory mentoring, campus honor's program, professional development workshops and graduate school visits, and STEM research on and off campus (Kendricks & Arment, 2011).

Faculty advisors used this time to track student progress, provide advice and study tips, and information about research opportunities. Students and their faculty mentors participated in nurturing relationships by doing things such as going out to eat or attending campus events together. The researchers found that these mentoring relationships were successful based on student feedback (Kendricks & Arment, 2011). Adedokun et al. (2012) studied longer duration intensive undergraduate research experiences to understand how these experiences influenced student aspirations for research careers and graduate education. Data was collected from 25 students involved in a faculty-mentored and STEM-focused undergraduate research experience. Students worked for 4-10 hours per week for 16 weeks in their faculty mentor's lab and participated in a seminar class. The semester concluded with a poster presentation. Journal entries from the participants were used to collect information in this qualitative study. Results showed that opportunities from undergraduate research experiences resulted in an increased awareness of career options, clarified career pathways, and increased professional credentials.

The elements of the undergraduate research experience that led to these outcomes included the opportunities for professional and academic networks and relationships, gain in research confidence and science identity, opportunities for research presentations and publications, and relationships with faculty. Future research could expand on this study by using additional data collection methods such as interviews and observations. Relying on journal entries alone may lead to missed opportunities for more in-depth data collection.

The present study specifically explores the mentoring relationship in undergraduate research experiences under the cognitive apprenticeship lens.

The Boyer Commission Report (1998) used the mantra “A Mentor for Every Student”. To that end, the studies above discussed the various types of mentoring relationships. Ragins and Cotton (1999) explored formal versus informal mentoring relationships, Terrion and Leonard (2007) discussed the peer-to-peer mentoring relationship, Tennebaum et al. (2014) studied near-peer mentoring relationships, and research presented here explored the mentoring relationship of a more experienced person helping a less experienced person (Adedokun et al., 2012; Chesler & Chesler, 2002; Hunter et al., 2007; Kendricks & Arment, 2011; Laursen et al., 2012; Linn et al., 2015; Mueller, 2004; Seymour et al., 2004; Thiry et al., 2011; Rogers et al., 2012). Although there are many types of mentoring relationships, the methodology for this dissertation focused on the faculty-student mentoring relationship because undergraduate research experiences, including those that were studied in my dissertation, are typically formally described in terms of this mentorship model.

The literature has demonstrated the benefits of participation in an undergraduate research experience within the paradigm of the cognitive apprenticeship theory, and with specific focus on the student-faculty relationship. The literature review has also identified gaps in research providing justification for the present dissertation. The Boyer Commission Report also urged that undergraduate education should provide students with opportunities to effectively use existing technologies and learn state-of-the-art practices that enrich learning. The literature review will continue by discussing the use of technology in undergraduate research experiences. This dissertation presents a novel examination of the mentoring relationship during undergraduate research experiences by exploring the role of technology in the facilitation of the mentoring relationship.

Technology

Thus far the cognitive apprenticeship theory has been discussed in terms of how it supports scientific learning and the critical role of the expert mentor in acquiring transferable skills. This study also considers how technology may facilitate the mentoring relationship in undergraduate research experiences.

Today's students are different than students from the past because they have been surrounded by technology their entire lives (Prensky, 2001). With internet and email integral to the lives of students, they process and communicate information differently than previous generations. Prensky referred to students who grew up with technology as Digital Natives because they are "native speakers" of the internet and computers. People who were introduced to the digital world later in life are known as Digital Immigrants. According to Prensky, an issue in education today is that the Digital Immigrants are struggling to teach the Digital Natives. Over ten years later, Henrie et al. (2015) noted similar findings. They stated that technology-mediated learning is becoming the norm for today's students.

Salomon (1998) discussed the first uses of technology in education. He provided a background of the history of technology including the CAI drill, programming, and then the introduction of multimedia via the Internet. Salomon recognized that technology in education would serve two purposes, first providing "needed tools for the realization of learning as construction" and as a "social process of meaning appropriation". This dissertation focuses on the second purpose by exploring the use of technology in facilitating communication.

Leveraging technology for communication was discussed by Barab et al. (2001) thereby providing a follow up example to Salomon's (1998) research. The purpose of their study was to explore the implications and benefits of online courses. Participants included 34 students enrolled in a graduate-level computer-mediated course in the fall of 1998. Students' experience with technology ranged from no prior exposure to extremely technology competent (Barab et al., 2001).

Referencing technology as a means for communication, one instructor told their students not to feel intimidated by technology. The instructor noted the importance for everyone to develop digital competencies to be effective in the future. The instructor encouraged students who are more comfortable with technology to help their less experienced peers. While it may be important to develop digital competencies, it is imperative for students to also have opportunities for face-to-face interaction. The present dissertation explores how technology can enhance or facilitate communication, not replace face-to-face communication (Barab et al., 2001) in an undergraduate research experience guided by cognitive apprenticeship theory.

The importance of technology for communication still holds true in recent years. Sinex and Chambers (2013) stated that an important goal in 21st century education is the development of students' online collaboration skills. With a focus on the use of technology in facilitating communication, this dissertation explores how technology may facilitate communication between faculty and students in mentoring relationships.

Griffiths and Miller (2005) studied e-mentoring and discussed the benefits afforded with the use of technology. Some of the advantages they discuss include: technology provides asynchronous flexibility, it transcends boundaries, provides access when face to face communication is unavailable, it may decrease feelings of intimidation or discomfort, and technology provides a means for the mentor to be readily accessible (Griffiths & Miller, 2005).

They also discussed several challenges associated with e-mentoring such as need for an internet connection, participants must have basic skills to use technology, e-mentoring programs must have continuous interaction and reflective influences, e-mentoring programs may be difficult to maintain, there have been few evaluations studies on its effectiveness, e-mentoring may compromise confidentiality and privacy, e-mentoring may be more time consuming than face-to-face mentoring, it may be difficult to establish rapport in e-mentoring, e-mentoring may lead to a loss in non-verbal communication cues such as body language. For these reasons e-mentoring should be considered in conjunction with face-to-face mentoring as a means to enhance additional communication between face-to-face meetings. In addition, their research was conducted in the context of the medical profession. Future research should be replicated in the context of other disciplines (Griffiths & Miller, 2005).

Another example of electronic mentoring comes from Mueller's (2004) study of e-mentoring in engineering education. At that time Mueller stated that electronic mentoring in engineering and science was a relatively new phenomenon. In this article Mueller defined mentoring, discussed common features of mentoring, explained the need for mentoring in engineering education, and discussed the benefits of mentoring in engineering education. Mueller also provided advantages and challenges of electronic mentoring programs.

Mueller's study explored electronic mentoring in engineering education for the specific purpose of retaining women and minorities in engineering and science. MentorNet was used to match students with professionals outside of academia. A MentorNet evaluation report showed encouraging results with 50% of participants stating the use of MentorNet increased their confidence to succeed, 52% said MentorNet increased their desire to pursue a career, and 64% were satisfied with their MentorNet experience.

Mueller concluded that more research needs to be done to gain a better understanding of electronic mentoring but believed there was enough current evidence to support the adoption of e-mentoring in engineering and science curriculum because of its benefits in supporting students in the challenges they encounter during college and during their transition to the workforce. This study is limited in its scope of exploring electronic mentoring for the specific purpose of retaining women and minorities in engineering and science. It would be interesting to conduct further research using MentorNet to explore if electronic mentoring can facilitate learning of STEM literacies and whether electronic mentoring would be sufficient in the cognitive apprenticeship model.

The studies mentioned above provide support for the role of technology in facilitating communication, specifically in mentoring relationships (Barab et al., 2001; Griffiths & Miller, 2005; Mueller, 2004; Salomon, 1998; Sinex & Chambers, 2013). This study expands on this past research to explore how technology can facilitate, but not replace face-to-face, communication in mentoring relationships as part of an undergraduate research experience at Purdue University. Exploring how technology can facilitate communication in this context is suitable for qualitative investigation because the results will unveil an in-depth understanding of the mentoring relationship in the contexts of this study. This research is significant because it addresses the how technology supports mentoring during in this specific setting of an undergraduate research experience.

Description of the Study

This study used the qualitative interpretive approach (Lincoln, 2002; Ryan & Bernard, 2000) to investigate the acquisition of STEM literacies in an undergraduate research experience. This study focused on how the mentoring relationship with faculty contributes to the attainment of these literacies. The data for this study was drawn from surveys and interviews with undergraduate research participants and faculty mentors. The surveys and interviews are described in more detail in the methods section. Data collection is designed to provide data to answer two key research questions:

1. What is the nature of interaction between student participant and faculty mentor?
   Subsidiary question:
   - What is the role of technology in the mentoring relationship?
2. How do students and faculty describe the development of STEM literacies in the undergraduate research experience?
   Subsidiary question:
   - How does the mentoring process contribute to the development of STEM literacies?

CHAPTER 3. METHODS

This study used the qualitative interpretive approach (Lincoln, 2002; Ryan & Bernard, 2000). The methodological framework for this qualitative study employs cognitive science methods for collecting and analyzing verbal data (Chi, 1997). Specifically, data was collected through a survey and scripted, semi-structured interviews adapted from Samarapungavan et al. (2006) and Ibrahim et al. (2017).

Sample

The participants consisted of students and faculty from the Summer Undergraduate Research Fellowship (SURF) program at Purdue University during the summer of 2019 and students and faculty from Engineering 499 in the spring of 2020.

Table 1

		Pre Survey N	Post Survey N	Interview N
SURF	Students	11	2	3
	Faculty	12	11	4
Engineering 499	Students	10	3	3
	Faculty	6	6	1

Table 2

		Pre Survey N			Post Survey N		
		Female	Male	No response	Female	Male	No Response
SURF	Students	7	4	0	2	0	0
	Faculty	5	7	0	2	9	0
Engineering 499	Students	3	3	4	2	1	0
	Faculty	4	1	1	2	3	1

Table 3

		Pre Survey N			Post Survey N		
		White	Participants of Color	No response	White	Participants of Color	No response
SURF	Students	7	4	0	2	0	0
	Faculty	9	3	0	6	4	1
Engineering 499	Students	4	2	4	1	1	1
	Faculty	5	0	1	5	0	1

The survey was distributed to all participants in the SURF program (~150) and all faculty mentors (~110-135). Eleven students responded to the pre-survey (Appendix A) and two of those students responded to the post-survey (Appendix C). Twelve faculty responded to the pre-survey (Appendix B) and 11 faculty responded to the post-survey (Appendix D). It is unknown if there is any overlap in respondents between pre- and post-surveys for faculty.

In addition to the surveys, three students and four faculty participated in an interview (Appendices E & F) at the conclusion of the SURF program. Interview participants were recruited through the pre-survey. Unfortunately the response rates for surveys and interviews did not meet expectations. Therefore, additional research was conducted with students and faculty participating in semester-length undergraduate research experience in the College of Engineering at Purdue University during the spring 2020 semester.

Ten students responded to the pre-survey and three other students responded to the post-survey. Six faculty responded to the pre-survey and two of those faculty also responded to the post-survey. An additional four faculty responded to the post-survey as well for a total of six. Three students participated in the end-of-experience interview as well as one faculty mentor.

This dissertation used purposive sampling by using students and faculty within the SURF program and College of Engineering research experience at Purdue University. This type of sampling differs from a random sample study that may take participants from all undergraduate research programs at Purdue University. Studying students participating in research experiences from other colleges would not be suitable for the objectives of this study.

Context of the Present Study

The SURF program is available to Purdue students and undergraduate students from higher education institutions in the United States. The program is best suited for students in STEM disciplines but students in other disciplines are considered if projects and funding are available. Students in the SURF program conduct authentic research under the direction of a faculty member and a graduate student. A few program outcomes include: opportunity to present research discoveries, increase proficiency and technical communication, and gain experiences that will help with career goals. SURF also requires students to attend professional development seminars and students have the opportunity to participate in social activities including a banquet at the end of the program (https://engineering.purdue.edu/Engr/Research/EURO/students/about-SURF).

Faculty are expected to mentor participants by assessing skills and knowledge, defining expectations and responsibilities, and providing constructive feedback. Faculty should meet with their mentees on a regular basis and get to know their students on a personal level by discussing career options and graduate school options (https://engineering.purdue.edu/Engr/Research /EURO/info-faculty).

Additional research was conducted with students and faculty participating in semester-length undergraduate research experience in the College of Engineering at Purdue University during the spring 2020 semester. This consists of students enrolled in the 499 research course. There are many variations of "499" research experiences which differ by department. As an example, the Materials Engineering department states that the goal of 499 research is to provide the opportunity for laboratory and library research outside of normal coursework. Students who participate in 499 research within the department of Materials Engineering work under the guidance of a faculty mentor.

Successful completion of the course results in earning three course credits and learning laboratory skills beyond those taught in core courses and demonstrate some knowledge in experimental planning and execution. Another example of 499 research in the department of Mechanical Engineering specifies that students must be in junior or senior level curriculum and have prior research experience with a faculty mentor.

Students interested in participating must contact a faculty member and request a meeting to discuss research opportunities. Faculty mentors will discuss research, time commitment, expectations, etc. with prospective students. As a measure of accountability, students who decided to participate must complete a research contract with the faculty mentor which outlines the commitment, expectations, and how students will be graded. Examples of research opportunities are available on the College of Engineering website: https://engineering.purdue.edu/ME/Undergraduate/Files/Spring-2021-Research-Project-List.pdf

Survey and Interviews

This study used surveys and interviews to address the two key research questions. Pre and post-experience surveys asked students about the knowledge and skills they expected to acquire and how those will be helpful in the future. They were also asked to describe expectations for the mentoring relationship, what they hoped to gain, how often they expected to interact, and how the mentoring relationship would enable acquisition of STEM literacies. In addition, participants were asked to think about and share how they would interact with their mentor, how they expected to use technology to facilitate communicate, and what are the benefits and cons of using technology. Faculty mentors were asked the same questions about their student mentee.

Post experience interviews asked student participants to describe their work, talk about the project and how they became involved, describe acquisition of STEM literacies, discuss how they evaluate their work, provide a definition of STEM literacies, share how the undergraduate research experience is differentiated from other experiences in the acquisition of these literacies, and share the importance that their faculty mentor provide support in various areas. In the post-experience interview with faculty they were asked to describe mentee acquisition of STEM literacies and how important it was for their mentee to achieve specific outcomes.

Pre- and Post-Surveys

Undergraduate research participants and faculty were first surveyed prior to the start of the SURF program which began on May 20, 2019 and at the beginning of the semester-length research experience in January 2020. The pre-experience survey for students (Appendix A) asked questions regarding their expectations of acquisition of STEM literacies and their upcoming mentoring relationship with faculty and how technology will be used in that relationship. The framework for questions about expectations are derived from Pacifici and Thomson (2011) but guided by the research questions for this dissertation. When expectations are different than outcomes it may impact how students behave in the future in terms of pursuing additional research experiences (Pacifici & Thomson, 2011).

The pre-survey also asked what knowledge and skills the student hoped to acquire and how that would help them in the future. Students were also asked to share their expectations of the mentoring relationship and what they hope to gain from that relationship. The pre-survey asked students to describe how the relationship would enable acquisition of STEM literacies. Finally, students were asked various questions about the role of technology. At the end of the pre-survey students were also be asked if they would be willing to participate in an interview at the end of their research experience.

The pre-survey for faculty (Appendix B) asked what knowledge and skills they expect the student to acquire and how that would help them in the future. Faculty were also asked to share their expectations of the mentoring relationship and what they hoped students would gain from that relationship. The pre-survey also asked faculty to describe how the relationship would enable acquisition of STEM literacies for their students. Finally, faculty were asked various questions about the role of technology. At the end of the pre-survey faculty were also asked if they would willing to participate in an interview at the end of the research experience.

