Title

Characterization of teaching, mentoring, and career exploration during STEM undergraduate research experiences at universities and national laboratories across three studies

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Characterization of teaching, mentoring, and career exploration during STEM undergraduate research experiences at universities and national laboratories across three studies

by

Laleh Esmaili Coté

A dissertation submitted in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy
in
Science & Mathematics Education
in the
Graduate Division
of the
University of California, Berkeley

Committee in charge:

Professor Anne M. Baranger, Co-Chair
Professor Kris D. Gutiérrez, Co-Chair
Professor Michael A. Ranney
Associate Professor Matthew F. Traxler

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Abstract

Characterization of teaching, mentoring, and career exploration during STEM undergraduate research experiences at universities and national laboratories across three studies

by
Laleh Esmaili Coté

Doctor of Philosophy in Science & Mathematics Education

University of California, Berkeley

Professor Anne M. Baranger, Co-Chair
Professor Kris D. Gutiérrez, Co-Chair

In this dissertation, I present readers with three studies about the ways in which science, technology, engineering, and mathematics (STEM) research experiences impact undergraduate learning, perspectives, and academic/career activities. In the first two studies I focus on this topic by investigating the ways in which undergraduates were impacted by completing a STEM internship. The first study is unique in focusing on an understudied population: **community college students interested in STEM fields**. Both the first and second studies make a novel contribution to the STEM education literature by investigating **U.S. Department of Energy (DOE) national laboratories as learning environments**. These institutions are largely missing from the wealth of academic literature about undergraduate education in STEM disciplines. In the third study I **define teaching and mentoring in STEM research experiences**, which are terms that are often used, but rarely defined by scholars. In the third study I apply these definitions and a new instrument to determine which teaching and mentoring practices graduate students used when working with undergraduates on STEM research projects, and produce a set of practices that both scholars and practitioners can use in the future.

Study 1 focuses on the perspectives of individuals who were taking STEM coursework while enrolled in community colleges. The majority of undergraduates who enroll in community college and/or begin their studies in STEM to obtain a degree do not meet this goal. Previous studies have shown that participation in technical and research internships can increase undergraduate academic achievement, graduation rates, confidence, and STEM persistence. However, very little is known about the benefits of these activities a) for community college students, b) when hosted by DOE national laboratories, and c) beyond the first few years after the internship. I applied the Social Cognitive Career Theory (SCCT) to investigate alumni perspectives about how the Community College Internship (CCI) at a specific DOE national laboratory – Lawrence Berkeley National Laboratory (LBNL) – impacted their academic/career activities. Specifically, I collected survey and interview data from 43 “CCI alumni,” most

of whom majored in civil engineering, mechanical engineering, or chemistry as undergraduates. Analysis of this data revealed that CCI alumni had low confidence and expectations of success in STEM as community college students, and were negatively impacted by the stigma associated with community colleges. Participation in CCI increased their professional networks, expectations of success, and STEM skills, identity, and self-efficacy/confidence. Hispanic/Latinx alumni recalled the positive impact of mentors who prioritized personal connections, and women valued "warm" social environments. These findings highlight program components and mentoring practices that had long-lasting effects on these individuals. Additionally, I propose several additions to the SCCT model, to better reflect the supports and barriers to STEM persistence for community college students. Future studies could build on this work to expand what is currently known about the impact of STEM educational opportunities at DOE national laboratories for community college students.

Study 2 is closely related to Study 1 because of its focus on DOE national laboratories as learning environments, which is a topic with very little representation in academic literature. For students attending baccalaureate granting institutions, it is well-established that participation in research experiences or internships hosted by colleges and universities can support retention in STEM degree programs. However, limited research has been published about these opportunities for community college students and/or hosted by the DOE national laboratories. Data was collected from individuals who participated in the Community College Internship (CCI) and Science Undergraduate Laboratory Internship (SULI) programs between 2009 and 2016, at Lawrence Berkeley National Laboratory (LBNL). The CCI and SULI programs are part of a suite of programs hosted at DOE national laboratories designed to expose students and recent graduates to career opportunities at these institutions. Of the CCI alumni, 94% transferred to a baccalaureate granting institution, 90% graduated with a STEM bachelor's degree, and 88% are on a STEM career pathway. Based on what is known about graduation and transfer of community college students in the U.S., CCI alumni transferred and graduated with bachelor's degrees at higher rates than expected. Of the SULI alumni, 91% graduated with a STEM bachelor's degree, and 71% are on a STEM career pathway. These findings suggest that – as compared to students attending baccalaureate granting institutions – community college students who engage in STEM professional development activities are likely to persist in STEM careers at similar rates. Additionally, participation in STEM professional development activities may increase the likelihood that community college students complete their academic degrees in STEM disciplines.

Shifting the focus *away* from the perspectives and activities of undergraduates, I investigate the topic of teaching and mentoring in undergraduate research experiences (UREs) in Study 3. It is common practice for undergraduates in STEM degree programs to participate in discipline-specific research experiences to gain new skills and knowledge, and to explore STEM careers. Similarly, many graduate students are expected to collaborate with undergraduates on a research project, which requires them to employ a combination of teaching and mentoring practices. Studies have shown that practices can vary dramatically between individuals, and these differences impact the overall experience for undergraduates (positively or negatively). However, the details provided in previous studies about STEM research experiences are insufficient to

determine which teaching or mentoring practices are being used in a particular learning environment, by whom, and how often. Many scholars have described benefits of understanding how teaching and mentoring activities differ from each other, which supports student learning and well-being, communication between research team members (including undergraduates), and the evaluation of teaching/mentoring quality in STEM research experiences. Study 3 describes the new *Berkeley Undergraduate Research Evaluation Tools Teaching and Mentoring (BURET-TaM)* instrument, which I developed collaboratively with research team members to identify the teaching and mentoring practices used in STEM research experiences. Additionally, I provide definitions for teaching and mentoring for UREs relevant to this new instrument that are informed by the literature and can be used by educational researchers, students, and practitioners alike. I applied the *BURET-TaM* instrument to written reflections from and interviews with 46 graduate students working with undergraduate researchers in faculty-led research teams at the university and/or at the nearby DOE national laboratory, and generated a list of teaching and mentoring practices used by this group. My findings suggest that a) teaching and mentoring practices are often intertwined in this context, b) teaching scientific concepts and processes can support undergraduates to learn how new scientific knowledge is created, and c) research environments can impact student learning, well-being, and success. In the future, departments or research teams could use this new instrument to implement training sessions or materials to support scientists and professionals in learning how to teach/mentor undergraduate researchers, or to improve their skills in these areas.

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First and foremost thank you to my husband Jed, and our kiddo Cyrus - I love you both, and appreciate your unwavering confidence in me, and how much you both have learned about academia over the past few years. Second, I would like to express my deepest gratitude to my advisor, Anne Baranger. During my doctoral program there have been so many challenges involving the COVID-19 crisis, California wildfires, school closures, parenting, staff turnover at work, etc., that it is hard for me to imagine how I could have completed my program if I didn't have an advocate and friend like you. I look forward to many more years of collaboration and community-building with you and your research group. Similarly, I have to give a huge shout-out to my parents (Rahim Esmaili and Laura Esmaili) and my father-in-law (Mark Coté), for their enormous commitment to spending time with Cyrus during my program - thank you for your support. And, to the women who helped me believe that I was capable of completing a doctorate – BreAnna Chaparro, Sinéad Griffin, Colette Patt, Anna Spurlock, and Rachel Woods-Robinson – I truly appreciate your role in this chapter of my life.

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[1] In tribute to the memory of Cris Alvaro, please read about Dragonfly Mental Health online here: https://mcb.berkeley.edu/news-and-events/department-news/how-tackle-mental-health-epidemic-academia-new-approach-uc-berkeley

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Introduction

Each year, thousands of students majoring in science, technology, engineering, and mathematics (STEM) in the United States (U.S.) engage in a research experience, allowing them to work on meaningful projects in their discipline and engage with the scientific community. STEM research experiences are available to undergraduates, post-baccalaureates, and graduate students, and can be a critical part of their academic/career trajectory. Colleges, universities, U.S. Department of Energy (DOE) national laboratories, companies, and research centers invest considerable resources to support these programs, and many scholars have studied the impacts of these opportunities on student learning and development, and the STEM workforce.

Many studies focus on the correlations between persistence in STEM fields and academic factors such as academic preparation, class ranking, grade point average (GPA), and undergraduate coursework taken. However other studies have shown that co-curricular activities, which impact psychosocial variables (e.g., identity, motivation, self-efficacy, sense of belonging), can play a large role in student learning and persistence in STEM (Linn et al., 2015). In 2010, Sadler and colleagues published an influential review article in which they explored learning outcomes as a result of participation in an undergraduate research experience (URE). They found that student gains include increased scientific content knowledge; improved confidence, self-efficacy, and career aspirations; and development of intellectual and technical skills. Since that time there have been many studies published to describe STEM research experiences across disciplinary fields and explore the wide variety of possible benefits for both students and the researchers who mentor them.

For an undergraduate, participation in a STEM research experience to complement their coursework can be a fundamental contributor to their pursuit of a career in their chosen discipline (Adedokun et al., 2013; Thiry, Laursen, & Hunter, 2011). Although research experiences vary widely in nature, there are some goals for students that are generally shared across different settings: contribute to faculty/scientist research projects, build leadership and collaborative skills, and gain exposure to career pathways and/or graduate school in STEM fields (Cooper et al., 2019a; Hernandez et al., 2018; Linn et al., 2015).

Undergraduate research experiences support national efforts to broaden participation in STEM fields

It is now very well-established that there are large disparities in scientific fields, which disadvantage groups such as women, certain racial and ethnic groups (e.g., American Indian, Alaska Native, Black, Hispanic/Latinx), and LGBTQIA, disabled, first-generation to college, low-income individuals. Although the rates of interest in STEM tend to be high across students from all backgrounds, Alaska Native, Black, Hispanic/Latinx, Native American, female, first generation to college, and low-income students leave STEM at *higher* rates than students from groups who are well-represented in these fields (Anderson & Kim, 2006; Griffith, 2010; Hill et al., 2010; Huang et al., 2000; Kokkelenberg & Sinha, 2010; Shaw & Barbuti, 2010).