Undergraduate research participants and faculty were surveyed again at the conclusion of the undergraduate research experience in August 2019 and May 2020. The post-experience surveys (Appendices C & D) asked the same questions as the pre-surveys.

Post-Experience Interviews for Students

This dissertation provides data on the nature of mentoring relationships in the SURF program and semester-length research experience, and how those experiences influence the acquisition of STEM literacies. Interview questions for this dissertation (Appendix E) were adapted from Samarapungavan et al. (2006) to understand students' acquisition of STEM literacies such as problems they countered in their research and how they tried to solve these problems. Students were asked to describe their work, talk about the problem and methods used in the research, STEM literacies and how those literacies may be applied outside of research, and how students evaluate their work.

Interview questions to understand the nature of the mentoring relationship were adapted from Ibrahim et al. (2017). Students were asked how important it is in their undergraduate research experience for the faculty mentor to: address their needs, tap into interests, encourage honest criticism of ideas and work, encourage creative risk-taking, model skills needed for the research experience, and give the amount of time needed and be flexible with time (Appendix E).

Interview questions adapted from Samarapungavan et al. (2006) were also used to understand faculty perceptions of students' acquisition of STEM literacies (Appendix F). Faculty were asked if students encountered experiences that would help them solve other problems in life and provide examples. As a follow up, faculty were asked a series of related questions about experiences that would help them with specific future outcomes.

Interview questions to understand the nature of the mentoring relationship from the faculty point of view were also adapted from Ibrahim et al. (2017). Faculty were asked how important it was in the undergraduate research experience for their student mentee to: understand key concepts, connect old and new knowledge, understand how preconceptions affect learning, address doubts directly, apply previous knowledge to new concepts, extend inquiry beyond the research experience, apply new knowledge to future experiences, evaluate the research experience, reflect upon the research experience, construct new knowledge, and follow-up the project with new questions (Appendix F).

Coding and Analysis of Data

Data analysis was guided by qualitative research approaches for verbal protocol analysis (Chi, 1997; see also Samarapungavan et al., 2006). Survey results were downloaded to Excel from the Qualtrics survey software (https://www.qualtrics.com) and formatted. A separate coding template was created using Excel, with a different worksheet for each survey question. The template was organized by participant and theme. Coding began by doing an initial review of all responses.

Survey question one was coded using a priori or deductive, top down coding using the Engineer of 2020 framework (Appendix G) and STEM literacies from previous literature (Roth & Van Eijck, 2010; Tucker-Raymond et al., 2017; see Appendix H). In the coding template, the applicable portion of the survey response was added. By including the response itself, as opposed to just including an indicator, it allowed for consistency because all responses and codes could be continuously reviewed.

The remainder of survey questions were coded using inductive, bottom-up coding because the themes emerged during the coding process. If a response does not fit into an existing nominal code a new code was be created (Samarapungavan et al., 2006). The coding structure for survey questions two through ten are available in Appendix I.

Interviews were transcribed using transcription software and responses were organized by question and/or theme in Word documents (separate document for student and faculty responses). Similar to surveys, responses were also coding using STEM literacies from previous literature as applicable (Appendix H). The remaining interview questions were organized based on the question itself (i.e. evaluate success of educational studies in general, success of SURF program/research this summer, best work, and what differentiates undergraduate research experience). This includes questions about the mentoring relationship adapted from Ibrahim et al. (2017) in Appendix F.

Data was triangulated using survey and interview responses. To check for inter-rater reliability a subset of responses for all ten survey questions were coded by the dissertation advisor. This included three student responses and two faculty responses. Inter-rater reliability was calculated at 92% across all ten questions.

CHAPTER 4. RESULTS

Data collected for this study provided insight for the research questions: 1. What is the nature of interaction between student participant and faculty mentor? Subsidiary question: What is the role of technology in the mentoring relationship? 2. How do students and faculty describe the development of STEM literacies in the undergraduate research experience? Subsidiary question: How does the mentoring process contribute to the development of STEM literacies?

What is the nature of interaction between student participant and faculty mentor?

The study addressed the nature of interaction between student participant and faculty mentor via three questions on the pre and post-surveys. The questions included: Can you tell me about your expectations for the mentoring relationship with your faculty mentor? How often do you expect to interact with your faculty mentor? What do you hope to gain from this relationship? Faculty were asked the same questions about their student mentee. In addition to the survey questions, interviews also provided data to answer these questions.

Students were asked in the pre-survey what expectations they have for the mentoring relationship with their faculty mentor. Responses were coded in six themes (see Appendix I): letter of recommendation; general involvement/feedback; research itself and passion for research; relationship; graduate student/limited contact with faculty; and other. Coding frequencies and example responses are provided in Table 4 with a detailed summary provided below.

Table 4

Can you tell me about your expectations for the mentoring relationship with your faculty mentor?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post		
Letter of recommendation	2	0	1	0	"I expect my mentor to be helpful (and hopefully friendly), and be willing to work with me through any problems I may encounter."	"I hope I can use my experience to help them build some basic skills for research, and ignite their passion for exploring interesting topics."
General involvement/feedback	16	2	9	3		
Research itself and passion for research	0	1	9	5		
Relationship	7	0	2	2		
Graduate student/limited contact with faculty	3	1	2	2		
Other - expectations aligned	0	2	0	3		
Other - mismatch of expectations	0	0	0	4		

The majority of student responses in the pre-survey (16) were coded as general involvement/feedback. For example, “I expect my mentor to be helpful (and hopefully friendly), and be willing to work with me through any problems I may encounter,” was one of the responses coded in this theme.

Seven student responses were coded in the relationship theme wherein students talked about their expectations for a good professional relationship. One student noted:

> I expect to get a good professional relationship with him, I know that he is gonna be traveling a lot but I expect that at the final of the internship he feel proud of my work and my results as a Surfer.

Two students shared the expectation for a letter of recommendation. For example, “I hope that by the end of the summer, my faculty mentor will be willing and able to write a solid recommendation letter for me.”

Interestingly, three students mentioned they expected limited interaction with their faculty mentor and one of them expressed an expectation to get closer to their graduate student mentor. This student said:

> I expect to become closer and get more advise from my grad student mentor than the faculty mentor. As of right now, I see the faculty mentor is very busy while the grad student has more time to dedicate into mentoring.

In the post-survey students were asked if expectations for the mentoring relationship with their faculty mentor aligned with actual outcomes. Five students responded to the post-survey. Two responses were coded as general involvement/feedback. One student remarked, “They are very close. My mentor is very helpful, and he was always there to teach me new stuff.”

One response was coded in the research itself and passion for research theme where the student shared, “He also trained me to be more independent in learning and doing research.” In addition, one response was coded as graduate student/limited contact with faculty. This student described the relationship like a balancing act, “I expected a little more guidance, but it actually was more beneficial that I had some independence.” Two students were coded under the added theme of other/expectations aligned, which was an additional theme for post-survey responses. These students described how expectations aligned with outcomes, “My expectations aligned with the outcomes,” and “We were on the same page throughout.”

Faculty mentors were asked the same questions on the pre and post-surveys. Nine faculty responses were coded as general involvement/feedback compared to the 16 student responses. An example indicating general involvement:

> I expect students to keep me informed on their schedule and plans for work in the lab. I do not have any expectations on prior knowledge that the students have, and encourage them to ask very basic things that they do not understand.

There were also nine responses coded in the research theme, whereas no student responses on the pre-survey were coded in this theme. One mentor shared, "I hope I can use my experience to help them build some basic skills for research, and ignite their passion for exploring interesting topics." Another mentor said:

> UGS are highly talented and motivated, but need direction and guidance on how to conduct research and make presentations. The main goal of the mentor is to teach methods, explain the research plan and help students with analysis and presentations. Once the student understands these, they become independent and more confident.

Two faculty responses were coded in the relationship theme. For example, "I also support and encourage them to develop a mentoring network with other students, researchers, staff, and faculty." In addition, two faculty responses were coded in graduate student/limited contact with faculty. One mentor explained, "If they are supervised by grad student, then talk with grad student primarily, particularly if finding an available meeting time is difficult." Another mentor said:

> When I first started at Purdue I mentored and supervised undergraduate student researcher directly. Now that my lab and responsibilities have greatly expanded, I can no longer do that. The students work directly with a graduate student and a post doc and I interact with them directly in one-on-one meetings only 2-3 times a semester. They do participate in project meetings and I can evaluate their progress through those also.

Finally, one faculty response was coded in the letter of recommendation theme.

In the post-survey faculty were asked if expectations for the mentoring relationship with their students aligned with actual outcomes. Five faculty responses were coded in the research theme. For example, "I would say they aligned pretty well. The student was able to understand most of the experiments that were conducted and was able to become independent in conducting said experiments after a certain period of time," was one of the responses coded in this theme.

Three faculty responses were coded as general involvement/feedback. One mentor described the relationship based on the preset expectations:

> I meet 1-1 with them for 30 minutes each week. If they signed up for one credit hours, the expectation is that they will do ~3 hrs of research, per honor system. If they have tests that week, they will do less research and make up later. I want the student to be responsible for the work, no spoon feeding from me… just trying to keep them on track.

Two responses were coded in the relationship theme:

> My expectations for the semester were to being able to engage the students both from a professional stand point as well as personal. The latter became important given the current COVID-19 situation. Overall, I am very happy of the outcomes of the mentoring relationship.

In addition, two responses were coded in the grad student/limited contact with faculty category. One mentor noted, “Most of the mentoring was accomplished by a senior post-doctoral researcher.”

Finally, three responses were coded as other/expectations aligned and three were coded as other/mismatch of expectations. Regarding aligned expectations, one mentor remarked:

> For the most part, yes these two aligned. Given the short time of the SURF project, as well as this year's student being relatively inexperienced, at least with respect to the overall knowledge needed for the project, we tempered our expectations somewhat. Nonetheless, some decent progress was made, and some help to the graduate student already on the project was provided.

With regard to expectations not aligning with outcomes, one mentor stated this:

> Poor alignment. Our student had a very impressive sounding resume, but much of that experience involved pushing buttons to acquire data without any effort made to understand the underlying science or broader context. It became very apparent that our SURF student had little experience doing much more than following orders. Consequently, the student fell well short of initial expectation. To be, clear this is not to say the experience was a negative one. Quite the contrary. Both we and student benefitted.

Overall, these results demonstrate that for faculty the mentoring relationship is beneficial for research whereas in general students expected general involvement/feedback from the mentoring relationship.

The nature of the relationship between student participant and faculty mentor is also described in terms of the frequency of meetings. The pre-survey asked students how often they expected to interact with their faculty mentor. Responses were coded in seven themes (see Appendix I). Coding frequencies and example responses are provided in Table 5 with a detailed summary provided below.

Table 5

How often do you expect to interact with your faculty mentor?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post		
Daily	2	0	6	5	"Maybe 5 times during the summer. I do expect more contact with my graduate mentor."	"As needed. Our SURF student was supervised by two graduate students. When the SURF student was engaged in an individual task, it was not uncommon for us not to interact for a day or two. Otherwise, there was a frequency and almost daily interaction."
Every other day	2	0	0	1		
1x per week	9	1	7	5		
More than 1x per week	3	2	3	3		
Biweekly	5	1	0	0		
Monthly	1	1	0	1		
Other	0	0	3	1		

The majority of students (9) of students said they expected to meet with their faculty mentor once per week. Five students reported that they expected to meet with their mentor biweekly, three noted more than once per week, two expected to meet every other day, two wanted to meet every day, and one thought they would meet with their mentor once a month.

As was the case in the question above on expectations for the mentoring relationship, responses to this question also mentioned the role of the graduate student mentor. In the pre-survey one student shared, "Maybe 5 times during the summer. I do expect more contact with my graduate mentor." Another student explained, "I interact directly with my graduate mentor, so I expect to see my faculty mentor maybe twice a month."

The post-survey asked student participants how often they interacted with their faculty mentor. Five students responded to the post-survey and two said they met with their faculty mentor more than once a week, one student reported once per week, one stated biweekly meetings, and one reported monthly. Meeting with the graduate student mentor was mentioned by one student in the post-survey as well. "My faculty mentor I saw twice a week. My grad mentor was there every day except the weekends I was in the lab."

Faculty mentors were asked the same questions as students on the pre and post-surveys. In the pre-survey six faculty said they expected to meet with their mentee every day, seven noted expectation to meet once a week, three talked about meeting more than once a week, and three were coded as other because they said they expected to meet with their mentee as needed or a few times a semester.

On the post-survey five faculty reported meeting with their mentee daily, another five cited meeting once a week, three mentioned meeting more than once a week, one said they met every other day, and one indicated a monthly meeting schedule. In addition, one faculty response was coded as other.

Faculty mentors also talked about mentees meeting with graduate students. In the post-survey one faculty mentor shared:

> As needed. Our SURF student was supervised by two graduate students. When the SURF student was engaged in an individual task, it was not uncommon for us not to interact for a day or two. Otherwise, there was a frequency and almost daily interaction.

Another faculty mentor noted:

> At least 1 meeting/week. Used to have one-one meetings with them until the last 2 years, when I've paired them more with grad students together once/week. Also have group lab meeting which most of them attend. Formal mid-semester evaluation, and setting goals at the beginning of the semester.

With respect to the nature of interaction between student participant and faculty mentor, it's important to take note of the emerging theme of the interaction between the student participant and graduate student mentor. Working with graduate student mentors was also discussed in the post-experience interview. One student said, "The only way I would get past something that I didn't know is contacting my grad student and asking questions. So I guess I learned to ask questions when I'm faced with a problem like that."

In an effort to learn more about the nature of the mentoring relationship the pre and post-surveys also asked students and faculty what they hope to gain from the mentoring relationship. Responses were coded in seven themes (see Appendix I): letter of recommendation; relationship/mentoring/networking; skills/general knowledge; research; qualities; future opportunities; and other. Coding frequencies and example responses are provided in Table 6 with a detailed summary provided below.

Table 6

What do you hope to gain from this relationship?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post	"I hope to glean as much knowledge and intuition as possible from my mentor to further my understanding of machine learning."	"I hope they gain an appreciation for the process of inquiry and the power of science. I also hope that they will recognize that science is not down in a vacuum and that by doing collaborative research they can achieve more than they can alone."
Letter of recommendation	6	0	0	1		
Relationship/mentoring/networking	6	3	3	5		
Skills/general knowledge	7	1	7	7		
Research	6	2	7	7		
Qualities	0	1	1	6		
Future opportunities	8	0	6	4		
Other	1	1	2	0		

In the pre-survey, eight students talked about future opportunities such as graduate school or career opportunities. One student shared, “He gives me insight as to what it’s like to be an engineer, and he has also given me help on deciding to pursue a Master’s in Mechanical Engineering.”

Seven students indicated they hoped to gain knowledge or skills. One student responded by saying, “I hope to glean as much knowledge and intuition as possible from my mentor to further my understanding of machine learning.” Another student responded said they hoped to gain inter personal skills.

Six responses were coded in the research theme. In the pre-survey one student remarked, “I hope to gain experience and wisdom when it comes to research and hopefully graduate school.” Another student noted, “I hope to enhance my understanding of the research process.”

In addition, six students expressed sentiments related to relationships and networking. For example, one student shared, “I hope to gain a good working relationship and a professional mentor.” Finally, six students indicated they hoped to get a letter of recommendation and one response was coded as other, citing, “He has certainly become an invaluable asset in my life.”

In the post-survey students were asked what they gained from the mentoring relationship. Three responses were coded in the relationship/mentoring/networking theme. One student shared, “I made good friends with my mentor” and another said, “A networking opportunity, and a faculty member that I could always go to if I needed a reference or help.”

Two responses were coded in the research theme, wherein one remarked, “I learned actual stuff relates to the research topic, and I gained a passion for the field and my major.” One response was coded in the skills/general knowledge theme. This student explained, “I gained experience in talking to people older than me and being comfortable asking questions.” In addition, one response was coded in the quality theme. “I gained a lot of confidence in myself I didn't know I had." Finally, one response was coded as other because the student mentioned earning academic credit.

In the pre-survey when faculty were asked what they hope students gain from the relationship the majority of faculty indicated research (7) and knowledge or skills (7). For example, regarding research, one mentor shared:

> I hope they gain an appreciation for the process of inquiry and the power of science. I also hope that they will recognize that science is not down in a vacuum and that by doing collaborative research they can achieve more than they can alone.

With regard to knowledge and skills, one faculty said, "Critical thinking requires practice and can be learned by observing others who engage in that skill."

Six faculty provided responses related to future opportunities. For example:

> I hope the students will realize that as a mentor I want them to succeed in all aspects of their life; career, interpersonal, relationships, and health. I want the students to know that I am here to push them in the right direction in all of these aspects.

Three faculty responses that were coded in the relationship/mentoring/networking theme. One mentor noted, "The ability to establish a working relationship with a mentor and what to look for and avoid with poor mentors." Finally, two responses were coded as other and one response was coded in the qualities theme.

In the post-survey responses from faculty followed the same pattern. Seven faculty responses were coded in the research theme and seven in the skills/general knowledge theme. Regarding research, one mentor explained, "Getting a sense that being interested in science does not mean one is actually interested in research. They gained an appreciation for what it takes to do high quality research." Pertaining to knowledge and skills, one noted, "It was helpful for the graduate student involved in the project to mentor the undergraduate. This helped with his communication skills, as well as learning how to guide a beginner into a difficult subject area."

Six faculty responses were coded in the qualities theme. For example, one mentor mentioned, "Ideally the students have gained confidence in their ability to do work, confidence in their ability to interact with a supervisor and be open/honest about what they do or do not understand."

In addition, five responses were coded in the relationship/mentoring/networking theme. For example, "I believe the student gained a deeper relationship with a professor," was one of the responses coded in this theme. Four responses were related to future opportunities. One mentor remarked, “Finally, all students have a better idea or what they would like to do post graduation.” Lastly, one faculty mentor mentioned that some students request letter of recommendation.

Results from this survey question, asking what they expected to gain, and what they actually gained, show that STEM literacies and cultural capital are important.

In addition to the information gleaned from the surveys, post-experience interviews from students and faculty also provided information on the nature of the mentoring relationship. During the post-experience interview when asked if the faculty mentor tapped into their interests one student responded by saying:

> Well, it's also important because, if you don't feel motivated to do something, you will not do it in the best way or with the... Yes, you will not do it the best way. So he, every time we made experiments, he was really motivated, and he say, Okay, you remember this time, how we read. Like he was involved a lot in the research. And I think that was a really good thing that I had, because I was very involved with my professor. I'm very involved with the research. And, we start from zero, so that was like a special thing that I had this summer.

More common was the sentiment of room for improvement in the relationship between the faculty and mentee. During the post-experience interview one student mentioned their faculty mentor but felt he/she had less support as compared to the classroom.

> I think in classes, it's usually the textbooks... If it's a good professor, the textbook is broken down for you. They will always stop. If you're not understanding, they will explain again, you can ask questions. But in terms of research, you have your mentor, you have your professor, but the volume of papers that you read and the breadth of papers that you read is I think a lot wider. There's also different writing styles for each paper, depending on who the author is. It's definitely not as concentrated as a formal education standpoint. For research, I would say it's different in that you had to be a lot more flexible, a lot more self-driven. I think ultimately it makes you stronger in obtaining a STEM literacy. But it definitely takes a lot more effort and is a lot more discouraging because of the overall lack of support. Not as much support.

During the post-experience interview when asked about the importance that the faculty mentor address their needs one student shared:

> That was very important to me. And I didn't feel like I always got that, just because I never saw them. Besides email and then setting up the meeting, which I didn't expect. I thought I would see them almost every day or every other day. But that's very important, because I didn't know what to do as a first time researcher. We have weekly meetings. And then I would schedule individual meetings whenever I needed. Whenever I felt like I needed more assistance or he came to me wanting to meet. So at least 11.

It seems that this student did not feel that their expectations of the faculty mentoring relationship were met. When asked during the post-experience interview if their faculty mentor tapped into their interests another student stated, "That would've been nice, but that didn't happen."

Another student expressed that he/she wished they had gained more of a relationship with their faculty mentor:

> I do wish I gained more of a relationship with my faculty mentors. Because I don't really think I have one. But, when I did meet with them, they were very helpful. They were very respectful. They know that I'm an undergrad and I don't necessarily know everything, but they didn't make me feel stupid either. Which was good. Professionally, all of that was really great. It's just the, I guess, personal relationship that I would want to have for, maybe, they talk about having them write graduate school recommendation letters. And I don't think I would, I'm close enough, to have that.

During the post-experience interview a faculty mentor described undergraduates not being comfortable working with faculty:

> And so sometimes, they work closely with a graduate student and the graduate student tends to work closely with me. The undergraduates are a little less comfortable working with faculty. I try to make that less of a barrier than you would typically experience. Faculty are people their parents age and they're not somebody that they actually closely collaborate with typically.

The faculty mentor continued by saying:

> The students are more closely their age and so they feel much more comfortable. So I try to do it, but ultimately they get to feeling comfortable enough that they come in and they will talk, and once they do that... Because you know, look, most of these people are close

> to getting their BS degree. And if they were to go off in industry, they would work with people my age in a close, professional relationship and have to participate as an equal and a team. And so they need to learn that they're certainly capable of that.

Survey and interview results provide examples of positive relationships between student participants and faculty mentors such as providing general feedback/involvement, facilitating the acquisition of STEM literacies, and helping students gain cultural capital. However, students also expressed room for improvement in the mentoring relationship.

What is the role of technology in the mentoring relationship?

The study addressed the role of technology in the mentoring relationship by asking student participants four questions on the pre and post-surveys. The questions included: How will you interact with your faculty mentor? How do you expect technology to facilitate your undergraduate research experience with regards to the relationship with your faculty mentor? What do you think are the benefits of using technology to interact with your faculty mentor? What are the cons of using technology to interact with your faculty mentor? Faculty were asked the same questions about their student mentee. In addition to the survey questions, interviews also gleaned salient information.

At the beginning of the SURF and spring semester research experience students were asked how they will interact with faculty mentor. Responses were coded in five themes (see Appendix I): in person one-on-one; in person group; email; virtual (including Slack, text, call); and other. Coding frequencies and example responses are provided in Table 7 with a detailed summary provided below.

Table 7

How will you interact with your faculty mentor (in person, email, etc.)?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post	"Emailed to set up in person meetings. Since the covid shutdown, all info has been communicated over e-mails."	"Face-to-face meetings cannot be substituted; they are the most effective. Weekly in person meetings are required."
In person - one on one	16	5	17	16		
In person - group	2	0	4	2		
Email	18	4	14	11		
Virtual (Slack, text, call)	3	1	5	5		
Other	0	0	1	4		

The majority (18) of student responses were coded in the email theme. All students had at least part of their response coded in this theme. As an example, one student remarked, “I will email when I have any questions or am asking to meet.”

Sixteen student responses were coded in the in person one-on-one theme. “I will meet with my faculty mentor in person.” Two more students indicated they would meet in person with their faculty mentor in group meetings. Finally, three responses were coded in the virtual theme.

In the post-survey students were asked how they interacted with their faculty mentor. Five responses were coded as in person one-on-one. Four responses were coded in the email theme. One student explained, “Emailed to set up in person meetings. Since the covid shutdown, all info has been communicated over e-mails.” One response was coded in the virtual theme because the student mentioned texting to set up meeting times.

Faculty were asked in the pre-survey how they expect to interact with their student mentee. Seventeen faculty mentors indicated an expectation to meet with their mentee in person one-on-one. One faculty mentor stated, “Face to face meeting cannot be substituted; they are the most effective. Weekly in person meetings are required.” In addition, Four mentor responses were coded in the in person group theme. For example, one mentor explained:

> We interact as a research team, where everyone has a role, but can get help from others. My job is to set the goals and research plan and see that everyone knows their role and feels like an important member of the team. This is done in person, with occasional emails.

In addition, 14 faculty mentors indicated they expected to interact with their mentee via email. Five responses were coded in the virtual theme which includes mediums such as Slack, text, or phone call. One mentor shared, “We have a lab Slack account that can be used for messaging as well.” Finally, one faculty response was coded as other. This mentor explained, “I don’t link to social media profiles until after they are finished in the lab, or until they are a grad student.”

Post-survey results from faculty were similar to pre-survey results with 16 faculty mentors indicating they interacted in person with mentees one-on-one. For example, one faculty mentor said:

> Mostly in person. Occasionally, I’d indicate coming deadlines, but follow up with in person meeting to outline what is necessary to meet the reporting requirements. In person

meeting allow for the students to ask questions and make clear what's required and discuss any other issue that's important.

Two faculty indicated they met with mentees in person for research group meetings.

Eleven responses were coded in the email theme. One mentor described the shift in communication as a result of the pandemic, "This semester the interactions were in person through Spring Break, and then frequent emails thereafter." Five faculty responses were coded in the virtual theme. One mentor indicated use of phone calls, GroupMe, and WebEx to interact with their mentee. Finally, four responses were coded as other. One faculty mentor said, "He also attended dinner and events at my home." Another mentor shared, "We also had research group get togethers every two weeks on Fridays for more informal hang out time."

The post-experience interview also provided insight on the interaction between faculty mentor and mentee. One mentor shared:

> Yeah, so we have regular meetings, and on an ongoing, daily basis, they interact with the graduate students that they're working with. So it turns out that the two that I have, one is here with the graduate students here, but one is actually in Colorado on an intern and so they have teleconferences on a regular basis. So they share information like that. So that's the technical data.

Students and faculty were also asked how they expect to use technology to facilitate the undergraduate research experience with regards to the mentoring relationship. Responses were coded in five themes (see Appendix I): basic communication; collaborative communication; presentations; research/data analysis; and other. Coding frequencies and example responses are provided in Table 8 with a detailed summary provided below.

Table 8

How do you expect to use technology to facilitate your undergraduate research experience with regards to the relationship with your faculty mentor?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post		
Basic communication (scheduling)	11	3	8	8	"Email is the best mode of contact for scheduling in-person meetings."	"Technology can be distracting - they already are too tied to phones and devices."
Collaborative communication	4	3	2	5		
Presentations	2	0	2	5		
Research/data analysis	4	0	3	3		
Other	3	0	7	5		

On the pre-survey 11 students indicated they expected to use technology for basic communication such as scheduling. One student mentioned, “Email is the best mode of contact for scheduling in-person meetings.”

Four student responses were coded in the collaborative communication theme. One student noted, “I expect to use technological platforms not only to communicate but also collaborate. For example, Box, Github, Slack, Fusion, etc.” Another student said, “Also, we do e-meetings with another Co-PI from Virginia Tech.”

In addition, four students indicated they expected to use technology for research or data analysis. One student explained, “My research centers around technology and allows are lab to share information quickly and efficiently.” Two students indicated they expected to use technology for presentations. For example, “We also use technology to present our weekly powerpoints.” Finally, three responses were coded as other. One student noted, “Our main resource is our lab’s website where information is stored regarding resource allocation and schedules.”

The post-survey asked students how technology was used to facilitate the undergraduate research experience with regards to the relationship with their faculty mentor. Three responses were coded in the basic communication theme. For example, “I used email to communicate with my faculty advisor,” was one of the responses coded in this theme. In addition, three responses were coded in the collaborative communication theme. One student shared, “Communication with my mentor is easier with the help of technology. He would share articles to our research topic with me through email.”

During the post-experience interview one student described the role of technology in collaborating with teammates:

> We have all of these cloud drive we had to use and databases for when I was doing literature research at the beginning and I'd have to take out the important parts and tag them and organize in the right files that my teammates and anyone else who's looking for the similar information can find it. And learn how to, for the code and for software stuff, how to download it and push it back to the cloud and making sure everything was updated and labeled so that everyone else could understand my work and why it was important or applicable to what I was working on that week.

Faculty were asked the same questions regarding use of technology in communicating with their mentee. In the pre-survey eight faculty responses were coded in basic communication. One mentor explained, “We use Slack for lab communication and a listserv for sharing seminar announcements. We also use Google calendar for meetings, lab/field activities, etc.”

Three faculty responses were coded in the research/data analysis theme. One mentor noted, “She will learn how to use python for data analysis.” Another mentor said, “Students keep electronic lab notebooks in my group so when we meet, we will use this to discuss their program and look directly at the data.”

Two faculty responses were coded in the collaborative communication theme. One faculty shared, “Technology allows us to have rapid communication to solve problems, share results, etc., as they occur, rather than wait for formal meetings, for example.” In addition, two faculty indicated they expected technology to be used for presentations. “Students present their work and presented via powerpoint,” was one sentiment shared by a faculty mentor. Finally, seven pre-survey responses from faculty were coded as other. For example, one mentor remarked, “In person communication abolishes the need for technology.”

Post-survey results were similar with eight faculty responses coded in basic communication. One mentor said, “Technology (email) allows for immediate needs. However, it has inefficiencies that then responses are limited and not fully discussed.” In addition, five responses were coded in the collaborative communication theme. For example:

> Since the project was very dynamic and needed constant communication, we set up a chat group to facilitate timely communications. WebEx helps staying in touch, reviewing progresses and challenges. I have engaged my graduate students as well to be part of the program to broaden the experience.

Five faculty responses were coded in the presentations theme. “The student was required to give a powerpoint presentation each week on research results.” Three faculty responses were coded in the research/data analysis theme. One mentor talked about their mentee analyzing results in Excel, Matlab, and Graphpad Prism. This mentor also noted that results are stored in cloud-based software. Finally, five pre-survey responses from faculty were coded as other. One response sheds light on how technology can be perceived differently but students and faculty, “Technology can be distracting – they already are too tied to phones and devices.”

Students and faculty were also asked about the pros and cons of using technology to interact during the undergraduate research experience. Students were asked: What do you think are the benefits of using technology to interact with your faculty mentor? Faculty were asked the same question about their mentee. Responses were coded in four themes (see Appendix I): communication – quick/easy/convenient; communication – effective; research/skills; and not effective/none/other. Coding frequencies and example responses are provided in Table 9 with a detailed summary provided below.

Table 9

What do you think are the benefits of using technology to interact with your faculty mentor?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post	"Using technology can be easier for communication in case my mentor is not in the office or is at a meeting. That means instead of waiting outside his office for him to return, I can email him and continue to work in the lab until he reads the email."	"The technology is the platform to summarize data (ie powerpoints/graphs) so this is critical to discussing the outcomes and results."
Communication - quick/easy/convenient	16	3	9	6		
Communication - effective	3	2	1	2		
Research/skills	0	0	5	3		
Not effective/none/other	0	0	5	4		

The majority of student responses on the pre-survey (16) were coded as communication – quick/easy/convenient. One student noted:

> Using technology can be easier for communication in case my mentor is not in the office or is at a meeting. That means instead of waiting outside his office for him to return, I can email him and continue to work in the lab until he reads the email.