Multiple scholars argue that Black and Hispanic/Latinx students and early career professionals do not receive adequate support needed to obtain their academic and career goals, and call for additional research on the subject (Carales & López, 2020; García & Garza, 2016; Gaxiola Serrano, 2017; Ornelas & Solorzano, 2004; Singleton et al., 2021). This issue is only exacerbated in STEM disciplines, and Black, Hispanic, and Latinx students benefit from opportunities to interact with a supportive community, receive academic and social support, learn to publish and present work, and develop a sense of belonging within their STEM field of interest (Abrica et al., 2022; Cervantes, 2021; Jain et al., 2020; Morton, 2021; Singleton et al., 2021). Low levels of psychosocial constructs (e.g., STEM interest, self-efficacy, STEM identity, confidence, enjoyment of math and science) are thought to be important to understanding the low graduation rates and persistence in STEM for Black and Latinx students who are interested in STEM careers (Bottia et al., 2021). Each of these factors contribute to varying levels of access to STEM careers, depending on the group a student belongs to. Considering the overall goal of diversifying STEM fields, shared by many institutions across the U.S., it is important to understand the unique challenges faced by students from groups who have been historically excluded from STEM fields in the past. Thus, it is critical to explore those factors that, in the context of a URE, contribute to student persistence in STEM. In other words, what encourages a student to "stay?"

Many studies suggest that gains related to retention in STEM (e.g., graduation rates, entry into the STEM workforce, graduate school attendance) are supported through participation in research experiences, especially for students from groups historically excluded from STEM fields (Carpi et al., 2017; Estrada et al., 2018b; Rodenbusch et al., 2016; Sadler et al., 2010). Especially true for women and people of color, many students cite a loss of interest in their discipline, a loss of confidence in oneself as a scientist (or future scientist), and the lack of a support system as reasons for switching out of STEM, and participation in STEM research experiences are suggested as a way to reduce the frequency with which this occurs over the course of their studies (Thiry et al., 2011). Factors such as a positive science identity, self-efficacy development, access to relatable mentors and role models, and engagement in research at the undergraduate level are critical to supporting students from groups who have historically been excluded from STEM based on race or ethnicity to persist in STEM (Mireles-Rios & Garcia, 2019; Mondisa, 2015).

The President's Council of Advisors on Science and Technology (PCAST) has called for DOE national laboratories to engage with community colleges in preparing a diverse future STEM workforce through internships and work-based learning experiences (PCAST, 2021). This is, in part, due to the fact that **community college students are collectively more diverse** than students attending public or private baccalaureate granting institutions, with respect to gender, race, ethnicity, neurodiversity, disability, career pathway, parental educational attainment, and socio-economic status (AACC, 2019; Jain et al., 2020; Newman et al., 2011; Provasnik & Planty, 2008; Radwin et al., 2013). Study 1 investigates the experiences of **community college STEM majors** before, during, and after they participated in an internship at a DOE national laboratory and how they believe their experiences impacted their academic and career activities.

Research experiences hosted at national laboratories support STEM workforce development

Considering the anticipated number of retirees in the coming years, experts predict that the energy and manufacturing sectors may not have enough staff to meet workforce demands, and loss of institutional knowledge across all STEM fields throughout the DOE national laboratory system (DOE, 2017; Energy Workforce Opportunities and Challenges, 2019; National Research Council, 2015). Several federal calls to action have focused on the importance of increasing the number of trainees to work in STEM fields in the U.S. (America COMPETES Act of 2022, 2022; PCAST, 2012, 2021). One strategy for addressing this issue involves offering internships and other professional development opportunities for students at DOE national laboratories and facilities across the U.S., and taking steps to retain some of these students as employees in the following years (DOE, 2017, 2022; DOE Office of Science, 2020).

Due to the potential benefits of STEM research experiences and internships, there are many studies published each year that assess their role in student success, examine newly developed interventions to support student learning, and highlight the perspectives of student participants. As a scholarly subject, **very little is known about these opportunities hosted at DOE national laboratories**, though they have been *extensively* studied when the host institution is a baccalaureate granting institution. (Krim et al., 2019; Linn et al., 2015; National Academies of Sciences, Engineering, and Medicine (NASEM), 2017). This is surprising, considering the fact that DOE national laboratories spend over $500 million each year to support students, recent graduates, postdoctoral fellows, and faculty members through sponsored research experiences, in collaboration with more than 450 institutions in the U.S. and Canada (DOE, 2017; Krim et al., 2019).

Although a collection of technical and meeting reports, conference papers, and abstracts have been published about STEM education and outreach activities at DOE national laboratories, most of these do not include data collected from the individuals involved in these activities (e.g., Bai et al., 2022; Bellis et al., 2022; Johnson et al., 2010; Kuehn & Jones, 2018; Sinnott et al., 2021). There is only one previous project I am aware of that examined how DOE internships compare to other federally funded programs and examined program outcomes, though these findings have not been published in a peer-reviewed journal (Foltz et al., 2011). To address this gap in the literature, Study 2 examines the **academic and career activities in the years following undergraduates' participation in internships at DOE national laboratories**. The Community College Internship (CCI) and Science Undergraduate Laboratory Internship (SULI) programs are the focus of this study. These programs are regarded as opportunities to foster diversity within the DOE workforce, and DOE national laboratories engage in outreach efforts to increase the likelihood that students and recent graduates from various backgrounds apply to participate (Hampton-Marcell et al., 2023; DOE SC, 2020).

Distinguishing between "teaching" and "mentoring" provides new opportunities to improve and study STEM research experiences

Although mentoring is just *one* component of STEM research experiences, there is a wealth of literature to suggest that positive mentoring can maximize the potential benefits of these experiences for undergraduates (Taraban & Logue, 2012). For example, studies show that interactions between undergraduates and faculty can support undergraduate academic identity, sense of belonging, integration into the professional community, access to career opportunities, and achievement of academic goals (e.g., Crisp & Cruz, 2009; Stanton-Salazar, 2011; Strayhorn, 2008). Working with faculty mentors to conduct scientific research can support undergraduates' ability to think "like a scientist," perceive themselves as scientists, and support their intention to pursue a STEM career (Aikens et al., 2016; Chemers et al., 2011; Eagan et al., 2013; Hunter et al., 2007; Thiry et al., 2011). Positive mentoring practices shown to be impactful for student mentees include providing emotional support, making time for one-on-one communication, fostering community within the laboratory environment, and encouraging mentees to develop their professional skills through technical writing, formal presentations, and contributing their own ideas to active research projects (Shanahan et al., 2015).

There is consensus that these benefits are desirable outcomes of STEM research experiences, which have been featured in thousands of previous studies. However, the concept of "mentoring" is not well-defined, used in conflicting ways between studies, and often include approaches and practices that should be characterized as "teaching" instead (Crisp & Cruz, 2009; Ehrich et al., 2004; Gershenfeld, 2014; Jacobi, 1991). Without clear definitions of teaching and mentoring, scholars cannot appropriately apply theory, programs cannot accurately assess the impact of their "mentors," and the individuals responsible for teaching and mentoring have less guidance about how to prioritize their time when working with undergraduate researchers (Dawson, 2014; Dolan, 2016; Fletcher & Mullen, 2012; Jacobi, 1991).

Despite the fact that many people working in STEM fields are expected to teach and mentor undergraduate researchers, training is not typically provided, and many people model their teaching and mentoring approaches on the strategies of their peers or the type of support that they received during their undergraduate or graduate studies (Austin, 2002; Amundsen & McAlpine, 2009; Duffy & Cooper, 2020; Hund et al., 2018). Informed by theory and a review of the literature, Study 3 provides readers with **new definitions of teaching and mentoring undergraduate researchers** and introduces an instrument that distinguishes between teaching and mentoring practices in this context. It is important for undergraduates and the STEM professionals working with them to understand how teaching and mentoring activities differ from each other in order to clarify responsibilities, improve communication, increase the chances of achieving desired outcomes, and support assessment of an undergraduate's progress (Shanahan et al., 2015; Steneck, 2006; Titus & Ballou, 2013). Additionally, clarification and study of the teaching and mentoring provided to Black, Hispanic/Latinx, and Native American students – who receive less career support and mentoring than their peers – is crucial for promoting equity in and access to STEM careers (e.g., Lane, 2016; Morton, 2021; NASEM, 2019; Rainey et al., 2019; Singleton et al., 2021).

CHAPTER 1

“When I talk about it, my eyes light up!” Impacts of a national laboratory internship on community college student success (Study 1)

Most undergraduates who enroll in community college and/or begin their studies in STEM to obtain a degree do not meet this goal. Previous studies have shown that participation in technical and research internships can increase undergraduate academic achievement, graduation rates, confidence, and STEM persistence. However, very little is known about the benefits of these activities a) for community college students, b) when hosted by DOE national laboratories, and c) beyond the first few years after the internship. I applied the Social Cognitive Career Theory (SCCT) to investigate alumni perspectives about how CCI at Lawrence Berkeley National Laboratory (LBNL) impacted their academic/career activities. Specifically, I collected survey and interview data from 43 “CCI alumni,” most of whom majored in civil engineering, mechanical engineering, or chemistry as undergraduates. CCI alumni reported low confidence and expectations of success in STEM as community college students, and were negatively impacted by the stigma associated with community colleges. Participation in CCI increased their professional networks, expectations of success, and STEM skills, identity, and self-efficacy/confidence. Hispanic/Latinx alumni recalled the positive impact of mentors who prioritized personal connections, and women valued “warm” social environments. These findings highlight program components and mentoring practices that had long-lasting effects on these individuals. Additionally, I propose several additions to the SCCT model, to better reflect the supports and barriers to STEM persistence for community college students. Future studies can build on this work to expand what is currently known about the impact of STEM educational opportunities at DOE national laboratories for community college students.

Introduction

National reports highlight the value of investing in STEM education to support the long-standing effort to increase the representation of women; Black, Hispanic/Latinx, and Native American people; and people with disabilities in these fields (America COMPETES Act of 2022, 2022; Hampton-Marcell et al., 2023; National Center for Science and Engineering Statistics, 2021). One component of the recent CHIPS and Science Act is to take active steps toward broadening participation in STEM disciplines, with the ultimate goal of increasing diversity across the workforce (CHIPS Act of 2022, 2022). To promote diversity, equity, inclusion, and accessibility across their large suite of programs, the DOE Office of Science recently implemented the Reaching a New Energy Sciences Workforce (RENEW) initiative, the Promoting Inclusive and Equitable Research (PIER) component of research proposals, and other related efforts (DOE, 2022). These initiatives are important to higher education and workforce development, because STEM majors in the U.S. are more likely to drop out of school or switch to a non-STEM major than their peers in non-STEM disciplines (Anderson & Kim, 2006; Chen, 2013). Additionally, Alaska Native, Black, Hispanic/Latinx, Native American, female, first generation to college, and low-income students leave STEM at higher rates than students from groups who are well-represented in these fields (Anderson & Kim, 2006; Hill et al., 2010; Griffith, 2010; Huang et al., 2000; Kokkelenberg & Sinha, 2010; Shaw & Barbuti, 2010). Thus, it is critical to explore those factors that contribute to student persistence in STEM and determine what encourages a student to "stay?"