Three student responses were coded in the communication – effective theme. One mentee shared, “Using technology to present data or plans for a project can be much more straightforward and effective than orally presenting. This can allow for deeper discussion.” Another student said, “We can efficiently and effectively communicate to not only each other, but the other students in the research group.”

The post-survey asked the same question. Three responses were coded in the communication – quick/easy/convenient theme. One student remarked, “Professor and researchers are both busy so using technology ensures that a message gets sent if one of the two people aren’t available to meet in person.” In addition, two responses were coded in the communication – effective theme. For example, “A record of conversation exists if using email, also don’t have to coordinate meeting time to fit busy schedules if using email,” was one of the responses coded in this theme.

Similar to students, in the pre-survey nine faculty responses were coded in the communication – quick/easy/convenient theme. For example, one mentor commented, “It takes less time and provides more flexibility.” One response was coded in the communication – effective theme, the mentor stated, “Transmit and document information when not in the same room.”

However, faculty responses differed from student responses in that they expected technology to be beneficial for research and developing skills whereas no student responses were coded in this theme. Five responses were coded in the research/skills theme. One mentor shared, “She will develop skills that can be applied widely in other studies.” Another mentor said, “The technology is the platform to summarize data (ie powerpoints/graphs) so this is critical to discussing the outcomes and results.”

Faculty responses on the expected benefits of technology reported on the pre-survey also differed from student responses in that several faculty expressed that they did not think technology would be effective or that there were no benefits. Five faculty responses were coded as not effective/none/other. One mentor remarked:

> I don't think technology adds to the interaction for a research project. Nothing, in my opinion, can replace the in person weekly meeting in which results are discussed, questions are asked, and you can get the real sense of how much the student is really learning about the topic. This info just cannot be completely gleaned from another type of interaction.

When asked about the benefits of technology in interacting with their mentee, another faculty mentor said, “None. With the exception that students need to learn email etiquette. Minimize number of emails through thoughtful crafting of text to avoid confusion. Emails should be treated as formal communications rather than text messages in the work place.” These sentiments provide additional examples of how technology is perceived differently by faculty and students in terms of how it is used for communicating.

In the post-survey six faculty responses were coded in the communication – quick/easy/convenient theme. For example, one mentor noted, “Maintain a connection when face to face meetings are impossible.” In addition, two faculty responses were coded as communication – effective. One mentor reflected on the experience by saying, “I am able to guide my mentee without physically being present in close proximity." Three faculty responses were coded in the research theme. One mentor explained:

> Always better to have high quality slides made each week for presentation of results, particularly this student who had to show pictures of the time evolution of her samples over several days (and to monitor and describe the visual appearance.

Finally, four post-survey responses were coded as other because they indicated technology was not effective or there was no benefit in using technology to interact with mentee. One faculty mentor said:

> It would be a liability. Humans are already suffering from too much reliance on electronic devices instead real human interaction. The opportunity for one-to-one human dialog is a major benefit of this program at a critical stage in the student's professional development.

Again, another example of the emerging theme mentioned above.

Students and faculty were also asked about the cons of using technology to interact. Responses were coded in four themes (see Appendix I): insufficient; impact on in person interaction; technology issues, and none/other. Coding frequencies and example responses are provided in Table 10 with a detailed summary provided below.

Table 10

What are the cons of using technology to interact with your faculty mentor?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post	"I don't think there are cons of using technology to interact with him."	"Students are already familiar with technology, often lacking in one on one communication skills or professional skills."
Insufficient	5	3	6	3		
Impact on in person interaction	7	2	11	7		
Technology issues	1	0	1	1		
None/Other	8	1	3	3		

In the pre-survey seven student responses were coded in the impact on in person interaction theme. One student shared, "Less personal, don't always know when they will reply or if they saw the message, easier for both sides to "ghost" each other." Another student said:

> If too much interaction occurs via email or through a screen, I think I could lose the personal aspect of the relationship. While it is professional, there is a chance to connect as people. This chance could be lost by using technology.

Five student responses were coded in the insufficient theme. One student commented, "Technology does not always allow for the best communication." One student response was coded in the technology issues theme. This student noted, “When technology failed, we had to present our powerpoint off a laptop screen.”

Finally, eight student responses were coded as none/other. One student said, “I don’t think there are cons of using technology to interact with him.” Another student said, “I can’t think of any.” Although some students did note cons in using technology, it’s interesting to note that the issue did not come up until students were prompted to actually think about how technology might be negative. Whereas the drawbacks of technology were noted by faculty several times without being prompted to think about cons. As noted above, even when prompted, a number of students didn’t think there were any issues with technology.

The post-survey asked the same question. Three responses were coded in the insufficient theme. One student said, “The wording of communications is hard to articulate, and if worded improperly could be cause for confusion.” Two responses were coded in the impact on in person interaction theme. For example, one mentee noted, “Less in person communication. Harder to get ideas across.” Finally, one response was coded as none/other.

In the pre-survey 11 faculty responses were coded in the impact on in person interaction. One mentor shared, “Students are already familiar with technology, often lacking in one on one communication skills or professional email skills.”

Six responses were coded in the insufficient theme. For example, “Use of email alone does not allow me to determine if the student is struggling, or what they do and do not know,” was one of the responses coded in this theme. In addition, one response was coded in the technology issues theme. This mentor said, “We all use many different platforms so can be challenging to remember to use them when starting.” Finally, three faculty responses in the pre-survey were coded as none/other.

In the post-survey seven faculty responses were coded in the impact on in person interaction. For example, “Face-to-face interactions cannot be substituted 100%. Being behind a monitor/cam provides a sense of distance.” Another said:

> I do not get to have as personal of a relationship with the students that do not reach out to ask for in person meetings. I don't feel that I know them quite as well or what they are going through, except through the descriptions of how their direct mentors give to me.

Three faculty responses were coded in the insufficient theme. One mentor shared:

> As noted in the previous answer, the main problem I have is that student learning does not generally occur at a regular pace/rhythm. Therefore, the typical "scheduled" use of technology for interaction does not lend itself well to students making meaningful progress...they feel pressed to have "something" to present (i.e., rush through work), or they fail to progress for long periods of time as they await the next meeting. Further, students often ask questions that can be answered quickly, but are more effective if we go into long digressions on side/background topics...and these do not generally fit in a "scheduled" meeting.

One faculty response was coded in the technology issues theme. This mentor noted, “When the network is slow, it is challenging to share needed information.” Finally, three responses were coded as none/other.

Survey and interviews regarding the role of technology in the mentoring relationship reveal some differences. Faculty saw the value as it relates to research but a pessimistic sentiment was noted when using technology for communication.

How do students and faculty describe development of STEM literacies in the undergraduate research experience?

The study addressed how students and faculty describe development of STEM literacies in the undergraduate research experience during the post-experience interviews and via two questions on the pre and post-surveys. The questions asked: What knowledge and skills do you expect to acquire from your undergraduate research experience? How will the knowledge and skills you hope to acquire through this experience help you in the future? Faculty were asked the same questions about their student mentee.

The pre-survey asked what knowledge and skills they expect to acquire from the undergraduate research experience while the post-survey asked what knowledge and skills were acquired. Responses were coded in 34 themes (see Appendices G and H). Coding frequencies and example responses are provided in Table 11 with a detailed summary provided below.

Table 11

What knowledge and skills do you expect to acquire from your undergraduate research experience?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post	"-Ability to work effectively in a research lab setting -Preparation for Graduate School -Concepts of Machine Learning and their recent applications."	"I believe my student acquired a range of skills including statistical analysis and data inspection through the program R, written and oral communication skills, an understanding of research and the iterative nature of study, and an appreciation for the challenges and insights of studying psychological phenomena through both quantitative and qualitative methods."
Abilities - communication	13	3	11	10		
Abilities - teamwork	2	1	3	2		
Abilities - other	2	1	5	6		
Knowledge - engineering fundamentals	5	0	0	2		
Knowledge - analytical skills	3	0	6	6		
Knowledge - other	17	4	15	12		
Qualities - other	3	1	4	2		
**Select themes out of 34*						

In the pre-survey, 13 responses were coded in the abilities – communication theme. Responses included learning how to write a technical paper and how to prepare presentations. For example, "I hope to improve many skills including my technical writing, ability to work in a team, problem-solving capability, and overall persistence in an environment that resembles graduate school." The technical writing portion of that student's response was coded in the abilities – communication theme.

In addition, two student responses were coded in the teamwork theme because they talked about working in a team and learning how to collaborate with a team. One student shared, "How to use the manufacturing tools in Bechtel. How to write research papers. How to design and perform an experiment. How to collaborate with a team on a long term research project." Finally, two responses were coded in the abilities – other theme. Those student responses were related to literature search and citation skills.

Seventeen student responses were coded in the knowledge – other theme. Students talked about developing research skills, lab etiquette, and preparation for graduate school. Five responses were coded in the knowledge – engineering fundamentals theme. One student explained, "Well, since my research experience was a Mechanical Engineering based experience, I expect that I will gain actual engineering experience and to make good connections with people that do research along the way." Three responses were coded in the knowledge – analytical skills theme. For example, one participant stated, "I hope to improve my Chemical Engineering analytical skills." Two responses were coded in the knowledge – science and math theme. Both of these responses mentioned machine learning. Finally, two responses were coded in the knowledge – open ended design and problem solving skills theme. One student talked about attacking open-ended research problems and the other mentioned problem-solving capabilities.

In the pre-survey only three student responses were coded in any theme related to qualities and they were all coded in qualities – other. These students described accountability, confidence in conducting research, and persistence. One student response was coded in the literacies – expand knowledge theme. This student noted:

> I hope to understand the methodology of research in the academic world and also the culture. As for skills I would like to know how to devise and operate my own experiments and how to collect and understand the data acquired.

Finally, one response was coded in the literacies – documenting making processes and/or milestones theme. “I expect to gain an understanding of the overall research process through documenting in a lab notebook, communicating with my professor and grad student mentor, and presenting my work.”

In the post-survey students were asked to describe the knowledge and skills they acquired during the undergraduate research experience. Three responses were coded in the abilities – communication theme. One student described their experience by stating, “I learned how to write a research paper, how to communicate with graduate students and professors, and how to work in a lab.” One response was coded in abilities – teamwork and one response was coded in abilities – other. This student talked about gathering information from online sources.

Related to knowledge, two post-survey responses were coded in the knowledge – open ended design and problem solving skills theme. Both students listed problem solving as part of their answer to the question. Four responses were coded as knowledge – other. These students discussed working in a lab and conducting research. One student said:

> Knowledge and skills besides what I learned in classes and lectures. For example, I learned how to operate devices in the lab such as the spin coater. I also learned that research is more independent. We need to learn how to gather information from online resources.

Three responses were coded in theme related to qualities. One response was coded as quality – innovative. This student mentioned innovative solutions when asked what knowledge and skills they acquired. Two responses were coded as qualities – other because independent learning was noted in their response.

In the pre survey, similar to students, 11faculty mentor responses were coded as abilities – communication. Mentors mentioned oral and written technical communication, scientific writing, and presentation skills. For example, “Some basic technical knowledge related to the project. How to carry out original research. How to design and carry out experiments/tests of a research hypothesis. How to communicate effectively research results in written and oral form.” Three faculty responses were coded in the abilities – teamwork theme. One mentor talked about their expectation for their mentee to function effectively in teams. Five responses were coded in the abilities – other theme. Faculty mentor responses coded in this theme talked about time management and conducing literature searches.

Regarding the acquisition of knowledge, the majority (15) of faculty responses were coded as knowledge – other. Most of these responses were related to research and lab skills. One mentor shared, “How to perform basic tasks performed in a modern biochemistry laboratory. How to formulate a well designed project and to be able to justify it to others.” Six faculty responses were coded in the knowledge – analytics theme. Faculty mentioned analyzing results, coding, and statistical techniques. In addition, two faculty responses were coded as knowledge – science and math. One mentor said they expected their mentee to “know some literature about the visual deficits in Fragile X syndrome (FX).”

Four faculty responses in the pre-survey were coded in the qualities – other theme. These responses mentioned independence, confidence, persistence and commitment. One response was coded in the qualities – strong work ethic theme. In response to what knowledge and skills they expect the student to acquire this mentor said:

> Strong work ethic and commitment to completing tasks. One response was coded in the qualities – ethically responsible in global, social, intellectual, and technological context. This mentor provided a list of knowledge and skills they expected the student to acquire and one was “ethics of human research.

Finally, one response was coded in the qualities – curious and persistent continuous learners theme. This mentor said:

> I would like my student to get more exposed to practical side of the biological systems so that they get better understanding of the processes. It will be nice to help them gain confidence and increase their curiosity to know more.

In addition, two faculty responses were coded in the literacies – expand knowledge theme. One mentor noted, “I would like my student to get better understanding of the system we are working on, more practical knowledge about the cellular processes.” Finally, one pre-survey response was coded in the literacies – documenting making processes and/or milestones theme. "Basic lab bench skills (pipetting, making solutions) and learning how to organize data and keep records (lab notebook). Basic generation of hypotheses, and understanding how to design experiments (controls)."

In the post-survey ten faculty responses were coded as abilities – communication. Similar to the pre-survey, faculty mentioned oral and written communication, scientific writing, and presentation skills. For example, "Professional skills such as presenting research work." In addition, two responses were coded in the abilities – teamwork theme. Finally, six responses were coded in the abilities – other theme. Responses in this category mentioned time management, project management, and literature review skills. One mentor said, "UG research generally starts with a comprehensive review of the literature. Students are analyzing and summarizing the papers they read, comparing one with another. They need to remain highly organized otherwise they will go around in circles."

Regarding knowledge outcomes, six faculty responses were coded in the knowledge – analytics skills theme. One mentor said:

> My students generally are involved in the post-data acquisition stages, so they learn current techniques for data processing/analysis, generally obtain some knowledge regarding appropriate statistical testing measures, and are often involved in preparing a conference abstract or poster. Some students get involved on the side of experimental design, requiring them to learn how we identify key measures, how we might go about collecting these measures, and then some technical skills (e.g., circuit design, PC board layout/fabrication) that will allow us to acquire said measures.

Two faculty responses were coded in the knowledge – engineering fundamentals theme. These faculty mentioned scientific and technical knowledge about the field. Two responses were coded in the knowledge – integration of analytical, problem solving, and design skills theme. One mentor answered:

> Differentiating between research (no one solution, work to identify best method) and homework (put down an acceptable solution). Learning how to read research articles with an eye towards understanding the underlying science, as opposed to regurgitating material for a report.

One response was coded as knowledge – open ended design and problem solving skills because the mentor mentioned the participant acquiring the ability to troubleshoot.

The majority (12) of faculty responses in the knowledge theme were coded as knowledge –other. Most faculty responses (12) were coded in the knowledge area under other and were related to lab skills and experimental design. For example, one faculty mentor provided many examples for this category:

> Experiment design, execution, and analysis. Project and time management skills. Technical writing. Trouble shooting. Lab skills vary by project but include pipetting, nucleic acid amplification, engineering design and component selection, microfluidics, particle diffusion, prototyping, electronic circuit design, biomedical measurements and statistical analyses (T-test, Dunnett's test, ANOVA, Bland-Altman). Figure design and data presentation.

Two responses were coded as qualities – other. One faculty noted that their mentee acquired professionalism and another mentor said their mentee acquired accountability. In addition, one faculty response was coded in the STEM literacy of posing and solving problems in the world and in the design process. This mentor remarked:

> I think the most important skill a student learns while conducting research at the undergraduate level is to ask questions. Research is a pursuit of trying to discover the unknown and I feel most people deprived of the opportunity to do research simply accept already established norms and practices and never question the status quo which is what actually drives progress.