As I will describe in Study 1, student engagement in STEM research experiences and internships are an effective way to increase participation of students from a diverse range of backgrounds and promote long-term retention in STEM (e.g., Hernandez et al., 2018b; Nerio et al., 2019; Thompson et al., 2021). Although these opportunities have been extensively studied when the host institution is a baccalaureate granting institution, very little is known about these opportunities hosted at DOE national laboratories and/or those in which community college students participate. Additionally, there are few studies that examine the long-term perspectives of students after their participation in a technical/research experience (e.g., Dou et al., 2021; Trott et al., 2020). With respect to the DOE, the CHIPS and Science Act calls for efforts to assess the rates of participation of people from groups historically excluded from STEM in DOE-supported programs, learn more about the barriers to participation for these groups, and identify solutions to these barriers (CHIPS Act of 2022, 2022). A recent report by the National Academies of Sciences, Engineering, and Medicine (NASEM) recommends that researchers examine connections between the identities of individual participants and their experiences in different contexts, including academic and professional settings (NASEM, 2023). Additionally, scholars call for the documentation of program characteristics, programmatic elements linked to positive student outcomes, unique experiences of students from different groups, and how programs differ across institution types (Gin et al., 2021; Lucero et al., 2021; NASEM, 2016; NASEM, 2017).

To address these calls to action, I studied the experiences of community college STEM majors before, during, and after they participated in an internship at a DOE national laboratory and how they believe their experiences impacted their academic and career activities. As part of Study 1, I investigated the following research questions:

RQ1: *Prior to applying to the Community College Internship (CCI) at Lawrence Berkeley National Laboratory (LBNL), what were the experiences of CCI alumni when they were community college students studying STEM?*

RQ2: *What skills, gains, and/or benefits do alumni of the CCI program at LBNL attribute to their participation in this program?*

RQ3: *In what ways do CCI alumni believe that their backgrounds, cultures, and identities impacted their experiences studying and pursuing careers in STEM?*

Overview of Study 1

I explored the ways in which community college students experience benefits as a direct result of participation in a STEM internship, to learn both how and why this program impacted its participants. Although many quantitative studies have documented achievement levels for undergraduates across different institution types, there is a gap in knowledge about the academic trajectories and experiences of students attending U.S. community colleges and the ways in which their personal experiences have impacted their academic and career success (Crisp et al., 2016; Taylor & Jain, 2017). Informed by many studies that link psychosocial, academic, and professional benefits for students who complete STEM research experiences and internships (e.g., Carpi et al., 2017; Jelks & Crain, 2020; Thompson et al., 2021), the lack of knowledge about the experiences of community college STEM majors, and the absence of studies documenting programs at DOE national laboratories, I considered the role of the CCI program on study participants' academic and career activities. I gained a deep understanding of participant experiences before, during, and after participation in the program through the documentation of their experiences as students and their opinions about the factors that influenced their academic/career trajectories (including their own community, culture, and background).

Asset-based approach

In Study 1, I take an **asset-based (anti-deficit) approach** to studying the experiences of individuals who began their STEM coursework as community college students. Deficit thinking involves labeling certain students as being "disadvantaged" or "lacking" in some way, and can be used to justify why some students "fail to achieve" at the same levels as students in other groups (Reed, 2020; Walker, 2011). An example of a deficit-oriented approach would place responsibility on students for "leaving" STEM – because they are less prepared or motivated – as opposed to considering the ways in which institutions may be differentially serving students from different groups (Harry & Klingner, 2007; Ladson-Billings, 2017; NASEM, 2023). These approaches are problematic because educators, programs, and institutions may have low expectations for some students, if they believe that their shortcomings "are incapable of being changed" (Reed, 2020). When considering the "lack of diversity" in the STEM workforce, it is important to consider the presence of racial and gender biases in admission processes, unequal allocation of educational resources for certain student groups, insufficient access to telecommunication in rural areas and tribal lands, and other obstacles to higher education and STEM careers (NASEM, 2021). In this study, I ask questions that allow me to investigate the reasons why community college students *persist* in STEM, aligned with the asset-based approaches taken by other educational research studies (e.g., Martin et al., 2020; Rincón & Rodriguez, 2021; Stanton et al., 2022). As educators and mentors, if we identify the factors that have a positive influence on students, we better position ourselves to reproduce these supports in the future.

Table 1.1

Definition of terms used in this study

Term	Definition
Community college	Accredited U.S. colleges offering associate degrees, such as the Associate of Arts (A.A.) and Associate of Science (A.S.); some offer specialized technical or vocational programs; often referred to “two-year,” “2-year,” “city,” “junior,” “local,” or “technical” colleges or schools (Ocean et al., 2022) even though many students require more or less time than two years (Complete College America, 2014; Jain et al., 2020).
Baccalaureate granting institution	Accredited U.S. colleges or universities offering degrees such as the Bachelor of the Arts (B.A.) and Bachelor of Science (B.S.) (Jain et al., 2020); many undergraduates attending “4-year” schools take longer than 4 years to complete their degree, transfer between schools, or transfer to a community college (Bowen et al., 2009; Complete College America, 2014; Townsend & Dever, 1999).
Transfer	Most common form is “vertical transfer,” when an undergraduate completes lower-division coursework at a U.S. community college in order to move to a baccalaureate granting institution to complete upper-division coursework and obtain a bachelor’s degree; additional forms include “horizontal transfer,” when an undergraduate moves from one baccalaureate granting institution to another (Townsend, 2001).
Graduate	Community college graduation refers to an undergraduate obtaining one or more associate degrees; graduating from a baccalaureate granting institution refers to obtaining one or more bachelor’s degrees.

Technical and research experiences benefit STEM majors at baccalaureate granting institutions

For students at baccalaureate granting institutions, numerous studies show that participation in a mentored research experience has many potential benefits, including increased academic achievement, likelihood of completing a STEM undergraduate degree, interest in completing a STEM graduate degree, and persistence in STEM (Chemers et al., 2011; Eagan Jr et al., 2013; Hampton-Marcell et al., 2023; Hernandez et al., 2018; Jelks & Crain, 2020; Nerio et al., 2019; Prunuske et al., 2016). Working on technical projects, engaging in research, and receiving support from mentors can clarify students' academic/career goals, and lead to gains in self-efficacy, confidence, technical skill level, and persistence in their field of study (Hernandez et al., 2018; Morales & Jacobson, 2019; Thompson et al., 2021). Factors such as self-efficacy, STEM identity, and internalization of the values of the scientific community are thought to act as mediators between STEM activities and overall persistence in STEM careers (e.g., Estrada et al., 2018a; Syed et al., 2019).

Undergraduates are greatly influenced by the activities they engage in during the first two years of their college experience, but many undergraduates do not participate in STEM technical work or research until the last two years of their bachelor's degree (PCAST, 2012; Russell et al., 2007). Studies suggest that participating in research during the first two years of undergraduate studies has the potential to increase student grade point average (GPA) at graduation, discipline-specific content knowledge, confidence, curiosity, interest, science identity, and institutional satisfaction (Bowman & Holmes, 2018; Magee & Simpson, 2019; Thiry et al., 2012). Aptly stated by Hagedorn and Purnamasari (2012), a student "will not elect to be a nuclear physicist" without some exposure to the field, or knowledge about what the career path entails; participation in research experiences or internships can provide these opportunities.

STEM technical and research experiences for community college students

Collectively, many community college students are interested in transferring to baccalaureate granting institutions, graduating with a STEM degree, and entering the STEM workforce, but very few meet these goals (Bahr et al., 2017; Bottia et al., 2020; Varty, 2022). Of those "entering" students taking STEM coursework at a community college, 75-80% aspire to graduate with a bachelor's degree, but only 15-16% of community college STEM majors achieve this goal (CCSSE, 2021; Horn & Skomsvold, 2011; Juszkiewicz, 2020; Sansing-Helton et al., 2021; NCES, 2019). The President's Council of Advisors on Science and Technology (PCAST) has called for DOE national laboratories to engage with community colleges in preparing a diverse future STEM workforce through internships and work-based learning experiences (PCAST, 2021). This is, in part, due to the fact that community college students are collectively more diverse than students attending public or private baccalaureate granting institutions, with respect to gender, race, ethnicity, neurodiversity, disability, career pathway, parental educational attainment, and socio-economic status (AACC, 2019; Jain et al., 2020; Newman et al., 2011; Provasnik & Planty, 2008; Radwin et al., 2013). Low levels of psychosocial constructs (e.g., STEM identity, confidence) are thought to be important to understanding the low graduation rates and STEM persistence of Black and Hispanic/Latinx undergraduates (Bottia et al., 2021). Previous work has shown that undergraduate research and internships for undergraduates attending baccalaureate granting institutions can increase these psychosocial constructs, and internship programs hosted by DOE national laboratories are a possible mechanism through which community college students might similarly benefit (Morales & Jacobson, 2019; Thompson et al., 2021).

It is clear that engagement of community college students in STEM research experiences and internships could have enormous impact on their retention in STEM. However, although nearly 50% of people with STEM bachelor's or master's degrees attended a U.S. community college, an estimated 6% (or fewer) of the studies published each year about STEM research experiences and internships include data from community college or transfer students (Creech et al., 2022; Krim et al., 2019; Lucero et al., 2021; Linn et al., 2015; Mooney & Foley, 2011; NASEM 2017; NSF, 2011; Tsapogas, 2004; Tuthill & Berestecky, 2017). This may be because fewer community college students participate in STEM research experiences and internships due to lack of access. Additionally, there may be a connection between concealable identities that "carry negative stereotypes" in the academic science community – such as attending a community college – and the lack of scholarly work dedicated to understanding those identities (Busch et al., 2024). There are some examples of programs designed for community college students that report positive outcomes (e.g., Ashcroft et al., 2021; Judge et al., 2022; Nerio et al., 2019; Stofer et al., 2021; Wise-West et al., 2013), but these are infrequently reported in the literature (Krim et al., 2019).

National laboratories' role in STEM education is underrepresented in the literature

Collectively, STEM education activities at DOE national laboratories include a diverse suite of opportunities for students to gain professional experience collaborating with employees on technical/research projects as student assistants, research associates, research assistants, or interns, through paid employment or as part of a formal program. In the past few decades, some technical and meeting reports, conference papers, and abstracts have been published about STEM education and outreach activities at DOE national laboratories, and a small number of peer-reviewed publications on the subject (e.g., Barajas et al., 2019; Hahn et al., 2018; Kolsky, 2005; Lincoln et al., 2019; Rippy & Joseph, 2022; Russell, 2011; Sahyun et al., 2006; Wurstner et al., 2005). Most common are references to these activities in reports or studies, but no inclusion of data from collected from the individuals involved (e.g., Bai et al., 2022; Bellis et al., 2022; Johnson et al., 2010; Kuehn & Jones, 2018; Sinnott et al., 2021). Beyond this, educational scholars at baccalaureate granting institutions – who produce the majority of studies about internships and research experiences for STEM students – rarely mention educational opportunities at DOE national laboratories in their work. With DOE national laboratories spending over $500 million annually to provide students, postdoctoral scholars, and faculty with opportunities to work on technical/research projects, an increase in the representation of these opportunities in scholarly literature would benefit funders, host institutions, and participants (DOE, 2017).