Finally, one faculty response was coded in the literacies – communicating information in new ways to different audiences theme. This mentor said:

> …Finally, the SURF students learn to give presentations, both oral and written. These skills are transferable to all aspects of their professional career. These soft skills are often not well developed in a standard scientific educational degree, or as much as is needed for a successful career.

The present dissertation also provided information on student and faculty sentiments regarding what differentiates the undergraduate research experience from other experiences in the acquisition of STEM literacies. For example, students discussed how undergraduate research experiences allow students to move beyond theory and provide an opportunity for hands on participation. During the post-experience interview one student shared:

> I think it was very important for me as someone who's in an engineering program, an engineering undergraduate program, to see how engineering can be applied outside of a typical industry trajectory, which is not something I'm interested in. So seeing it applied in a research context is really important for me because now I can see a path forward in terms of me going into grad school and hopefully becoming a researcher or some type of academic. That's what I'd like to do and now I can actually see that, which I wouldn't have been able to without SURF because I don't think I would've been able to easily as find a project that aligned with my interests without all of the projects nicely listed right there on that page, which was very useful.

Another student talked about undergraduate research providing an avenue to expand on learning:

> Research definitely gives you an area to look into and learn more about a topic that I wouldn't say you would ever think about in just your daily classes. And, even though I guess I wasn't thinking and coming up with problems and solutions like you maybe would do in grad school, it still provides you with that environment to do it. Whereas, in school, you're set. You have structure and problems. And you're learning, (We have to learn this. We have to learn this.) Whereas, in research, you can kind of branch off and learn different things.

Similar to the student above who touched on more flexibility in the undergraduate research experience, another student felt the experience provided more autonomy and freedom:

> I think the most, the biggest differences that it's kind of in a course or something it's kind of like your knowledge and your learning is kind of decided by a teacher or a professor or some kind of instructor, whereas in your research, obviously you have research mentors and professors that you're working with, but your work is kind of led by you. What you want to do, the way you're going to do it. There's a lot more freedom there, which is good and bad in its own way.

The student continued by saying:

> Obviously it's like you would, so it's a lot more difficult to kind of find your own way than just be told what to do. But I think it really improves your self-sufficiency and

> ability to solve problems and gain those STEM literacies, hone them on your own as opposed to just kind of mindless or following of a plan.

Faculty also described how the undergraduate research experience is differentiated from other experiences in a positive way. During the post-experience interview one faculty said:

> I don't think it's kind of the environment in the university. You know, most technical people... I've been all over the world doing science and I know people in businesses global, in sciences global and the top people are global. So we sort of have sort of a local focus. The group. And we actually go up to Argonne, which is in the Chicago area, to do some stuff at a national lab. And the students go. That's a little bit off-campus. But if I have a problem, I actually send samples to China from somebody I know because they can do something that nobody else does. And so I think that is an important thing, this networking and collaborations on a global scale is something that, you know, people who are very successful also do very well.

Another mentor discussed their mentee learning to see the big picture:

> I was super proud of the resilience he showed when we finally got to the culmination of the project and the posters. He spent a lot of time doing the analysis and thinking about the little details of the project, but I kind of wondered, how is he going to connect this back to the bigger research questions? I was super impressed. It was super cool to see him persist through the weeds of the project to get the big picture.

On the other hand, one faculty talked about how one of their mentees expected things to be laid out for them because that is the format of general education. However, the mentor noted that this student quickly learned that research is different. In general, this faculty expressed that undergraduate students need a lot of affirmation:

> I think there's a lot of need for affirmation from the undergraduate students. A lot of times they do something and its like, Did I do it right? What do I need to fix? They're just uncertain about a lot of things. The content, the analysis, the coding. I got a lot of requests, like, "Can you look at this code? Can you look at this table? Is this it? Is this the thing that I should be doing?"

The pre-survey and post-surveys also asked how the knowledge and skills they hoped to acquire would help them in the future. Responses were coded in five themes (see Appendix I): prepare for graduate school, future career, communication skills/publications, other skills, daily life.

Coding frequencies and example responses are provided in Table 12 with a detailed summary provided below.

Table 12

How will the knowledge and skills you hope to acquire through this experience help you in the future?

	Students		Faculty		Student	Faculty
Themes	Pre	Post	Pre	Post	"It would give me a unique background experience. I would be a more versatile employee, understand more of the entire product development process."	"Excellent training for future career - these skills will translate directly to any work environment I envision the students doing - the technical skills are good, but learning how to plan a project, organize their time, prioritize activities, and written and oral communication skills are especially key."
Prepare for graduate school	13	3	9	5		
Future career	13	0	11	12		
Communication skills/publications	4	1	6	9		
Other skills	4	2	10	10		
Daily life	2	1	6	7		

In the pre-survey, 13 responses from students were coded in the graduate school preparation theme. One student said:

> My position as an undergraduate research assistant provides me a network of highly accomplished individuals in the ECE Department who have dedicated their careers to the study of Machine Learning. This network and the skills I acquire will allow for an easy transition into Graduate School, as I hope to continue in my current research lab to obtain a Master's Degree.

In addition, 13 responses were coded in the future career theme. One student noted:

> After doing a semester of research I realize that doing research is one of the most rewarding experiences that I will have in my undergraduate experience. That being said I am getting out what I put into it. Getting actual engineering experience has given me the opportunity to realize that I am on the right career path for me.

Another student expressed, "It would give me a unique background experience. I would be a more versatile employee, understand more of the entire product development process."

Four responses were coded in the communication skills/publications theme. For example, "Having strong technical communication will allow me to publish more papers," was one of the responses coded in this theme. Four responses were also coded in the other skills theme. Students mentioned anti-procrastination skills, teamwork, and time management. Finally, two responses on the pre-survey were coded in the daily life theme. One mentee stated, "Further, I believe that lifelong learning is extremely important for a happy and successful life."

In the post-survey students were asked how they thought the knowledge and skills would help them in the future. Three responses were coded in the graduate school preparation theme. One student reflected on the experience by saying, "Graduate school is one of my options after I get my undergraduate degree, and the research experience would prepare me for that." Two responses were coded in the other skills theme. For example, "I can now perform better searches online and I can work well with other people." One response was coded in the communication skills/publications theme. "I think it also made me a better communicator." Finally, one response was coded in the daily life theme. This mentor shared, "Will be directly applicable to grad school and indirectly applicable to working on projects at home or in the community."

In the pre-survey 11 faculty responses were coded in the future career theme. One mentor said:

> Excellent training for future career - these skills will translate directly to any work environment I envision the students doing - the technical skills are good, but learning how to plan a project, organize their time, prioritize activities, and written and oral communication skills are especially key.

Ten responses were coded in the other skills theme. For example, mentors mentioned critical thinking, decision making, time management, and technical skills. In addition, nine responses were coded in the graduate school preparation theme. For example, one mentor shared, "For many pre-vet, pre-med or BME undergrads, co-authorship on publication and presentation at regional or national conferences almost requirement for vet school or med school admission or for graduate program admission to a decent BME program."

Six responses were coded in the communication skills/publications theme. One mentor noted, "Plus we all need to learn how to communication effectively." Finally, six responses were coded in the daily life theme. For example, "This experience should help them in decision making, planning, being responsible which will in every day life and also in any field they choose in future."

In the post-survey, 12 faculty responses were coded in the future career theme. In some cases these responses all mentioned acquisition of skills, but they were couched in an overall theme of benefitting the student's career. One faculty remarked:

> Project and time management, critical thinking, data presentation and technical writing are critical in all fields and throughout life. Individual skills sets will vary in importance but the process of learning a new skill will be critical. Statistical literacy and design will enable them to critically compare ideas presented to them and solve challenges throughout life and their careers.

Ten responses were coded in the other skills theme and included skills such as critical thinking, time management, and how to interpret scientific findings. Seven responses were also coded as daily life. One mentor shared, "They can transfer these skills to anything they want to do with their future. It makes them more conversational, confident, and marketable." Finally, five responses were coded in the graduate school preparation theme. In addition, nine responses were coded in the communication skills/publications theme. For example, "Student will appreciate what it really means to read scientific literature. The focus and active listening required will serve them well in whatever field they apply their minds to."

These responses from students and faculty provide examples of they describe the development of STEM literacies in an undergraduate research experience. However, discussions with student participants during the post-experience interviews also demonstrated that students cannot always articulate what a STEM literacy is. For example, one student shared:

> The STEM is science, technology, engineering and them, I don't remember. I think mostly to conduct really good research. I think that's the thing. If you are a STEM student, like a student in the STEM community, you will use all these four, literally these four words, in your research, conducting your research and methodology.

During the post-experience interview another student responded to this question by saying:

> STEM literacies? So I would say... Well, STEM is a weird word because it encompasses a lot of different fields, and I think that the terms and the phrases and not those types of things used in STEM fields are very different across fields that are in STEM. So I don't know if I can properly... It would just be the literacy... That's a very hard question. I would say the outcomes, but that's probably what I consider... I align heavily with outcomes of understanding engineering in a global context and understanding the social impacts of engineering and all those things. I feel like outcomes very much aligned with what I think are important for engineering students to be learning.

Another student shared a brief answer, "STEM literacies? I think just technical papers, that's what I think of."

A few students were more confident in their responses but still lacking a full comprehension or ability to articulate STEM literacies. For example:

> So I'm not exactly sure what that word means, but what I interpret it as is just being educated and field, and up to date with the literature of what's going on. And the ability to understand these STEM concepts I guess.

During the post-experience interviews another student explained:

> I think the biggest thing for me is being able to digest technical information into understandable sentences. The most literate person would be one who is be able to take a technical paper and be able to present it to every level of previous education. I guess what goes into that is first having whatever domain expertise for being able to digest the technical paper. Just the intelligence of being able to understand it. And then a vast amount of communication and being able to see yourself in other people's shoes.

Another student articulated STEM literacy in terms of application of knowledge:

> I guess what I would say for that would be probably more so problem solving and the ability to adapt to situations. I guess, whether it's an application of your knowledge, whether it's in math or science, you're always taking what you learned and applying it to different usages and trying to expand your knowledge.

These findings suggest there may be a need for educating students on what STEM literacies are, the importance of being STEM literate, and the goals for acquiring STEM literacies in an undergraduate research experience.

How does the mentoring process contribute to the development of STEM literacies?

Students were asked in the pre-survey how they think the relationship with their faculty mentor will enable their acquisition of STEM literacies during the undergraduate research experience. Responses were coded in eight themes (see Appendix I): STEM knowledge, graduate school/future career/big picture thinking, research/lab, critical/creative thinking, writing/communication, qualities, not familiar with STEM literacies, and other. Faculty were asked the same question about their student mentee. Coding frequencies and example responses are provided in Table 11 with a detailed summary provided below.

Table 13

How do you think the relationship with your faculty mentor will enable your acquisition of STEM literacies during an undergraduate research experience?

Themes	Students Pre	Students Post	Faculty Pre	Faculty Post	Student	Faculty
STEM knowledge	3	1	1	5	"I will learn how to prepare and perform chemical reactions and how to use and make catalysts."	"I would be helping them most with understanding the background for why they are doing this project and with thinking about the project in broader, health relevance terms."
Graduate school/future career/big picture thinking	3	1	7	2		
Research/lab	8	1	4	8		
Critical/creative thinking	1	0	1	1		
Communication/writing	2	0	0	0		
Qualities	0	0	2	1		
Not familiar with STEM literacices	2	0	1	2		
Other	3	2	2	0		

The majority of student responses (8) were coded in the research/lab theme. One student mentioned," I will learn how to prepare and perform chemical reactions and how to use and make catalysts." Another student explained, "My mentor is very knowledgeable in both qualitative and quantitative research methods, so she has been a large help in developing my literacy in these areas."

Three responses were coded in the STEM knowledge theme. Regarding the acquisition of STEM literacies, one mentee described the mentoring relationship by saying:

> They should be more off a guide than a traditional teacher. Due to the specific nature of research, the professor should make sure that researchers understand the basic concepts first. Professors should also guide students by showing and explaining the best review publications in their field.

Another three responses were coded as graduate school/future career/big picture thinking theme. One student shared, "Forming a good relationship with my faculty mentor will allow me to ask him more questions about his experiences working in the lab and his career path from undergraduate school forward."

Two responses were coded in the communication/writing theme. One student remarked, "He will review all of my writing and make comments which will allow me to develop a professional style of writing." One response was coded in the critical/creative thinking theme. This student said, "I think it will encourage me to be creative in the development of solutions to problems. I hope to learn better how I can process issues that arise and rectify them."

In addition, two responses were coded in the theme indicating they were not familiar with STEM literacies. One student stated:

> I am not familiar with the term STEM literacies. However, having a relationship with my faculty mentor will help me to learn from someone with much more experience who can teach me some of the smaller details of research and learning that tend to be overlooked.

Finally, three responses were coded as other. For example, “I believe I will learn a lot from him,” provides an example of one of the responses coded in this theme.

The post-survey asked students how the relationship with their faculty mentor enabled their acquisition of STEM literacies during the undergraduate research experience. One response was coded in the STEM knowledge theme. This student said, “I asked my graduate student for STEM literacies, not my professor.” Another response was coded as graduate school/future career/big picture thinking. “I think this mentorship has opened doors for future plans. He helped connect me to others in my field who have started labs and are actively recruiting graduate students.”

In addition, one response was coded in the research/lab theme. This student shared, “Helped me understand research process, especially collecting background information and trying to find solutions, better.” Finally, two responses were coded as other. One of those students explained, “Was definitely a beneficial opportunity. I would not feel like I was largely lacking I’d I didn’t though.”

In the pre-survey the majority (7) of faculty responses were coded in the graduate school/future career/big picture thinking theme. For example, one faculty mentor said, “I would be helping them most with understanding the background for why they are doing this project and with thinking about the project in broader, health relevance terms.” Four responses were coded as research/lab. One mentor noted, “Interacting with graduate students and post docs, reading and discussing literature, writing and presenting their results, participating in weekly lab meetings.”

Two responses were coded as qualities such as self-motivation and confidence. For example, “A good mentoring relationship will keep the student engaged in the project, and will help them to remain self-motivated. They should then be learning more on their own as the project proceeds.” The other mentor said, “New students are generally nervous with little confidence. Throughout the process, they can confidence and self reliance. This carries over to their studies and careers.”

One response was coded as critical/creative thinking where the faculty mentor stated, "I think it would help her develop abilities in critical thinking and troubleshooting." In addition, one response was coded as STEM knowledge. "This relationship will help to clarify STEM concepts that a student may not gain normally." In addition, one response was coded as not familiar with STEM literacies. This mentor simply said, "I am not certain what the STEM literacies are." Finally, two responses were coded as other. For example:

> I don't think the relationship per se has anything to do with their acquisition of STEM literacies. It is through their participation in the research, reading background literature, learning the technology behind the experiments that they gain literacy in STEM.

In the post-survey the majority (8) of faculty responses were coded in the research/lab theme. One mentor reflected by sharing:

> Each student starts their project with a review of relevant literature and discussing with their direct graduate/postdoc mentor. They perform design, experimental analysis and statistical analyses along the way. They discuss their results with respect to expected outcomes and the literature. By talking through the processes at each of these stages, they develop a deeper understanding of various STEM literacies.

Five responses were coded as STEM knowledge. For example, one mentor explained:

> I feel that our discussions helps. He would ask me questions and we would talk. I would communicate what was expected in this field and more importantly why. I talked about my motivations for my work. I helped him try to feel more comfortable putting himself in the work he did.