Although previous publications about programs or outreach at DOE national laboratories provide useful information about previous activities, many of these publications include data collected from students without documentation of informed consent or review/guidance from an Institutional Review Board (IRB); make claims about student learning that are not supported by the type of data collected or previous studies; or make sweeping generalizations about undergraduate education and/or student learning that may lead to inaccurate conclusions about program impacts (Lund, 2013). At the time of this writing, I am not aware of any previously published studies that include data from program participants in DOE national laboratory programs aligned with IRB standards for human subjects research. This may be due to the fact that the IRB review has not taken place prior to collecting data from program participants or that this step was not documented as part of a manuscript (e.g., Beshyah et al., 2018; Taber, 2014). This is problematic because it limits a) knowledge about how these programs compare to other similar programs, b) the extent to which scholars at other institution types can find and make contributions to what is already known about these programs, and c) productive collaborations with experts at DOE national laboratories on the subject. Similar to the lack of representation of community college students in the literature, it is possible that there are a larger number of published studies that *do* include data from students participating in formal programs or other opportunities for undergraduates hosted by DOE national laboratories, but this information is not specified.

Theoretical Framework[2]

Social cognitive career theory

Initially adapted from the social cognitive theory described by Bandura in 1986, the social cognitive career theory (SCCT) framework was developed in order to understand the ways in which people develop their interest in a subject and make choices that ultimately impact their level of success in that field (Lent et al., 1994, 2000). The theory focuses on the relationship between certain cognitive-personal variables (**self-efficacy** and **outcome expectations**) with the supports and barriers an individual faces, and how this relationship influences the development of their career (Lent et al., 2000). In this study I applied SCCT to explore the impact of a particular **learning experience** on the academic and career trajectories of individuals who studied STEM while attending a U.S. community college (Brown & Lent, 1996; Carpi et al., 2017; Fouad & Santana, 2017). Valuable to my application of this framework for Study 1, SCCT heavily weighs an individual's belief in their ability to be successful in/on a given subject/task (**self-efficacy**) on their actual success in/on that subject/task. For example, if a student grows to believe that they are capable of being successful in STEM, this belief will work to shape their subsequent **interests** (which are fluid over time), **goals**, and **actions** related to STEM. In this way, the SCCT model proposes a connection between student experiences and perspectives with their future academic or career trajectory. **Self-efficacy** appears widely in the science education literature, related to

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[2] Throughout the text, there are bolded terms that represent categories from the SCCT model (e.g., self-efficacy, learning experience, interest). These terms have been bolded when they are used to describe connections between the data from Study 1 and the SCCT model. There are instances where these terms are referenced, but do not describe a connection supported by the data, and thus do not appear in bold.

numerous topics such as performance in STEM coursework, **career interest**, engagement in research, and success in graduate school.

Another component of the SCCT model relevant to this study are **outcome expectations**, which are an individual's "beliefs about the consequences or outcomes of performing particular behaviors" (Lent & Brown, 2006). In contrast to **self-efficacy** (an individual's perspective about their capabilities), **outcome expectations** involve predicting what will happen to them in the future, while striving to accomplish their **academic and career goals**. For example, a student may believe in their ability to learn and develop proficiency in biology, but they may not envision themselves being successfully admitted into a biology graduate program. In this example, a student may feel high **outcome expectations** related to pursuing a bachelor's degree in biology, but low **outcome expectations** related to their application to graduate programs in this discipline. Studies suggest that academic and/or career-related **outcome expectations** may be a powerful influence over student behavior, even in the face of **contextual factors** that can be barriers to success, such as limited access to research opportunities and/or mentoring; experiences with discrimination and/or racism; or lack of career role models (Byars & Hackett, 1998; Lent et al., 2005). This perspective is well-aligned with many studies that have used SCCT to understand the impact of science research experiences on persistence in STEM, an outcome which can be especially apparent for Black, Hispanic/Latinx, Native American, and female students (e.g., Burton et al., 2019; Frantz et al., 2017).

The pursuit of a STEM career requires "buy-in" from others, in the form of recommendation letters, information about funding, program, and employment opportunities, advisors or collaborators for new projects, etc. The SCCT model provides insight into the multiple ways in which students develop, sustain, and change their **career interests** in STEM, and are influenced by their experiences to make decisions to gain additional knowledge and professional experience over time (Lent et al., 1994, 2000). Students may have preconceived notions about working in their STEM field of interest from their interactions with others in school or the content of their coursework. However, these ideas may be misaligned with the actual experiences of people working in those fields. The SCCT model thus highlights the potential influence of regularly communicating with members of the STEM community on the process of clarifying and making decisions about possible career paths (Brown & Lent, 1996; Carpi et al., 2017).

Role of SCCT model in STEM internships

I hypothesize that a STEM internship for community college students can serve as a **learning experience** aligned with the SCCT model, and elements such as interactions with mentors and role models can serve as **contextual factors**. Completing an internship could therefore influence the **interests**, **goals**, and **actions** of community college students, related to their academic and career trajectories. I recognize that a STEM internship is only *one* of many possible factors influencing career choice behavior (**actions**) for a particular student. However, previous evidence about the ways in which undergraduates are impacted by mentored professional development and research experiences suggest that **self-efficacy** and **outcome expectations** are impacted by participation in this type of **learning experience** (e.g., Carpi et al., 2017; Chemers et al., 2011; Lent et al., 2018; Syed et al., 2019). This is likely to be true especially when the nature of the work during the STEM internship relates to the academic courses taken at the community college and/or a students' specific **academic and career goals**.

An internship hosted by an institution such as a DOE national laboratory gives students the opportunity to meet and interact with members of the STEM professional community *outside* of their college or university community. This increases the potential for social integration into the STEM community and increased awareness about the spectrum of career options in their field of interest. Thus, a STEM internship may serve as a mediating factor between community college students' initial curiosity or **interest** in STEM and their graduation and **persistence** in the STEM workforce.

Methods

Internship Characteristics

Founded in 1999, the Community College Internship (CCI) program[3] seeks to encourage community college students to enter technical careers relevant to the DOE mission – to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions – by providing technical training experiences at one of the 16 participating DOE laboratories/facilities across the United States. This program is sponsored and managed by the DOE Office of Science (SC) Office of Workforce Development for Teachers and Scientists (WDTS) in collaboration with the DOE laboratories. Selected community college students work on technologies, instrumentation projects, or at major research facilities supporting DOE's mission, under the guidance of staff scientists and/or engineers at the host national laboratory.

This study focused on the CCI program at Lawrence Berkeley National Laboratory (LBNL)[4], which is managed by the Workforce Development & Education (WD&E) department. Applications for the CCI program are solicited annually for three separate internship terms; spring, summer, and fall, which are 9 to 10 weeks in length. To be eligible for participation in CCI, students must be enrolled full-time at a community college, have completed at least 6 credits of STEM coursework and 12 credits toward a degree, and have a minimum Grade Point Average (GPA) of 3.0. Upon their selection, each community college student is placed with a Mentor Group at LBNL – which consists of their research mentors and associated colleagues (e.g., staff members, postdoctoral researchers, graduate students) – for whom they will work as "interns" during the term. Ideally, in addition to teaching new skills to support intern development from novice to advanced scientists or engineers (e.g., read and understand primary literature, perform laboratory techniques), the Mentor Group engages in mentoring practices (e.g., career exploration), as well (Haeger & Fresquez, 2016; Helix et al., 2022). WD&E provides interns with materials to support their professional development, such as textbooks about research ethics and technical writing. Additionally, the Mentor Group provides access to a desk, phone, and computer to each intern, for use during the internship term.

During the program, interns spend the majority of their time each week working with their Mentor Group to learn new technical/research skills and apply these to a

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[3] Website for the national CCI program: https://science.osti.gov/wdts/cci

[4] Website for the CCI program at LBNL: https://education.lbl.gov/internships/cci/

specific project. Orientation is an introductory event on the first day of the program to showcase the program elements and highlight many resources interns have access to. Intern Check-ins are small group meetings with the program coordinator to discuss intern experiences, provide interns with information about resources, and address issues as needed. Internship Meetings are opportunities for interns to hear from (and interact with) guest speakers and panelists about a number of topics related to STEM careers, academic and professional success, and research projects in a variety of disciplines. These meetings take place once a week during summer terms, and once every two weeks during the longer fall and spring terms. In addition to interacting with members of the STEM professional community, these weekly events also provide an opportunity for interns to interact with others in their cohort. The Poster Session is an event where interns present their work to staff members, members of the Mentor Group, collaborators, and personal guests. The program ends with a “check-out” day, which consists of a conversation with the program coordinator about intern experiences and final deliverables. To WDTS, interns submit written deliverables (e.g., paper, poster) and pre- and post-surveys online. Optional activities include tours of User Facilities[5]; lectures and seminars on-site at LBNL and the University of California, Berkeley; an intern-mentor networking lunch; and workshops about graduate school. An exit survey is administered to all CCI interns by WD&E during the final week of their program, to allow program staff to make improvements.

Previous studies have shown that being paid through an educational program or research experience contributes to undergraduate academic success, self-esteem, self-efficacy, and feelings of being valued by the sponsoring group or organization (Coté et al., 2023; Minasian, 2019; Pratt et al., 2019; Romero et al., 2023). The financial compensation provided to CCI interns at LBNL in 2016 included a stipend of $800 per week, a housing supplement of $300 per week, and reimbursement for travel costs to and from LBNL. To be eligible for these financial benefits, CCI interns completed their “onboarding” forms, worked 40 hours per week (which includes project tasks with the Mentor Group, completing required training, and attending internship meetings) during the internship term, and submitted deliverables (e.g., surveys, technical paper).

Study Population

The study population for Study 1, referred to in this study as “CCI alumni,” consists of individuals who participated in (and successfully completed) the CCI program at LBNL between Summer 2009 and Fall 2016 terms. In total, 93 individuals completed the CCI program in this time frame. I collected survey responses from 43 CCI alumni, and conducted interviews with 12 of these individuals. At the time of their participation in CCI at LBNL, their primary academic majors were as follows: 15 (35%) in civil and/or mechanical engineering, 14 (33%) in chemistry, 5 (12%) in biology, 4 (9%) in physics and/or mathematics, 3 (7%) in environmental science, and 2 (5%) in computer science and engineering. Of the CCI alumni represented in this study, 40 (93%) attended one of the California Community Colleges, and the remaining 3 (7%) attended schools in Illinois, Massachusetts, and New York. More than half of the CCI alumni in this study attended one of the following schools, listed in descending order:

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[5] Learn more about User Facilities at LBNL: https://www.lbl.gov/capabilities/

Contra Costa College, City College of San Francisco, Diablo Valley College, College of Marin, Hartnell College, Ohlone College, and Sacramento City College.

I use the definitions of “science and engineering occupations” (e.g., life scientists, engineers, mathematicians) and “science and engineering-related occupations” (e.g., science teachers, laboratory technicians, laboratory managers) from the National Academies of Sciences, Engineering, and Medicine (2018) and National Science Board (2016) to define “STEM” in this context. Currently, 5 (12%) are graduate students, 36 (84%) have entered the STEM workforce, and 2 (5%) have entered the health workforce. Additionally, 20 (47%) have completed one or more A.A./A.S. degrees, 41 (95%) have completed one or more B.A./B.S. degrees, 11 (26%) have completed a master’s degree, 9 (21%) have – or have nearly – completed a Ph.D. in STEM, and 2 (5%) have completed a health-related degree (e.g., Ph.D., D.D.S., M.D., M.D.-Ph.D.).

Table 1.2

Demographic information for CCI participants at LBNL and study participants

Demographics	CCI full group		CCI surveys		CCI interviews	
	n	*%*	*n*	*%*	*n*	*%*
Total	93	100	43	100	12	100
Gender						
Female	28	30	18	42	5	42
Male	58	62	24	56	7	58
Unknown[a]	7	8	1	2	0	0
Ethnicity/race						
Asian	22	24	11	26	2	17
Black	4	4	0	0	0	0
Hispanic and/or Latinx	18	19	9	21	3	25
Two or more races	8	9	2	5	1	8
White	25	27	17	40	6	50
Unknown[a]	16	17	4	9	0	0

Note. The “CCI full group” category refers to all of the individuals who completed the CCI program at LBNL between the years 2009 and 2016 and completed an exit survey; the “CCI surveys” category refers to the individuals who consented to participate in Study 1 (and to my use of their exit survey data) and completed the *Community College Internship (CCI) Alumni Survey*; the “CCI interviews” category refers to the individuals who were interviewed for Study 1.
[a] For both gender and ethnicity/race data, the “unknown” group includes both “decline to state” responses and missing data.

Positionality statement

The primary author (L.E.C.[6]) is a woman who was born and raised in California, and grew up in a multicultural household in the U.S. with native-born and immigrant parents. Culturally she identifies as American and Middle Eastern. Her previous experiences as a community college student, participating in the CCI program at LBNL, conducting biological research as an undergraduate, and transferring to a California State University were helpful in establishing rapport with study participants. C.L.F. and L.E.C. have 14 and 12 years of experience, respectively, as practitioners working with a suite of internship programs at LBNL. A.M.B. has 27 years of experience working with and studying UREs for STEM majors, and L.E.C. has worked with A.M.B. on these projects for 7 years. Researchers E.W.L., J.J.S., and S.V.D. worked with WD&E internships as student assistants or employees. Researchers A.M., A.N.Z., and G.O.M. worked on this project as research assistants. Collectively, the authors of this work include individuals who identify as men, women, Asian, Black, Hispanic, Latinx, White, and mixed race. At the time of data collection and analysis, this team included undergraduates, post-baccalaureates, graduate students, faculty, and professionals in disciplines related to biology, chemistry, education, mathematics, medicine, physics, and public health.

As researchers our academic experiences, backgrounds, and identities prepared team members to add context to the data collected for Study 1 and determine the best way to represent the findings. Community colleges have very little representation in the higher education literature, and authors of this study who attended community colleges worked to verify that this work did not perpetuate existing stereotypes about these institutions. Previous work I completed as part of the Collaborative Around Research Experiences for Teachers (CARET)[7] found that most studies about science research experiences do not report the proportion of participants from groups historically excluded from STEM fields, and/or present “disaggregated outcomes” for members of these groups (Krim et al., 2019). It became clear during the data collection process (for Study 1) that study participants’ experiences differed between groups, based on gender, race/ethnicity, and status as a first-generation college student. To ensure that the data analysis strategy I employed would yield findings that highlighted these unique perspectives, research team members who shared these identities were involved in exploratory conversations about the data. This is discussed further in the “Data analysis” section.

Data collection

An exit survey was administered to CCI participants during the final week of their internship (e.g., Summer 2009 interns completed exit survey in August 2009, Fall 2009 interns completed exit survey in December 2009), which provided some baseline information about those elements of the program that were impactful to community college students at the time of their participation. This survey data was not available for

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[6] In this dissertation I am using the Method Reporting with Initials for Transparency (MeRIT) approach as described by Nakagawa and colleagues (2023). For Study 1, L.E.C. = Laleh Cote, C.L.F. = Colette Flood, A.M.B. = Anne Baranger, E.W.L. = Esther Law, J.J.S. = Julio Jaramillo Salcido, S.V.D. = Seth Van Doren, A.M. = Aparna Manocha, A.N.Z. = Astrid Zamora, and G.O.M. = Gabe Otero Munoz.

[7] Information about the Collaborative Around Research Experiences for Teachers (CARET) can be found online here: https://serc.carleton.edu/StemEdCenters/caret.html

students who completed CCI prior to 2009, so I chose to include study participants from 2009 and later.

Exit survey responses and published literature about community colleges, internships, and research experiences informed the development of the *Community College Internship (CCI) Alumni Survey* and interview protocol, which was written for use in Study 1 (see **Figures A1.1 and A1.2**). During recruitment in 2018, the research team found that some email addresses belonging to CCI alumni were missing or inactive, so the remaining CCI alumni were contacted through online platforms such as LinkedIn or Facebook. Consent forms and the *CCI Alumni Survey* were administered through Qualtrics. Semi-structured interviews were conducted a) in-person and recorded as audio files with a handheld recorder, or b) using Zoom and recorded as both video and audio files. Interviews with participants were between 60 to 90 minutes in length. I (L.E.C.) conducted these interviews, some of which were observed by S.V.D., and both of us took field notes during interviews. The audio files were then transcribed and checked for accuracy by A.N.Z., E.W.L., G.O.M., J.J.S., L.E.C., and S.V.D.

The collection of *CCI Alumni Survey* data, interview data, and follow-up communication with study participants occurred between 2018 and 2021. This study was approved by the Institutional Review Board at LBNL (Protocol ID: Pro00023065) with the University of California, Berkeley, as the relying institution (Reliance Registry Study #2593). All contributing researchers completed training in the responsible and ethical conduct of research involving human subjects, administered through LBNL or the University of California, Berkeley.

Data analysis

When survey results were first obtained, A.N.Z. and G.O.M. organized open-ended responses into major categories, and these initial themes were used to guide discussions among researchers and with others who possess expertise regarding community college staff, faculty, and students in STEM departments (see “Credibility and trustworthiness” section). Data sets were organized by S.V.D. into individual folders for each study participant, to allow for review of all of the data collected from a particular individual for this study and guide discussions by researchers. Survey responses and interview transcripts (referred to as “documents”) were analyzed using an approach that combined both grounded theory and content analysis: a) codes were generated based on the SCCT framework and literature related to professional development opportunities and research experiences for undergraduates, b) documents were read in full, c) sections aligned with the research questions were tagged, d) certain sections of each document were assigned one or more individual codes, e) codes that did not appear in the data were removed from the list of codes, and f) major themes identified in multiple documents were kept (Bloomberg & Volpe, 2018; Glaser et al., 1968). After these major themes were identified, a first draft of the “Findings” section was written to summarize the ideas conveyed by study participants, supported by illustrative quotes. **Table A1.6** shows the list of categories identified from the SCCT model, the coding categories, and individual codes and sub-codes developed for use in this study. As a research team, we discussed this draft to identify text that framed study participants’ experiences through a deficit lens, and made adjustments aligned with the asset-based perspective. For example, when study participants described their experiences and attitudes toward STEM before CCI, they often recounted stories in which they felt “clueless” about research and the work of scientists and engineers. The research team felt that it was important to balance the presentation of study participants’ stories “in their own words,” with the representation of their experiences in the context of the resources available to them, and the external factors impacting their perspectives. In the example above, I decided to include the word “clueless” in Study 1, but worked to ensure that readers understood this to be the *perception* of study participants, and not my own interpretation of their preparation or potential for success. Finally, I identified areas of the text which might be clarified or strengthened by conversations with others who have direct experience with the scenarios described by study participants (e.g., when a community college faculty member made announcements to enrolled students about professional development opportunities during an event hosted by the “science club” on campus). Research team members then discussed these preliminary findings with community college students, faculty, and advisors and those who have served as technical/research mentors for community college students, which led to some additional insights. Finally, as a team we discussed the content related to study participants’ unique experiences based on gender, race/ethnicity, and status as first-generation college students. Through these conversations, we identified the ways in which the data from these groups a) were characteristically different from the study population as a whole, b) could be supported by previously published educational research about these groups, c) could be framed through an asset-based lens, and d) furthered my understanding of the SCCT model applied to community college STEM majors. For example, the first draft addressed the importance of socializing during the learning experience, but did not include a connection between “warmth” in the social environment and the benefits of a learning experience as perceived by women. The identification of this connection led to some of the content that now appears as part of the “Gender” section (in Section 3). Coded documents were read again closely in order to modify/verify existing codes and apply new codes, and this led to multiple revisions of the “Findings” section text.

Scholars have called on educational scholars to report on the perspectives of Hispanic/Latinx community college students (NASEM, 2023; Reddy & Siqueiros, 2021; Sólorzano et al., 2005). When analyzing the data for Study 1, I found that some study participants shared unique experiences connected to their **Hispanic and/or Latinx** identities. I acknowledge that the terms “Hispanic” and “Latino/a/x,” do not describe a singular racial, ethnic, or linguistic community (Abrica et al., 2022). As shown in **Table 1.2**, approximately one-fifth of study participants are Hispanic/Latinx. To protect the identities of the study participants, I have only used data in the “Findings” section that reference an individual’s self-identification as Hispanic or Latinx when that information was disclosed as part of an open-ended survey response or interview. Additionally, I have named the specific identity of one or more study participants when reporting a finding that connects to background, culture, or identity in my writing, instead of referring to a group as “students of color” or “underrepresented minorities” (NASEM, 2023).

Credibility and trustworthiness

In this section, I describe my efforts to promote credibility and trust between researcher team members and those individuals who a) will read/use this study in the future and b) enrolled to serve as the study population for Study 1. The topic of this study, CCI, is a national program funded by the DOE, and has multiple sites across the U.S. However, I chose to study the CCI program hosted by one particular DOE national laboratory: LBNL. One benefit of examining the impact of the CCI program on participants who have all completed the program at LBNL is the reduction of *institutional variability*, as compared to a study comparing CCI across different sites (Jones et al., 2010). Multiple research team members have direct experience with CCI at LBNL – as program participants, staff, and managers – and leveraged their institutional knowledge to inform the design and implementation of this study.