Two responses were coded as graduate school/future career/big picture thinking. One mentor expressed:

> This has been the largest benefit to the students --- conversations/discussions associated with projects are generally of great benefit not only for the project at-hand, but also in allowing them to contextualize and integrate what they are learning in their various courses.

In addition, one response was coded as critical thinking. This mentor said, "STEM literacies? They more fully understand that everything written is not necessarily true and that there are error bounds around all data points." Another response was coded in the qualities theme wherein the mentor shared, "I'm not sure what this means. The process that I follow is much like the organization of the SURF weekly topics, however, I also emphasize teamwork, independence, decision making, leadership and collaborative interactions." Finally, two responses were coded as not familiar with STEM literacies. One example is the same as the quote above where the mentor said, "I'm not sure what this means."

Students and faculty described how the mentoring process contributed to the development of STEM literacies in their pre and post-survey responses. They also discussed the development of STEM literacies during the post-experience interviews, although not all responses touched on the mentoring process specifically. During the post-experience interview one student said:

> Yeah. I think I kind of mentioned this already, but not only can you rely on like other people within the group who have more experience, like my professor, my mentor, there's obviously the internet for all of the Google scholar paper or any open access papers. But then also being able to integrate just everything else that you've learned, whether that's class, whether that life, or just how to take all that information and be able to incorporate it into a plan is really important.

This student notes the important role of their faculty mentor as the expert but also touches on the exploration phase where the students begin to problem-solve on their own. Another student discussed learning to maneuver as you go. The student shared:

> It's very interesting trying to talk about my research now just because I've been through every single step in iteration and trying to figure out that maneuvering every second, it feels like sometimes. You have to decide continuously ... Just there's so many decisions. So yes, I feel like I've learned how to definitely maneuver through making decisions.

Dealing creatively with the unexpected is another STEM literacy that was described during the post-experience interview. One student explained:

> So I guess it was just more like team based kind of situations where we had to do that. Especially when a program was having an issue, we would all come to kind of in our weekly meetings, be like, Oh, what do you think about this issue? Or, How can we fix the sampling frequency and how are we going to make it to these two circuits don't cause nodes with each other? And just, How do we improve on these issues that we're having? And that was a lot of team based kind of throwing ideas back and forth. Even if it wasn't

> my teammate's major focus, we all kind of share input where we solve those problems and make it a more efficient product.

Another student talked about acquiring the ability to communicate information in new ways to different audiences:

> I feel like that's definitely applicable, at least for me just because I'm an engineering education and a lot of the people in SURF are engineering students or STEM students. So communicating social science to non-social science people is a huge thing, and just trying to build my credibility. That's definitely been challenging as I'm thinking about my presentation because I'm trying to figure out how I'm going to build my credibility as someone who's in social science, or at least my research is in social science with non-social science individuals.

Students also reflected on the experience by sharing processes that fall under the STEM literacy of documenting processes and/or milestones. One student tells of the improvement they saw in themselves over the course of the research experience:

> I think I struggled with that more so at the beginning, but I'm starting to get better at commenting my code, that sort of thing where I say what I'm doing, why I'm doing it, so that someone else who goes back through my code can know what I've been doing. And then also, just creating documents that are essentially like a table of contents to explain all of my resources for whoever wants to go through my files and pick something out or whatever.

Another student commented how documenting processes are helpful to others:

> I had to do lots of write-ups whenever we finish something or made progress, we'd have to document what we did, like write the methods up, write down the materials. So for if we do a future paper or even if we need to come back and look at what we did or... And make sure we always have procedures written for any experiments that when we go back to analyze it later, well, or if someone else tries to read our work, it will be clear for them to know what we did.

Some students described how the mentoring relationship with their graduate student was beneficial. One student shared:

> The biggest one was learning about grad school. Because we had, the program had, multiple sessions explaining what grad school is. Talking to current grad students and

> asking them questions. And just different things like that that I wouldn't have known without the program.

Another post-experience interview example:

> And then for the experimental one, my grad student would explain the problem and what needs to be done, and then he would show me how to use the big machines and what techniques we need to do. And then once he trained me, then I would do it myself. But he already had his project way before I joined, so he would tell me what needs to be done for him to make progress.

Post experience interviews with faculty also found that students acquired STEM literacies as a result of the undergraduate research experience. One faculty shared this sentiment about the ability to maneuver as you go:

> And so to me, people who are able to, one, have a plan, they do it more efficiently, but two, don't just blindly go on that plan. If it starts to look like it's not going to work, you have to reassess and you make a new plan based on what you've learned. This is, to me, one of those things that translates through your whole life.

Faculty also found that students acquired the ability to demonstrate resilience to problems that are difficult or hard to deal with:

> "But what I really want them to do is for them to figure out for themselves what they should do. Make decisions. Making decisions is a really difficult skill for some people. They like to be told what to do because then it's not their responsibility. But these kids are really, really quite good. And so they really like the opportunity to take the initiative and, to make decisions, right or... And it's no penalty for being wrong. I mean you have to able to take risks. Okay. And that's what we try to do with the projects we give them.

The ability to integrate information across sources was discussed as well.

> They have to integrate literature sources, so what others have done on similar projects, with what other people in our group have done, and it's sometimes they're bringing together different data sets, and integrating them into maybe a mathematical model that has a predictive part, that they're then trying to validate in the laboratory. They combine, at least in our group, simulations with experimental data.

Faculty mentors also found that their mentees acquired the ability to communicate information in new ways to different audiences. One mentor reflected on the experience by saying:

So talking within the group and the students and to me, we get very technical, very geeky. Now Max, we just practiced her talk last week and we said, look, these are not chemical engineering students. They're doing completely different majors in different backgrounds. I think you have to explain it in a much more high-level overview-istic thing and communications is all about who is your audience, right? And so they don't know that there is a tendency to just be technical. You're talking like they're all experts. And so we really emphasize a lot of that in the communication.

The faculty mentor continued by discussing written work:

> Now on a written report, and I have Max's report to go over today, you have to learn to write clearly. It can be a little more technical because you don't know who's going to read this and what their background is. And there will be a few people who are technically knowledgeable, so we put in a little bit more technical details. So yeah, we work on those things. And again, I think this is crucial. When you go off and I worked in an industry, you give a talk to technical people, you get very geeky and when you go to management, you get very financial. They don't care about all the details, they care about how much money it makes and whether they are ready to implement something and try to move it on to commercialization. And so you knowing your audience is crucial for success as a professional career.

One mentor talked about documenting processes but admitted that he/she could do a better job of monitoring to make sure students are acquiring this literacy. This mentor said:

> So in my lab, we have a lab notebook that's online. And unfortunately, I'm probably not as good as I should be about monitoring every note that goes into them. But students are still expected to keep track of what experiments they've done, in multiple forms. Photographing stuff and writing a description, those kinds of notes.

Another faculty mentor discussed the importance of being STEM literate but that he/she was unsure if the student fully reached that outcome:

> I think that's a really important piece that they don't always do. That zooming out of multiple, bigger skills you've learned, besides just the specific project details, what are you going to take away from this? How does it improve your development or maybe even your pathway? Those are things that are incredibly important, connecting the experience back to the larger context of their lives and the direction that it's going in.

That faculty mentor continued on to say:

> I'm not a very reflective person by nature. I have to kind of force myself to do that, and I feel like maybe that's an opportunity that I've missed with working with the undergrads, was how they actually, I don't know if SURF does it. Are they actually reflecting the big picture back to where they started at the beginning of the summer? I don't know if that's part of the program, but I think that reflection piece is really important. Max seems very reflective. I'd expect he probably does it more than I would naturally do, but I didn't structure anything to help him do that.

These example demonstrate that the SURF program and spring semester undergraduate research experience at Purdue University provide opportunities for students to acquire STEM literacies.

CHAPTER 5. DISCUSSION

This project proposed to examine the nature of mentoring relationships during an undergraduate research experience. Informed by literature in cognitive apprenticeship and STEM education, this proposal examined how university students learn to engage in the practices of scientific inquiry via research apprenticeships, and how such experiences prepare them for their future careers. In this section, I will discuss how my findings relate and contribute to the literature on the nature of undergraduate students' learning from authentic research experiences, and the role of research mentorship in the development of students' career preparation and learning.

Results from this dissertation aligned with, and expanded on, the cognitive apprenticeship theory which highlights the importance of learning by engaging in authentic activity under the guidance of mentor experts. Stewart and Lagowski (2003) referenced four dimensions of cognitive apprenticeship outlined by Collins et al. (1989) including content, methods, sequence, and sociology.

Students and faculty from the current study also referred to these dimensions in characterizing what was learned from the research experience. For example, students and faculty talked about content in terms of knowledge gained during the research experience. In their responses students and faculty also touched on the various methods of the cognitive apprenticeship theory including modeling, coaching, articulation, reflection, and exploration. Participants discussed these methods in terms of working with the faculty mentor but also provided examples of how participants learned from graduate student mentors. Students and faculty also provided examples of sequencing where students learned to understand a broader perspective. SURF and Engineering 499 research experiences also met the criteria of the sociology dimension because learning occurred in the appropriate context.

Overall, participation in these research experiences provided examples supporting the cognitive apprenticeship model outlined by Collins (et al.) in Stewart and Lagowski's (2003) research. Students provided many examples of acquiring the skills they would need to advance. Faculty responses also support the idea of students transitioning from non-expert to expert during the undergraduate research experience.

Benefits of Undergraduate Research Experiences

This dissertation adds to the body of literature on how students and faculty perceive outcomes of undergraduate research experiences compared to other educational experiences. Several national organizations have supported undergraduate research including the National Science Foundation (NSF), the Council of Undergraduate Research (CUR), and the National Conferences on Undergraduate Research (Hunter et al., 2007; Laursen et al., 2012; Pacifici & Thomson, 2011).

Motivational Benefits

Collins & Kapur (2014) have noted that an important benefit of cognitive apprenticeship models is that they leverage students' intrinsic motivation for learning by engaging them in meaningful problems as part of a community of practice. When asked what differentiates the undergraduate research experience from other experiences in the acquisition of STEM literacies, students in the current study shared how undergraduate research experiences allow students to move beyond theory and provide an opportunity for hands on participation. Other participants spoke about undergraduate research providing an avenue to expand on learning and felt the experience provided more autonomy and freedom. Ryan and Deci (2017) have argued that the experience of autonomy is a critical component of human motivation and will lead to enhanced student learning. Thus, it appears that the undergraduate experiences studied in this dissertation were successful in fostering a sense of student autonomy and enhancing their motivation for STEM.

Students Gain Cultural Capital via Participation in Undergraduate Research Experiences

In the last two decades a literature has emerged on mentoring relationships as a form of cultural capital (Rios-Ellis et al., 2015; Smith, 2007). Interestingly several of the undergraduates explicitly recognized forms of cultural capital that they expected to gain from their mentoring relationships which would serve their future career aspirations such applying to graduate school. For example, both students and faculty mention the opportunity to co-author research, or gain a letter of recommendation for graduate school as expected benefits of the research experience. Other researchers have also found that undergraduates describe such professional credentialing benefits of research experiences as key to their future career aspirations and professional development (Adedokun et al., 2012). Future research should continue to explore cultural capital as an outcome of undergraduate research experiences and how the pursuit and acquisition of culture capital may vary by demographic group.

Impacts of Research Experience on STEM Literacy

As discussed in the review of literature, the acquisition and growth of STEM Literacy is considered to be a key desired educational outcome for undergraduates (Tucker & Raymond et al., 2017; Zollman, 2012). From the perspective of cognitive apprenticeship, a key area of knowledge growth for the undergraduate students engaged in research experiences should be STEM literacy.

In the current study, several participants did mention the acquisition of skills that have been described as “STEM Literacies.” For example, in the post-experience interview students discussed learning to maneuver as you go, dealing creatively with the unexpected, acquiring the ability to communicate information in new ways to different audiences, and documenting processes (Tucker-Raymond et al., 2017). Students discussed the improvement they saw in themselves in these areas over the course of the research experience.

Post experience interviews with faculty also found that students acquired STEM literacies as a result of the undergraduate research experience. Faculty mentors described how their mentees acquired the ability to demonstrate resilience to problems that are difficult or hard to deal with, learned how to integrate information across sources, and mentees acquired the ability to communicate information in new ways to different audiences.

However, in my study some students could not articulate what it means to be STEM literate. Without knowing what means is or why it is important, it may be difficult for students and faculty to look beyond concepts and content at the bigger picture. Therefore, programs should clearly articulate to both students and faculty the importance of being STEM literate and set goals for attaining literacies during the undergraduate research experience.

It may be the case that using “STEM” as a prefix to literacies leads to confusion among student and faculty participants. At its core, the idea of being STEM literate is that students are learning skills beyond STEM content knowledge. In other words, the goal is for students to learn life skills, not just technical skills. Therefore, it may make more sense to reframe STEM literacies to something broader. Recent research by Succi and Canovi (2020) asserted that soft skills are increasingly relevant and have been emphasized over the last several years by both employers and graduates. They found that graduates are not appropriately taught the importance of soft skills and therefore lack soft skills that employers are looking for. STEM literacies could be folded into the broader literature on soft skills.

Matching Faculty Mentors with Mentees Based on Expectations

Prior research has suggested that that the success of mentoring relationships in the context undergraduate research experiences depends in part on a match of expectations for mentors and mentees (Pacifici & Thompson, 2011). However, as found by Pacifici & Thompson (2011), the current study also suggested areas of mismatch in faculty and student expectations of the mentoring relationship. Students and faculty had different expectations for the mentoring relationship wherein faculty conveyed how the mentoring relationship would facilitate research itself whereas students expressed generalities about the relationship or feedback they expected to receive. Indeed, some of the student and faculty responses indicated limited communication and monitoring by the research mentor because of time constraints, which undoubtedly influenced the nature of the student experiences and learning.

For example, during the post-experience interview one student felt he/she had less support in the research experience as compared to the classroom. Another student said that it was important that their faculty mentor address their needs but did not feel like that expectation was met because they never saw their mentor. Another student noted that it would have been nice for their mentor to tap into their interests but that it did not happen Simultaneously, some faculty reported that their undergraduate mentees were not always sufficiently knowledgeable or prepared for taking on more independent research roles, while others report having provided insufficient time to provide the level of monitoring needed by their students.

These finding are consistent with other research showing that mere participation in research experiences does not always lead to high quality learning and that the nature of participants' roles and engagement influence what they take away from such experiences (Leach et al., 2003; Samarapungavan et al., 2006).

In the future, attempting to match faculty mentors and students better with regard to faculty expectations of what students must know in order to be successful in their research apprenticeships and what prior knowledge and experiences students actually have is likely to lead to more productive experiences for both mentors and their mentees. Brownell and Kolser (2015) have made similar observations with regard to undergraduate research experiences in biology.

Tiered Mentoring in Undergraduate Research Experiences

As discussed in the literature review, undergraduate research experiences are often framed as opportunities for undergraduate students to be mentored directly by a lead faculty researcher. However, the reality is that the active mentoring of undergraduate research participants is often delegated informally to other research team members such as post-doctoral researchers or graduate students (Adedokun et al., 2012; Pacifici & Thompson, 2011; Samarapungavan, Westby & Bodner, 2006). For example, Pacifici and Thomson (2011) found that while some students expressed gratitude for the support they received from graduate students and post-doctoral researchers, their expectations for developing a connection with faculty were not met. This finding was replicated in the current study.

There was a great deal of variation in how students described their mentorship experiences in the context of the current study. Some students described positive relationships and high levels of engagement with their faculty mentor.