Used in several ways, triangulation was a key aspect of my approach to Study 1 (Golafshani, 2003; Stahl & King, 2020). This study involved the analysis of multiple data types, allowing me to employ *data triangulation* (Patton, 1999; Stahl & King, 2020). My primary method for collecting data was through the collection of survey responses. Conducting in-depth interviews allowed me to more clearly understand the survey responses by asking for clarification, collecting new stories, and allowing me to confirm or refine my initial interpretations of the survey data.

I also used *analyst triangulation*, in which multiple observers or analysts contribute their expertise to enhance the quality and credibility of the findings, in three ways (Patton, 1999; Stahl & King, 2020). 1. There is a long history of assessment and evaluation of community colleges by people outside of the community college setting, which prevents those with expertise from contributing to knowledge about this system (e.g., McKinney & Hagedorn, 2017; Ocean et al., 2022). As described in the “Data analysis” section, research team members consulted with current and previous community college students, community college and university faculty, university advisors who work with transfer students, and STEM professionals who serve as mentors. 2. During the data collection and analysis stages, multiple researchers read and discussed the data and the themes I constructed to present the findings. As I interpreted data from a particular study participant or group of study participants, I consulted with research team members with similar backgrounds, lived experiences, or identities. 3. Over the course of this study, I communicated with CCI alumni at multiple time points for the purposes of recruitment into the study, scheduling interviews, and member checks to establish transparent relationships and rapport with this group (Chicago Beyond, 2019; Kornbluh, 2015; Patton, 2005; Thomas, 2017). I dedicated time to “break bread” with potential and enrolled study participants during the recruitment process, interviews, and follow-up communication (Chicago Beyond, 2019). For example, at the beginning and/or end of an interview, I often engaged in informal discussion with a participant about my goals for Study 1 and the ways in which their research data would be used. Although CCI alumni shared information about their lives that would eventually become data for this study, I took extra steps to express gratitude and reduce the amount of “transactional” communication. In addition to the opportunity to gather additional information, these activities aligned with the asset-based approach and my desire to accurately present participant narratives (Kornbluh, 2015). After survey and interview data was collected, I sent emails to study participants to clarify certain comments and include these study participants in the research process (Chicago Beyond, 2019; Thomas, 2017). This resulted in follow-up communication with CCI alumni, some of whom would send emails to check in on the progress of this work, or update me on their current academic or career activities. Responses from CCI alumni included gratitude for the opportunity to provide their perspectives, excitement for the eventual publication of this work, and hope that this work leads to additional internship opportunities for community college students.

Limitations

Selection bias is a common critique of studies focusing on the impacts of programs, internships, research experiences, research opportunities, professional development opportunities, etc. In this context, selection bias refers to the scenario in which a student makes the decision to apply to and/or has a greater than average chance of participating in a program as a result of their a) professional network, b) knowledge of its existence, or c) skill level in applying to the program (e.g., experience writing essays, relevant experience on their resume/CV, strong recommendation letters). I recognize selection bias as a potential limitation of this study, and thus cannot claim that participation in the CCI program directly caused the outcomes reported in this study. Instead, I make the case that participation in CCI influenced student perspectives about working in STEM fields, their own abilities and interest in STEM fields, and other related topics, aligned with the SCCT model. The findings in Study 1 thus center around those outcomes that CCI alumni *attribute* to their participation in the program.

Findings

My findings are organized into three sections: a) experiences of study participants when they were enrolled as STEM majors at a community college, *prior* to their participation in the CCI program, b) experiences of study participants *during* and *after* their participation in the CCI program, in which connections are made between their experiences in the CCI program and their subsequent academic and career activities, and c) study participant perspectives about the ways in which their background, culture, and identity have impacted their academic and career activities. For many of the topics addressed in the findings, CCI alumni shared stories in open-ended survey responses that were then expanded upon during interviews with a subset of study participants who completed surveys.

All of the themes I constructed as part of these findings were informed by previous literature about SCCT, higher education, persistence in STEM, and student learning during research experiences and internships. Connections between the major findings of Study 1 and the SCCT model are summarized in **Table 1.5**. In Sections 1 and 2, the findings include major trends from study participants in the “CCI surveys” group (n=43; 42% female, 26% Asian, 21% Hispanic/Latinx, 5% two or more races, and 40% White) unless otherwise specified; see **Table 1.2** for details. For example, a theme specific to Hispanic/Latinx study participants is described in the “Received support from and made connections with the LBNL community” section. Section 3 references a subset of the study population (n=16) that – through surveys or interviews – included stories from their lives to connect their experiences in STEM with their background, identity, etc. Although I gathered useful stories from surveys, the richness of my interview data (n=12) allowed me to develop common themes associated with gender, race/ethnicity, and “first-generation to college” status. The characteristics of interview subjects are in **Table A1.1**.

I have included two types of quotes to accompany my findings. Some quotes come from responses to open-ended survey questions, in which CCI alumni typed out one or more sentences. These quotes were copied as originally written, and may include sentence fragments, or incomplete punctuation. The rest of the quotes come from responses to interview questions, during which CCI alumni verbally responded to questions. In some cases, they told stories that were several minutes in length, which resulted in longer and more detailed responses than those from surveys. As part of these quotes, CCI alumni refer to LBNL in a variety of ways, including “Berkeley Lab,” “the Berkeley Lab,” “the lab,” “the Lab,” “Lawrence Berkeley National Lab,” and “LBNL.”

Section 1. Pre-program experiences, supports, and barriers

Support from community college faculty, STEM groups, and peers

While attending community colleges, the faculty, staff, and student peers at their home institution were a key source of support for CCI alumni. Aligned with recent studies about the supportive social environments at community colleges, 30/43 (70%) of CCI alumni described their positive experiences with small class sizes, community-building activities, and mentorship (Buenaflor, 2023). Some compared the individualized attention they received at their community colleges with the inaccessibility of faculty at baccalaureate granting institutions after transferring.

> *For me it was a really positive experience … I had really good professors who, I think, spent a little more one-on-one time with the students. Class sizes were a lot smaller, typically. … In math there’s typically twenty, twenty-five students, and then the science classes have something like eighty … And, I felt like I got to know my professors really well. It’s something I honestly would do all over again.*
>
> *I would be remiss if I didn’t say I definitely had a better connection with my professors at community college than I ever had at the university … I talk to people that did their undergrad at a large institution and they don’t have that same experience. They just were thrown into this wood chipper, and just had to get through it.*
>
> *Especially the physics classes that I’ve taken, the professors are very passionate and really willing to help out students.*
>
> *If you were to ask me what school made more of a difference in my educational journey, the community college or the university, I would tell you [it was] the community college. That’s where I gained a lot of insight and exposure to all these programs. But, once you become part of a bigger institution, you’re not able to talk to teachers that easily.*

Although many alumni were originally not planning to apply to any STEM internship or other research opportunity, 21/43 (49%) of CCI alumni reported that they were supported to do so through a “nudge” from community college faculty members, STEM club leaders, program staff, or peers. I conceptualize the “nudge” as strong and deliberate encouragement to pursue a particular opportunity, despite student reservations and/or low self-confidence. Some explained that they were introduced to the idea of engaging in professional development or research opportunities during class, conversations with peers, or while attending an event hosted by a STEM club, group, or other organization designed to support STEM majors attending community college. Following these announcements, the aforementioned individuals or groups would increase the intensity and complexity of support over time (e.g., reminders in class, announcements during club meetings, writing recommendation letters).

> *Something that helped a lot was the [STEM club] ...That was key for me. Getting in a group with people that were open-minded and willing to connect and doing it together … You see them again, and again, and again in the same classes, and that was something that was really vital, having that support system there.*
>
> *... the professors, the department, they mentioned it in classes, they mentioned this internship. They pushed [us] a little bit, but weren't twisting everyone's arm … they made it really easy for [us] to get the information. Reminders about deadlines and stuff like that.*
>
> *... we had instructors that … had careers in industry or worked at these research centers, so they want to share what they learned … my instructor told me about CCI ... and said, 'You know, you've got a good shot of getting in. Would you be interested?'*

For some CCI alumni, the lack of support from their families to pursue an undergraduate degree in STEM was a barrier to their academic success. 9/43 (21%) of CCI alumni described how this lack of familial support was challenging on an emotional level (e.g., self-doubt, embarrassment), or in terms of their understanding of what steps to take to pass their courses and/or transfer to a baccalaureate granting institution. Several Hispanic/Latinx alumni from rural agricultural communities explained that their upbringing did not prepare them to confidently select a major or obtain professional development opportunities, but that the social networks at their local community colleges were beneficial in helping them to achieve their goals. This is aligned with a 2019 study by Mireles-Rios and Garcia, in which Latinx undergraduates described the importance of support from mentors and campus organizations to their academic success, confidence, and emotional well-being.

> *I am from a very traditional sort of community, and they did not put a lot of stock into higher education. … going to college seemed like a joke [to them]. ... if I had gone straight into a 4-year university, I wouldn't have had the motivation and confidence to keep struggling when things are so difficult. … without the [STEM club] at my community college, I would not be doing a STEM major. I would not have finished my degree.*
>
> *I started taking science classes and I loved [them] … my professor at the time, he was a great instructor, very hands-on, very enthusiastic … their whole goal is to try to get you out of the area and into a major school ... so that our local kids from out in the agricultural fields, children of immigrants, can make it … to me, that was the best.*
>
> *... if I hadn't had that [STEM club] at that time, I would not have finished my major, I would have wound up doing something like business or something that would have been easier to juggle work and school … because it connects you with people that are interested in the same things as you and sort of give you the support you need to sort of pursue those goals that don't seem real when you're in that sort of position.*

Few opportunities for community college students

Alumni described a variety of goals for wanting to participate in the CCI program, including curiosity about research, a desire to apply the concepts learned in their STEM courses at the community college, or an interest to work on a particular STEM topic (e.g., clean energy, actinide chemistry, HVAC systems). However, 28/43 (65%) of CCI alumni articulated the lack of resources available to community college students. CCI was often described as being “one of the only” programs specifically for community college students, and one in which they were not in competition with students attending baccalaureate granting institutions as applicants. Multiple alumni explained that community college students were generally unaware of the opportunities available to them.

> *… people at my school, I have noticed that they don’t know about opportunities. When they find out I’ve had internships, they’re shocked!*
>
> *As a community college student, it was difficult for me to find lab work related to my major. The DOE programs were convenient in that sense. The CCI program sounded great because it gave community college students an opportunity.*
>
> *I’m glad that you’re doing research on this community college program. I think not enough opportunities are made available, or that we’re aware of [as students] … at [my school], it was unheard of. I know that <u>no one</u> prior to me had done the program.*

Lack of knowledge about research, jobs, and careers in STEM fields

As community college students, 38/43 (88%) of CCI alumni, explained that they had little to no understanding of what it would be like to work in their STEM field of study before the program. Self-described as “clueless,” or having “no idea” about the work involved, many alumni shared stories about the moment when they found out that they had been accepted or in the weeks following. These were often connected to their fears, reservations, or predictions about the program. Others explained that although they had some conceptions of what research scientists do (e.g., biologists use microscopes, physicists use complex equations), they did not understand the goals, processes, or rationale for this work. While attending community college, some individuals enhanced their interest in STEM through science-themed shows or magazine articles, but in retrospect, they explained that this media did not give them an accurate understanding of working in their STEM discipline.

> *I had absolutely no idea, I would say. [In] high school, it was different. Everything is like, "derive this problem." You have some axioms, "prove this, do that." That was the extent of the science I knew back then.*
>
> *I was really surprised when I got it … I’m thinking, I have no idea what optics or x-ray beams are … I was talking to my chemistry professor, and I was like, “I don’t know what I just got myself into!”*
>
> *I didn't even understand the idea of research, right? So, I remember being really puzzled, because I got into CCI, and before that, I couldn’t grasp what scientists do … I could understand that chemists probably wear lab coats and do titrations, … I couldn't really grasp what they do.*

> *My internship … it opened my eyes [to] what science is, because I had this false perception that it was just mixing chemicals and shooting things into space.*

Low expectations of success in STEM

After taking some college-level courses in STEM subjects, but before completing the CCI program, 37/43 (86%) of alumni reported low expectations of their success in the pursuit of a STEM career. Beyond transferring and completing their studies at a baccalaureate granting institution, survey and interview responses revealed that their academic and career goals were vague, as compared to their goals after completing the CCI program. Some explained that they believed they could support themselves with a job, but felt unsure that they could be successful in the STEM workforce.

> *I had no idea what I was going to do. Here's the thing, I knew I wanted to do some kind of engineering, but I knew also that I was so ignorant to the options and possibilities.*
>
> *I would tell others I wanted to get a Ph.D. in civil engineering because it intersects sciences with social impact. But, I didn't know the steps to do it … my college would invite speakers, and I'd hear about their experiences, but I was unsure how to connect the dots. Point 'A' was college, and Point 'Z' was graduate school. There were a lot of points in between that I didn't know.*
>
> *… there's so many different options, you could take time off before you go [to graduate school], or take a couple classes to test it out, you can go to a 4-year, there's just so many different options. I think part of it is not knowing what your options are, that's the biggest thing.*

Although all of the study participants applied to and successfully completed the program, 18/43 (42%) of CCI alumni reported their initial low expectations of being admitted. Some described their previous belief that most professional development opportunities are meant for students attending baccalaureate granting institutions, putting community college applicants at a disadvantage. Television shows, films, and books produced in the U.S. rarely include depictions of community college students, but inaccurately portray them as "mediocre" and "unmotivated" when they are included in storylines (Bourke et al., 2008; LaPaglia, 1993; Tucciarone, 2007). Some CCI alumni explained that they themselves previously had misconceptions about community colleges, but did not agree with negative media portrayals about these schools (Hawk & Hill, 2016).

> *… my mentors told me [about] programs that I should apply to, and felt it was out of my league. Students across the country from top schools were applying, so why should I apply?*
>
> *I initially applied because I was encouraged by my community college mentors. I was extremely reluctant and felt that I did not compare well as a qualified candidate … Never thinking that I would ever get accepted.*
>
> *I don't know, I feel like a lot of people think, "oh, community college," and have a bad sort of attitude. For me, looking back, [it] was an incredible decision for me, that completely changed my life.*

Table 1.3

Experiences of CCI alumni as community college students taking STEM coursework

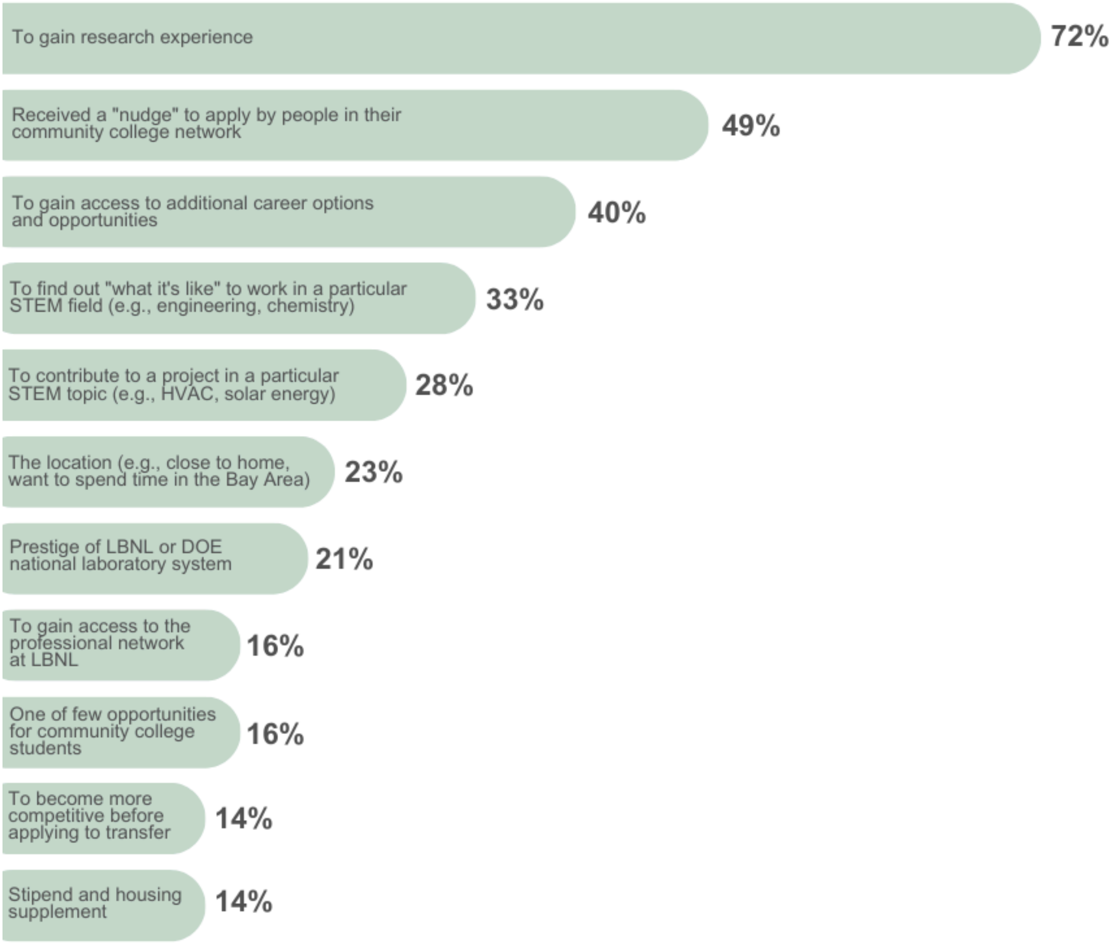
Theme	Sub-theme	Representative quote	%
Lack of knowledge about research, jobs, and STEM careers		"Before [CCI] I probably had no idea what a research question was … on a zero to ten scale, before, it would be zero."	88
Low expectations of success in a STEM career		"... my mentors told me to start applying to internships … I had developed street smarts, so I had no issues in putting myself [into the] workforce, but when I exposed myself to science, I had uncertainties. I was worried if I'd find gainful employment that would make me happy."	86
Support from community college faculty, STEM groups, and peers		"For me it was a really positive experience … I had really good professors who, I think, kind of spent a little more one-on-one time with the students. … I felt like I got to know my professors really well. It's something I honestly would do all over again."	70
	Received a "nudge" from one or more people associated with the community college	"... the professors, the department, they mentioned it in classes, they mentioned this internship. They pushed [us] a little bit, but weren't twisting everyone's arm … they made it really easy for [us] to get the information. Reminders about deadlines and stuff like that."	49
	Lack of support from family	"I am from a very traditional sort of community… going to college seemed like a joke [to them] … without the [STEM club] at my community college, I would not be doing a STEM major. I would not have finished my degree."	21
Few opportunities for community college students		"... people at my school, I have noticed that they don't know about opportunities. When they find out I've had internships, they're shocked! So, I think maybe other students are just going through this path, and they don't know what else is out there …"	65

Low expectations of being admitted into CCI	"I initially applied because I was encouraged by my community college mentors. I was extremely reluctant and felt that I did not compare well as a qualified candidate … Never thinking that I would ever get accepted."	42

Note. It is important to note that these perspectives are valuable to Study 1, because they describe CCI alumni perspectives while they were attending community college, but before their participation in the program at LBNL. These themes are aligned with the social cognitive career theory (SCCT), and were developed from analysis of both open-ended survey responses and interview data. The proportion of CCI alumni (n=43) who reported experiences in each category are shown, with representative quotes for that category. Those study participants who completed a survey and an interview were counted only once. Many responses were multi-thematic.

Figure 1.1

Study participants' primary reasons for applying to the CCI program at LBNL



Note. Alumni applied to the CCI program between 2008 and 2015, and participated between 2009 and 2016. The data in this figure was collected through open-ended survey responses The percentage of CCI alumni (n=43) who listed each reason are shown. Respondents usually listed more than one reason.

Section 2. Experiences during and after the CCI program

Shared through open-ended survey responses and interviews, CCI alumni explained what they gained from CCI, and how the program shifted their perspectives about a number of topics. During interviews many of these gains were positioned in contrast with their perspectives as community college students before CCI. The following themes were described most often by CCI alumni, and stand out as salient and impactful to them, years after completing the program.

> *When I did my interviews for grad school, they asked me a question about internships. The first thing I talked about was my experience at LBNL, talking research projects, collaborating with professionals, problem solving on the spot. When I talk about it, my eyes light up! I'm in the moment, it really gets me excited. They see it, and they notice that, and they feel that, and then they know that I'm being honest and genuine. And they themselves understand that these experiences helped me get to where I am now.*

Increased self-efficacy, confidence, and STEM identity

Before the program, including the period of time during which they were preparing their application, many CCI alumni explained that their background and/or lived experiences made it challenging for them to envision someone "like them" being successful at LBNL. However, 36/43 (84%) of CCI alumni reported that they experienced an increase in self-efficacy and/or confidence to work on technical projects and pursue their academic/career goals in STEM after the program. CCI interns had opportunities to work in ways that pushed them beyond their comfort zone, including scenarios in which they were completing a new type of task, learning a new skill, or maintaining motivation in the face of challenges. The process of "getting through" these challenges was useful to their perception of their own capabilities (self-efficacy), and many referenced themes of perseverance and patience in their stories. Notably, these stories often included a description of what they were tasked with doing, but no information about whether the end result was positive, mixed, or negative. Regardless of the way in which a particular individual was challenged during CCI, these stories were often connected with gains in confidence, feelings of accomplishment, and the perception that they were more well-prepared to pursue their academic or career goals.