However, many students experienced little direct mentoring from their faculty mentor and described graduate student or post-doctoral members of the research group as their primary mentors. For example, in the post-experience interview one student talked about leaning on a graduate student for help rather than their faculty mentor. These results are also consistent with the findings of Samarapungavan et al. (2006) that undergraduate students in chemistry research apprenticeships sometimes had little direct mentorship from the faculty lead of the research group and were assigned low level tasks.

If graduate students or post-doctoral researchers are playing the critical role of mentor, it is imperative that they receive proper training consistent with cognitive apprenticeship theory to foster learning on the dimensions of content, methods, sequence, and sociology (Collins & Kapur, 2014). The training of graduate student mentors should be addressed, and will be discussed as a future direction for research.

With that said, mentorship by graduate students should not replace mentorship by faculty entirely. Based on results from this study, faculty could learn to be better mentors by addressing the needs of their mentees, tapping into their interests, and connecting on a personal level, in particular, using digital communication platforms preferred by students.

The findings of the current study as well as that of other researchers cited above, suggests that tiered mentoring structures are common in larger research groups with multiple members at different levels of expertise. However, undergraduate research experiences are often described formally, only in terms of mentorship from the lead faculty member of a research group.

More research is needed to better understand the nature of varied mentorship structures that undergraduate research trainees might experience, especially the tiered mentorship that seems to be more typical in large research groups. Based on such research, it would be possible to provide guidance to faculty on effective mentoring practices within the context of multi-tiered research groups.

Generational Gap in Technology Preferences and Use

One area of interest in the current study was the use of technology to support communication in the context of undergraduate research experiences. Salomon (1998) discussed the potential uses technology to provide "needed tools for the realization of learning as construction" and as a "social process of meaning appropriation". This study focused on the second purpose by exploring the use of technology in facilitating communication within the research group.

Although all participants mentioned that technology was used to support communication, there was considerable variation in the use of technology. Some groups appeared to use primarily asynchronous technology such as email while others reported using virtual conferencing and group collaboration platforms to conduct shared work.

Prensky (2001) referred to students who grew up with technology as "Digital Natives" and those who did not grow up surrounded by technology as "Digital Immigrants." Evidence of this generational emerged in this study. The study found some students alluding to faculty use of dated technologies and some faculty expressing reluctance to communicate via contemporary social media platforms preferred by their students.

It is possible that the reluctance to use technology for communication demonstrated by faculty in the current student may change in the future as a result of the COVID-19 pandemic. As the world shifted to remote work, and continued that model for over a year, it is likely that faculty sentiments regarding technology have changed. However, even if the pandemic had never happened, faculty should be more open to the technology mediums preferred by their students. Willingness to adopt new mediums may help students feel more comfortable connecting with their mentors. The present study just scratches the surface of the role of technology in undergraduate research experiences and the mentoring relationship. Further research is needed to examine the nature of technology use to support communication and mentoring relationships, particularly in light of the changing world as a result of COVID-19.

Limitations, Significance, and Directions for Future Research

The intent of this dissertation was to study undergraduate research experiences via the SURF program at Purdue University. In the sections above, I presented the key findings from my survey and interview data and discussed them in relation to the broader literature on mentorship and learning from undergraduate research experiences. My research identified areas of strength such as descriptions of positive mentoring experiences contributing to intellectual growth both by faculty and by students, as well as the development of STEM literacies through the undergraduate research experience. It also identified some areas of challenge that were described above. In this section, I would like to acknowledge key limitations of this study that constrain generalizability and need to be addressed in future research.

One limitation of this research is that the data for this study are self-reports by faculty and students of their mentorship experiences. While understanding participant perspectives on their mentorship experiences is valuable in its own right, observational data (for example of research group meetings or digital mentoring communications), could provide additional information about the nature of mentorship. Additionally, because many undergraduates experience mentoring primarily from graduate students or post-doctoral members of their research group rather than the lead faculty, it would be important to interview these members as well in the future.

The COVID-19 pandemic undoubtedly had an impact on this research, particularly during the second round of data collection in the spring 2020 academic term. Despite the pandemic, the study still yielded rich data via surveys and interviews both during the SURF program and Engineering 499 research experience. The COVID-19 pandemic actually opened the door to new research questions and directions for future research such as studying how faculty sentiments may have changed.

The current research collected demographic data via the pre and post-surveys but results were not analyzed by demographic group. Future research could expand on this study by exploring differences based on gender and race/ethnicity.

This study also demonstrates the need for more attention to be placed on the mentoring relationship in terms of the goals of the structure of the relationship. For example, results demonstrated that some students are working more with graduate students rather than the faculty mentor. If this is not intentional, the undergraduate research experiences provided to students need to address this issue. On the other hand, if the programs recognize that students may work more with graduate students than faculty mentors than the programs should make this expectation clear to students in the beginning. Further, research is needed to understand how to make tiered mentoring structures (where graduate students or post-doctoral researchers mentor undergraduates) more effective and to provide this information to research groups that use tiered mentoring.

Finally, the participant responses suggest wide variation in the use of technology for communication among research groups and an emerging mismatch between student and faculty expectations about the frequency and use of preferred technology platforms for communication. Although this data is preliminary, additional research focused specifically on the relationship between types of digital communication and their effects on the mentoring relationship would be valuable. In addition, research exploring how views of technology have changed as a result of the COVID-19 pandemic would also be interesting.

Conclusion

Despite the areas in need of improvement, overall these examples from students above affirm that they find undergraduate research experiences beneficial as compared to other experiences. Research afforded them the opportunity to understand how research can be applied, gain knowledge that they would not have gained in the classroom, and increased autonomy and freedom.

REFERENCES

Adedokun, O. A., & Burgess, W. D. (2011). Uncovering Students' Preconceptions of Undergraduate Research Experiences. *Journal of STEM Education, 12(5&6),* 12-22. Retrieved from https://www.proquest.com/scholarly-journals/uncovering-students-preconceptions-undergraduate/docview/893425535/se-2?accountid=13360

Adedokun, O. A., Zhang, D., Parker, L. C., Bessenbacher, A., Childress, A., & Burgess, W. D. (2012). Towards an understanding of the processes of the effects of undergraduate research experiences on students' aspirations for research careers and graduate education. *Journal of College Science Teaching, 42(1),* 82-91.

Barab, S. A., Cherkes-Julkowski, M., Swenson, R., Garrett, S., Shaw, R. E., & Young, M. (1999). Principles of self-organization: Ecologizing the learner facilitator system. *The Journal of The Learning Sciences, 8(3&4),* 349-390. https://doi.org/10.1080/10508406.1999.9672074

Barab, S. A., & Plucker, J. (2002). Smart People or Smart Contexts? Cognition, Ability, and Talent Development in an Age of Situated Approaches to Knowing and Learning. *Educational Psychologist, 37*(3), 165-182. https://doi.org/10.1207/S15326985EP3703_3

Barab, S. A., Thomas, M. K., & Merrill, H. (2001). Online learning: From information dissemination to fostering collaboration. *Journal of Interactive Learning Research, 12(1),* 105-143. Retrieved from https://sashabarab.org/wp-content/uploads/2015/03/jilr-informationDis.pdf

Bauer, K. W., & Bennett, J. S. (2003). Alumni Perceptions Used to Assess Undergraduate Research Experience. *The Journal of Higher Education, 74(2),* 210-230. https://doi.org/10.1080/00221546.2003.11777197

Boyer Commission on Educating Undergraduates in the Research University.1998. *Reinventing undergraduate education: A blueprint for America's research universities*. State University of New York–Stony Brook.

Brown, J., Collins, A., & Duguid, P. (1989). Fostering Deep Learning in Problem-Solving Contexts with the Support of Technology. *Journal of Educational Technology & Society*, *20(4),* 162–165. Retrieved from http://www.jstor.org/stable/26229214

Brownell, S. E., & Kloser, M. J. (2015). Toward conceptual framework for measuring the effectiveness of course-based undergraduate research experiences in undergraduate biology. *Studies in Higher Education, 40(3),* 525-544. https://doi.org/10.1080/03075079.2015.1004234

Chesler, N., & Chesler, M. (2002). Gender-Informed Mentoring Strategies for Women Engineering Scholars: On Establishing a Caring Community. *Journal of Engineering Education, 91(1*), 49-55. https://doi.org/10.1002/j.2168-9830.2002.tb00672.x

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences, 6(3),* 271-315. https://doi.org/10.1207/s15327809jls0603_1

Collins, A., Brown, J., & Holum, A. (1991). Cognitive Apprentice: Making Things Visible. *American Educator: The Professional Journal of the American Federation of Teachers, 15*.

Collins, A., Hawkins, L., & Carver, S. M. (1991). A cognitive apprenticeship for disadvantaged students. In B. Means, C. Chelemer, & M.S. Knapp (Eds.) *Teaching advanced skills to at-risk students: views from research and practice.* San Francisco: Jossey-Bass.

Collins, A., & Kapur, M. (2014) Cognitive Apprenticeship. In R. Sawyer (Ed.), The Cambridge Handbook of Learning Sciences (Cambridge Handbooks in Psychology, pp. 109-127). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.008

Craney, C., McKay, T., Mazzeo, A. Morris, J., Prigodich, C., & de Groot, R. (2011). Cross-Discipline Perceptions of the Undergraduate Research Experience. *Journal of Higher Education, 82(1),* 92-113. https://doi.org/10.1080/00221546.2011.11779086

Dillner, D. K., Ferrante, R. F., Fitzgerald, J. P., & Schroeder, M. J. (2011). Integrated Laboratories: Laying the Foundation for Undergraduate Research Experiences. *Journal of Chemical Education, 88*(12), 1623-1629. https://doi.org/10.1021/ed101180f

Gresty, K. A., & Edwards-Jones A. (2012). Experiencing research-informed teaching from the student perspective: Insights from developing an undergraduate e-journal. *British Journal of Educational Technology, 43(30),* 153-162. https://doi.org/10.1111/j.1467-8535.2010.01156.x

Griffiths, M. D., & Miller, H. M. (2005). E-mentoring in schools: A brief review. *Education and Health, 23(1),* 5-8. Retrieved from https://www.academia.edu/429541/Griffiths_M.D._and_Miller_H.M._2005_._E-mentoring_in_schools_A_brief_review._Education_and_Health_23_6-8

Henrie, C., Halverson, L., & Graham, C. (2015). Measuring student engagement in technology-mediated learning: A review. *Computers & Education, 90*, 36. https://doi.org/10.1016/j.compedu.2015.09.005

Hunter, A., Laursen, S. L., & Seymour, E. (2007). Becoming a Scientist: The Role of Undergraduate Research in Students' Cognitive, Personal, and Professional Development. *Science Education*, *91*(1), 36-74. https://doi.org/10.1002/sce.20173

Hurtado, S., Cabrera, N. L., Lin, M. H., Arellano, L., & Espinosa, L. L. (2009). Diversifying Science: Underrepresented Student Experiences in Structured Research Programs. *Research in Higher Education, 50(2),* 189-214. https://doi.org/10.1007/s11162-008-9114-7

Ibrahim, A., Aulls, M., & Shore, B. (2017). Teachers' Roles, Students' Personalities, Inquiry Learning Outcomes, and Practices of Science and Engineering: The Development and Validation of the McGill Attainment Value for Inquiry Engagement Survey in STEM Disciplines. *International Journal of Science and Mathematics Education, 15(7),* 1195-1215. https://doi.org/10.1007/s10763-016-9733-y

Jones, M. T., Barlow, A. E. L., & Villarejo, M. (2010). Importance of Undergraduate Research for Minority Persistence and Achievement in Biology. *The Journal of Higher Education, 81(1),* 82-115. https://doi.org/10.1080/00221546.2010.11778971

Keebaugh, A., Darrow, L., Tan, D., & Jamerson, H. (2009). Scaffolding the Science: Problem Based Strategies for Teaching Interdisciplinary Undergraduate Research Methods. *International Journal of Teaching and Learning in Higher Education, 21(1),* 188-126. Retrieved from https://files.eric.ed.gov/fulltext/EJ896251.pdf

Kendricks, K., & Arment, A. (2011) Adopting a K-12 Family Model with Undergraduate Research to Enhance STEM Persistence and Achievement in Underrepresented Minority Students. *Journal of College Science Teaching, 41(2),* 22-27. Retrieved from https://hdl.handle.net/11299/180922

Kolikant, Y., Gatchell, D., Hirsch, P.L., & Linsenmeier, R. (2006). A Cognitive-Apprenticeship-Inspired Instructional Approach for Teaching Scientific Writing and Reading. *The Journal of College Science Teaching, 36*, 20-25. Retrieved from https://www.semanticscholar.org/paper/A-Cognitive-Apprenticeship-Inspired-Instructional-Kolikant-Gatchell/edc8eeed9a0bb66bdc52748695e7313c53a76100

Laursen, S., Seymour, E., & Hunter, A. B. (2012). Learning, Teaching, and Scholarship: Fundamental Tensions of Undergraduate Research. *Change: The Magazine of Higher Learning, 44(2),* 30-37. https://doi.org/10.1080/00091383.2012.655217

Lave, L., & Wenger, E. (191)1). *Situated learning: Legitimate peripheral participation.* New York: Cambridge University Press.

Leach, J., Hind, A., & Ryder, J. (2003). Designing and evaluating short teaching interventions about the epistemology of science in high school classrooms. *Science Education, 87(6),* 831-848. https://doi.org/10.1002/sce.10072

Lincoln, Y. S. (2002). Emerging criteria for quality in qualitative and interpretive research. In N. K. Denzin & Y. S. Lincoln, (Eds.), *The qualitative inquiry reader* (pp. 327-346). Thousand Oaks, CA: Sage.

Linn, M., Palmer, E., Baranger, A., Gerard, E., & Stone, E. (2015). Education. Undergraduate research experiences: Impacts and opportunities. Science (American Association for the Advancement of Science), 347(6222), 1261757. https://doi.org/10.1126/science.1261757

Lopatto, D. (2004). Survey of Undergraduate Research Experiences (SURE): First Findings. *Cell Biology Education*, *3*(4), 270-277. https://doi.org/10.1187/cbe.04-07-0045

Lopatto, D. (2006). Undergraduate research as a catalyst for liberal learning. *Peer Review, 8*(1), 22-25. Retrieved from https://www.proquest.com/scholarly-journals/undergraduate-research-as-catalyst-liberal/docview/216599120/se-2?accountid=13360

Mueller, S. (2004). Electronic mentoring as an example for the use of information and communications technology in engineering education. *European Journal of Engineering Education, 29*(1), 53-63. https://doi.org/10.1080/0304379032000129304

Murray, S., Ryan, J., & Pahl, C. (2003). A tool-mediated cognitive apprenticeship approach for a computer engineering course. *Advanced Learning Technologies, 2003. Proceedings. The 3rd IEEE International Conference on,* 2-6. https://doi.org/10.1109/ICALT.2003.1215014

Musante, S. (2011). Forging a 21st Century Model for Undergraduate Research. *Bioscience, 61(1),* 18. https://doi.org/10.1525/bio.2011.61.1.6

National Academic of Engineering, N., Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*.

National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press. https://doi.org/10.17226/13165

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press. https://doi.org/10.17226/13165

National Science Foundation. (n.d.) Retrieved June 25, 2019, from https://www.nsf.gov/crssprgm/reu/list_result.jsp?unitid=10006&d-8001259-p=3

National Research Council. 2013. *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press. https://doi.org/10.17226/18290

Pacifici, L., & Thomson, N. (2011). What Do They Expect? A Comparison of Student Expectations and Outcomes of Undergraduate Research Experiences. *Journal of College Science Teaching, 41*(1), 54-60. Retrieved from https://www.proquest.com/scholarly-journals/what-do-they-expect-comparison-student/docview/893894385/se-2?accountid=13360

Prensky, M. (2001), "Digital natives, Digital Immigrants Part 1", *On the Horizon,* Vol. 9 No. 5, pp. 1-6. https://doi.org/10.1108/10748120110424816

Prensky, M. (2001), "Digital Natives, Digital Immigrants, Part 2: Do They Really Think Differently?", *On the Horizon,* Vol. 9 No. 6, pp.1-6. https://doi.org/10.1108/10748120110424843

Ragins, B., Cotton, J., & Murphy, Kevin R. (1999). Mentor Functions and Outcomes: A Comparison of Men and Women in Formal and Informal Mentoring Relationships. *Journal of Applied Psychology, 84*(4), 529-550. https://doi.org/ 10.1037/0021-9010.84.4.529

Rios-Ellis, B., Rascón, M., Galvez, G., Inzunza-Franco, G., Bellamy, L., & Torres, A. (2015). Creating a model of Latino peer education: Weaving cultural capital into the fabric of academic services in an urban university setting. *Education and Urban Society*, *47*(1), 33-55. https://doi.org/10.1177/0013124512468006

Rogers, D. L., Kranz, P. L., & Ferguson, C. J. (2012). A Strategy for Involving Undergraduates in Research. *Journal of Hispanic Higher Education, 11(1),* 55-66. https://doi.org/10.1177/1538192711435558

Roth, M. W., & Van Eijck, M. (2010). Fullness of Life as Minimal Unit: Science, Technology, Engineering, and Mathematics (STEM) Learning Across the Life Span. *Science Education, 94(6),* 1027-1048. https://doi.org/10.1002/sce.20401

Ryan, G. W., & Bernard, H. R. (2000). Data management and analysis methods. In N. K. Denzin & Y. S. Lincoln, (Eds.), *Handbook of Qualitative Research* (pp. 769-802). Thousand Oaks: CA: Sage.

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Publications.

Sadler, T. D., & McKinney, L. (2010). Scientific Research for Undergraduate Students: A Review of the Literature. *Journal Of College Science Teaching*, *39*(5), 43-49. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eft&AN=508161821&site=eds-live

Salomon, G. (1998). Technology's promises and dangers in a psychological context. *Theory Into Practice, 37(1),* 4-10. https://doi.org/10.1080/00405849809543780

Samarapungavan, A., Westby, E., & Bodner, G. (2006). Contextual Epistemic Development in Science: A Comparison of Chemistry Students and Research Chemists. *Science Education, 90*(3), 468-495. https://doi.org/10.1002/sce.20111

Santora, K., Mason, E., & Sheahan, T. (2013). A Model for Progressive Mentoring in Science and Engineering Education and Research. *Innovative Higher Education, 38*(5), 427-440. https://doi.org/10.1007/s10755-013-9255-2

Seymour, E., Hunter, A.B., Laursen, S., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science Education, 88(4),* 493-534. https://doi.org/10.1002/sce.10131

Sinex, S. & Chambers, T. (2013). Developing Online Collaboration Skills in General Chemistry Laboratory. *Journal of Chemical Education, 90(9),* 1244. https://doi.org/10.1021/ed300705t

Smith, B. (2007). Accessing social capital through the academic mentoring process. *Equity & Excellence in Education*, *40*(1), 36-46. https://doi.org/10.1080/10665680601088465

Stewart, K. & Lagowski, J. (2003). Cognitive Apprenticeship Theory and Graduate Chemistry Education. *Journal of Chemical Education, 80(12),* 1362–1367. https://doi.org/10.1021/ed080p1362

Street, B. (2003). What's "new" in New Literacy Studies? Critical approaches to literacy in theory and practice. *Current Issues in Comparative Education, 5(2), 77-91.* Retrieved from https://www.tc.columbia.edu/cice/pdf/25734_5_2_Street.pdf

Succi, C. & Canovi, M. (2020). Soft skills to enhance graduate employability: comparing students and employers' perceptions. *Studies in Higher Education, 45(9),* 1834-1847. https://doi.org/10.1080/03075079.2019.1585420

Tennebaum, L., Anderson, M., Jett, M., & Yourick, D. (2014). An Innovative Near-Peer Mentoring Model for Undergraduate and Secondary Students: STEM Focus. *Innovative Higher Education, 39(5),* 375-385. https://doi.org/10.1007/s10755-014-9286-3

Terrion, J., & Leonard, D. (2007). A taxonomy of the characteristics of student peer mentors in higher education: Findings from a literature review. *Mentoring & Tutoring: Partnership in Learning, 15*(2), 149-164. https://doi.org/10.1080/13611260601086311

Thiry, H., Laursen, S., & Hunter, A.B. (2011). What Experiences Help Students Become Scientists? A Comparative Study of Research and Other Sources of Personal and Professional Gains for STEM Undergraduates. *Journal of Higher Education, 82*(4), 357-388. https://doi.org/10.1080/00221546.2011.11777209

Tucker-Raymond, E., Gravel, B., Kohberger, K., & Browne, K. (2017). Source Code and a Screwdriver: STEM Literacy Practices in Fabricating Activities among Experienced Adult Makers. *Journal of Adolescent & Adult Literacy, 60*(6), 617-627. https://doi.org/10.1002/jaal.612

Wang, J. (2017). Course-based undergraduate research experiences in molecular biosciences-patterns, trends, and faculty support. *FEMS Microbiology Letters, 364*(15), 1-9. https://doi.org/10.1093/femsle/fnx157

Wilson-Lopez, A., Mejia, J., Hasbún, I., & Kasun, G. (2016). Latina/o Adolescents' Funds of Knowledge Related to Engineering. *Journal of Engineering Education, 105*(2), 278-311. https://doi.org/10.1002/jee.20117

Zollman, A. (2012). Learning for STEM Literacy: STEM Literacy for Learning. *School Science and Mathematics, 112*(1), 12-19. https://doi.org/10.1111/j.1949-8594.2012.00101.x

APPENDIX A

Pre-Experience Survey for Students

What knowledge and skills do you expect to acquire from your undergraduate research experience?

- How will the knowledge and skills you hope to acquire through this experience help you in the future? (consider education, career, and everyday life)

Can you tell me about your expectations for the mentoring relationship with your faculty mentor?

- What do you hope to gain from this relationship?
- How often do you expect to interact with your faculty mentor?
- How do you think the relationship with your faculty mentor will enable your acquisition of STEM literacies during the undergraduate research experience?

How will you interact with your faculty mentor (in person, email, etc.)?

- How do you expect to use technology to facilitate your undergraduate research experience with regards to the relationship with your faculty mentor?
- What do you think are the benefits of using technology to interact with your faculty mentor?

  What are the cons of using technology to interact with your faculty mentor?

APPENDIX B

Pre-Experience Survey for Faculty

What knowledge and skills do you expect students to acquire during the undergraduate research experience?

- How will the knowledge and skills help students in the future? (consider education, career, and everyday life)

Can you tell me about your expectations for the mentoring relationship with your students?

- What do you hope they gain from this relationship?
- How often do you expect to interact with your student mentee?
- How do you think the relationship with the student will enable their acquisition of STEM literacies during the undergraduate research experience?

How will you interact with your student mentee (in person, email, etc.)?

- How do you expect to use technology to facilitate communication with your student mentee during the undergraduate research experience?
- What do you think are the benefits of using technology to interact with your student mentee?

    What are the cons of using technology to interact with your student mentee?

APPENDIX C

Post-Experience Survey for Students

Can you describe the knowledge and skills you acquired during the undergraduate research experience?

- How do you think the knowledge and skills will help you in the future? (consider education, career, and everyday life)

Can you tell me about your expectations for the mentoring relationship with your faculty mentor aligned with the actual outcomes?

- What did you gain from this relationship?
- How often did you interact with your faculty mentor?
- How did the relationship with your faculty mentor enable your acquisition of STEM literacies during the undergraduate research experience?

How did you interact with your faculty mentor (in person, email, etc.)?

- How did you use technology to facilitate your undergraduate research experience with regards to the relationship with your faculty mentor?
- What do you think are the benefits of using technology to interact with your faculty mentor?

    What are the cons of using technology to interact with your faculty mentor?

APPENDIX D

Post-Experience Survey for Faculty

Can you describe the knowledge and skills students acquired during the undergraduate research experience?

- How do you think the knowledge and skills will help students in the future? (consider education, career, and everyday life)

Can you tell me about your expectations for the mentoring relationship with your students aligned with the actual outcomes?

- What did they gain from this relationship?
- How often did you interact with your student mentee?
- How did the relationship with your student mentee enable their acquisition of STEM literacies during the undergraduate research experience?

How did you interact with your student mentee (in person, email, etc.)?

- How did you use technology to facilitate communication with your student mentee during the undergraduate research experience?
- What do you think are the benefits of using technology to interact with your student mentee?

  What are the cons of using technology to interact with your student mentee?

APPENDIX E

Post-Experience Interviews for Students

Theme 1: Description of Own Work

- Could you tell me about the research you did this summer?
- What was the purpose of the research?

Theme 2: Choice of Problem and Methods

- How did you become involved in this research?
- How did you come to choose the specific problems you worked on?
- How did you decided upon specific methods to investigate those problems?
- What is the purpose of the specific methods you used in your research this summer?

Theme 3: Handling STEM Literacies

- In the course of your research have you encountered experiences that will help you solve other problems in life? Can you give me some examples?
- In the course of your research have you encountered experiences that will help you with the ability to maneuver as you go? Can you give me some examples?
- The same question format used for the remainder of the STEM literacies:
    - Expand knowledge; demonstrate resilience to problems that are difficult or hard to deal with; deal creatively with the unexpected; possess orientation toward motives of activities and goals of actions; posing and solving problems in the world and in the design process; identifying, organizing, and integrating information across sources; creating representational forms and traversing representational systems and materials; communicating information in new ways to different audiences; documentation making processes and/or milestones

Theme 4: Criteria for Evaluating Own Work

- How do you evaluate the success of your educational studies in general?
- What do you consider to be your best work? Why do you think it is your best work?
- How do you evaluate the success of your research this summer?

Theme 5: What are STEM literacies?

- What are STEM literacies?
- What differentiates the undergraduate research experience from other experiences in the acquisition of STEM literacies?

How important was it in your undergraduate research experience for your faculty mentor to:

- Address your needs
- Tap into your interests
- Encourage honest criticism of your ideas and work
- Encourage creative risk-taking
- Model skills needed for the research experience
- Give the amount of time needed and be flexible with time

APPENDIX F

Post-Experience Interviews for Faculty

Handling STEM Literacies

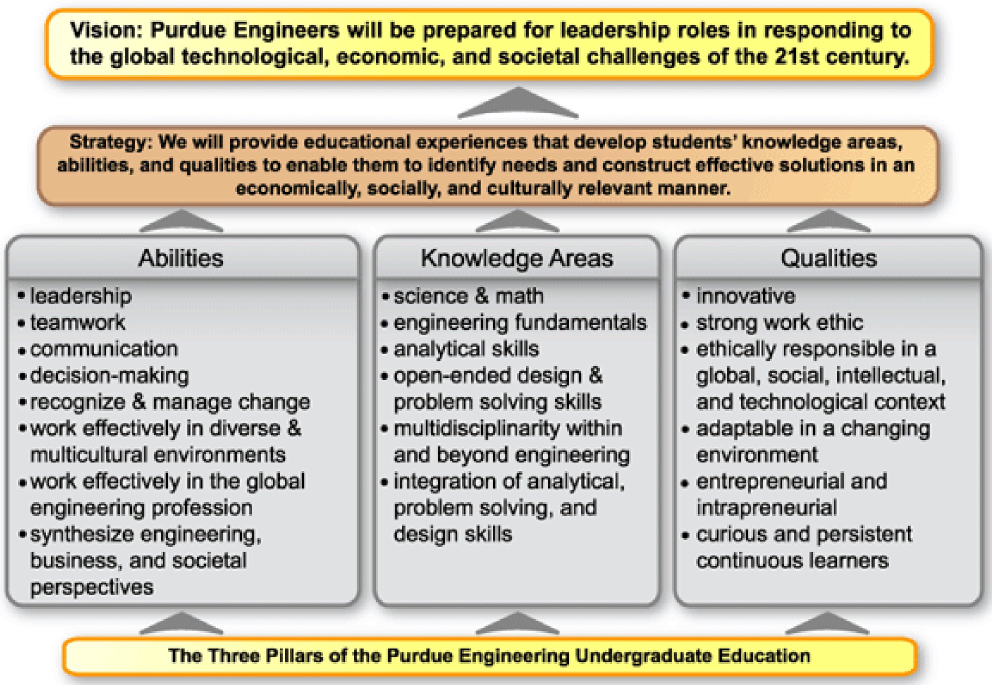
- In the course of the undergraduate research experience did the student encounter experiences that will help him/her solve other problems in life? Can you give me some examples?
- In the course of the undergraduate research experience did the student encounter experiences that will help him/her with the ability to maneuver as you go? Can you give me some examples?
- The same question format used for the remainder of the STEM literacies:
    - Expand knowledge; demonstrate resilience to problems that are difficult or hard to deal with; deal creatively with the unexpected; possess orientation toward motives of activities and goals of actions; posing and solving problems in the world and in the design process; identifying, organizing, and integrating information across sources; creating representational forms and traversing representational systems and materials; communicating information in new ways to different audiences; documentation making processes and/or milestones

How important was it in the undergraduate research experience for your student mentee to:

- Understand key concepts
- Connect old and new knowledge
- Understand how preconceptions affect learning
- Address doubts directly
- Apply previous knowledge to new concepts
- Extend inquiry beyond the research experience
- Apply new knowledge to future experiences
- Evaluate the research experience
- Reflect upon the research experience
- Construct new knowledge
- Follow-up the project with new questions

APPENDIX G

Engineer of 2020 Initiative



APPENDIX H

STEM Literacies for Coding

Roth and Van Eijck (2010)	Maneuver as they go, expand their knowledge, demonstrate resilience to problems that are difficult or hard to deal with, deal creatively with the unexpected, and possess an orientation toward motives of activities and goals of actions
Tucker-Raymond, Gravel, Kohberger, and Browne (2017)	Posing and solving problems in the world and in the design process; identifying, organizing, and integrating information across sources; creating representational forms and traversing representational systems and materials; communicating information in new ways to different audiences; and documenting making processes and/or milestones

APPENDIX I

Coding for Survey Questions

Question 2	Prepare for graduate school; future career; communication skills / publications; other skills; daily life
Question 3	Letter of recommendation; general involvement / feedback; research itself (including research related to presentations) and passion for research; relationship; grad student / limited contact with faculty; other; (On post survey coding "other" was split into "other / expectations aligned" and "other / mismatch of expectations"
Question 4	Letter of recommendation; relationship / mentoring / networking; skills / general knowledge; research; qualities; future opportunities; other
Question 5	Daily; every other day; 1x per week; more than 1x per week; biweekly; monthly; other
Question 6	STEM knowledge; graduate school / future career / big picture thinking; research / lab; critical / creative thinking; communication / writing; qualities; not familiar with STEM literacies; other
Question 7	In person – one on one; in person – group; email; virtual (including Slack, text, call); other (including non research social interactions)
Question 8	Basic communication (scheduling); collaborative communication; presentations; research / data analysis; other
Question 9	Communication – quick/easy/convenience; communication – effective; research / skills; not effective / none / other
Question 10	Insufficient; impact on in person interaction; technology issues; none / other