> *... [we] couldn't figure out how to utilize [the] photomultiplier. We tried for over a day to figure out the proper orientation to apply voltage … It was incredibly frustrating and we were afraid [of looking] stupid … This moment was key… This experience … gave me confidence and ignited a passion for investigational projects.*
>
> *Working on a challenge whose results had actual consequences for a collaboration made me work hard to complete the project … [I got] real results …*
>
> *During my CCI program, my mentor assigned me a large project throughout the internship … I had to focus on estimating the time of completion for my project while also learning about the importance of … completing the work [and] understanding the systems involved. This prepared me well for future internships because I was better able to organize myself when assigned a task.*

In the survey, CCI alumni were asked to select the term that best describes their own experiences and career goals, and alumni most commonly listed the terms “scientist” or “engineer.” Some CCI alumni recalled “always” having an interest in science or engineering, sharing stories from their childhood to illustrate the importance of these subjects in their lives. However, this early interest in STEM did *not* translate into confidence in their pursuit of a STEM career as community college students. Some described feeling a mismatch between their personal traits and/or accomplishments and those they expected STEM professionals to have. Overall, 30/43 (70%) of CCI alumni reported “feeling like” a scientist or engineer during the program. Aligned with a 2020 study by Trott and colleagues, most CCI alumni attributed an increase in their STEM identity to the novel experiences of being involved in the activities of a scientist or engineer. Additionally, opportunities in which CCI interns were given the freedom to share their opinions, be involved with generating real data, work independently, and make meaningful contributions were very impactful to their STEM identity. For some, it was meaningful to be paid a stipend by the CCI program, because this legitimized their roles as professionals in training (Coté, 2023). Others referenced the importance of being immersed in the LBNL community as a key feature of the CCI program that contributed to their STEM identity development.

> *When I completed the flow schematics for an entire building, along with my team, and we had all the work in a giant portfolio. It really made us feel like we had completed our first engineering job.*
>
> *Yeah, just being in the cafeteria during lunch, that's when I felt like a scientist. A strong emotional experience I [had] … taking the blue buses up to the hill … made me feel like a scientist every day of the summer program. It was just a phenomenal program that was a morale booster for me … I love that it felt like home.*
>
> *The fact that we were doing more hands-on kind of research, that made a big difference for us … “Look at us, we’re professionals now!” We really felt like it at the time … And just sharing it with people around, and at the cafeteria. “What are you doing?” “Oh, I’m doing this.” “Oh yeah, that’s pretty cool, I’m doing this.” “Yeah? Wow!” You know, telling them what kind of stuff you’re doing, and where it’s taking you.*
>
> *Perhaps it was just the fact that I had to put on a uniform (lab coat and safety glasses) to "go to work," but working in a chemistry lab definitely made me feel like a scientist.*

Table 1.4

Most common benefits of participation in the CCI program at LBNL

Theme	Sub-theme	Representative quote	%
Formed a connection with members of the LBNL community		"... I got to meet people in all stages of their careers: grad students, post docs, junior scientists, senior scientists. Conversations with diverse groups of people at each stage helped me figure out what is important to me for my career."	95
	Sustained network after completion of the program	"The relationships I cultivated were by far the most important things I took away from the program because they helped [me] create career opportunities elsewhere after I graduated from college."	70
	Experienced kindness from others in the LBNL community	"All of the people that I met … were all kind and supportive. They always helped whenever I would ask for help and didn't make me feel bad that I didn't know certain things … it [would be] amazing if I ever had the chance to work there as a full-time employee in the future."	49
	Mentor Group supported their project ownership	"I felt especially engaged … when I designed a cable measurement system that the superconducting magnet group could actually use ..."	42
Higher expectations of academic or career success		"... while doing the internship … it made me realize that I can go anywhere if I try hard enough. … I think 'the sky's the limit' is a great way of putting what I learned about confidence and ambition."	91
	Increased expectations of achieving career goals	"It solidified my path to engineering because going into the program I wasn't sure if I fully wanted to pursue this. It's enhanced my perspective if anything, for instance, it made me look forward to completing my degree and being a part of a similar/same team in the future."	86
	Increased expectations of working in research	"My experience at Berkeley Lab exposed me to life in a research community, which I came to love. It made me realize that I wanted to be involved in research, in some capacity, as a	63

		professional.”	
	Increased expectations of graduating from a baccalaureate granting institution	“My experience with the lab made me want to continue to pursue a degree in civil engineering.”	37
	Increased expectations of attending graduate school	“My experiences at Berkeley Lab influenced my academic trajectory by [helping to] confirm my desire to attend graduate school in the field that my internship was in and … [the] letter of recommendation necessary to make that goal a reality.”	35
Learned critical skills		“I like doing hands-on things [more] than sitting in a lecture. It was the hands-on experience, actually getting to do research. You read things from a book, but it’s not the same thing!”	88
	Science communication skills	“The scientific writing part had the biggest impact because being able to communicate properly helped me to get my M.S. and helps me every day at work.”	70
	Research skills	“Doing research and writing it up had the biggest impact on my career -- doing research to determine the state of things in the field, coming up with a question, coming up with a hypothesis, designing a study to address the question, obtaining data, analyzing the data … ”	65
	Technical skills	“I learned about cooling systems and … what the construction and maintenance process is like. I eventually decided to pursue this side of mechanical engineering because I had such an enjoyable experience at the Berkeley lab.”	63
Increased self-efficacy and/or confidence		“I was taught, by my mentor … to be self-directed … spend the time to figure it out ... This helped me get a start in industry with confidence because I knew that if I was assigned a task that I didn't know how to do, I could say: ‘I can figure this out.’ "	84
Increased STEM identity		“Now I feel like a scientist. I feel I’m one of them. I remember coming into CCI and by the time I left, I was part of that club of scientists and researchers …”	70

Increased knowledge about STEM careers (what it’s like and how to succeed)	“For sure, I didn’t just gain technical skills, I learned new perspectives … I learned what a PhD [is], how long does it take, [and] what are the options out there? It wasn’t just how to use a pipette.”	65

Note. These themes are aligned with the social cognitive career theory (SCCT), and were developed from the analysis of both open-ended survey responses and interview data. The proportion of CCI alumni (n=43) who self-reported gains in each category are shown, with representative quotes for that category. Those study participants who completed a survey and an interview were counted only once. Many responses were multi-thematic.

Received support from and made connections with the LBNL community

The most commonly reported gain, expressed by 41/43 (95%) of CCI alumni, was forming a connection with members of the LBNL community. They reported that the program was useful in terms of meeting, networking with, and leveraging interactions with graduate students, postdoctoral researchers, and other STEM professionals working at LBNL to help them achieve their goals. Some explained that this network was most impactful to them *during* the program itself. These interpersonal interactions were often connected to a deepened understanding of STEM careers, related to the nature of a certain career pathway and/or the knowledge needed to take steps toward a particular career goal.

The professional relationships developed with mentors, colleagues, program staff, or peers contributed to CCI interns’ overall confidence. CCI alumni shared their emotional response to working alongside people at LBNL who they perceived to be successful, values-driven, and accomplished. Several CCI alumni linked this professional network to their increased confidence in themselves as STEM majors upon returning to school after the program. One individual explained that having conversations with people at LBNL about physics – on the shuttle bus or in the cafeteria – gave them a “psychological boost” that was useful to them when they went back to school. Some comments related to the value of working with a diverse set of people and attending presentations from a variety of guest speakers; both of these taught the interns about how each person constructs their own career pathway, based on their unique interests, skill set, personality, and the opportunities they have access to. These comments were often linked to new expectations, and the realization that there are many possible career pathways that could ultimately lead to success.

> *… being on-site, being around the people … one of the [other students], he would always pitch in as well, he was a master … in terms of putting together our circuit boards or giving us tips on how to solder efficiently. We also went to [the] machinist at the shop. He was wonderful, he was always in a good mood … We had a couple grad students that were there, as well … they were brilliant, always giving good advice, always willing to talk to us. Then we would go to the cafeteria and meet some of the other interns. … Yeah, there were a lot of people.*

> *I think it was really wonderful how the program organized all these events, opportunities to talk to different scientists to hear research talks from different scientists … just being in that environment was very beneficial.*
>
> *... after CCI, I went back to [my community college] for another year and [took] some very difficult, very science-oriented classes. … I feel like my experience at the Lab sort of showed me that, you know, this is what you're working towards. You met all of these incredibly smart people doing these really interesting things, [and] these are all things they had to go through. They had to get through the beginning. You have to get through the classes before you can start doing that kind of work.*
>
> *It was very awe-inspiring … There's all this peripheral learning that goes on [when] you interact with other scientists.*
>
> *My first summer, when I went to LBNL, and when I saw everything that was going on, and I spoke to everybody … all the local technicians, local researchers, undergrads, international students … It was exciting. It was fun! … These people were willing to talk about their research. Sharing some of their expertise.*

Sustained network.

Many CCI alumni stayed connected with the LBNL community after the program in different ways. For some, the Mentor Group or other staff members supported them as they moved forward with their academic and career goals. 30/43 (70%) of CCI alumni described how this network was sustained after the completion of the program, leading to direct career benefits, including access to internships, jobs, graduate programs, and research collaborations. Examples of this sustained support include receiving advice to inform academic/professional decisions; obtaining recommendation letters for applications; having additional opportunities to collaborate with the team; being introduced to other scientists or researchers; and learning about additional relevant academic (e.g., graduate programs, fellowships) or professional (e.g., jobs, internships) opportunities. There were several examples of CCI interns eventually collaborating with the Mentor Group or other groups from LBNL as employees or graduate students. Others commented on staying in touch with peers they befriended during the program.

> *The relationships I cultivated were by far the most important things I took away from the program because they helped [me] create career opportunities elsewhere after I graduated from college.*
>
> *… after the two CCI internships, I actually was hired on as a research assistant with that group … it was during the school year, and then they had me come back part-time in the summer.*
>
> *… I have stayed in touch and [stayed] friends with many of the people I have met at the lab. The social aspect … was something that made the CCI at Berkeley Lab so special compared to other internships.*
>
> *… my mentors and I stay in touch over email. They have helped me with feedback on application materials like my CV [and] cover letters and writing recommendation letters. I now work with a different research group in the same collaboration, so I discuss [my new project] with my mentors*
>
> *I gained friends and two mentors willing to help me progress in my career. They've offered to be references in the future as well as mentors whenever I had any future questions about my career.*

Mentor Group supported interns' project ownership.

During the CCI program, members of the Mentor Group (their mentors and associated colleagues) engaged in teaching their interns new technical skills and how to approach problems in their field. 18/43 (42%) of CCI alumni reported how important it was to feel as though their Mentor Group trusted them to be responsible for some aspect of the CCI project after initial training was complete. These are opportunities to develop "project ownership," in which students take an active role in their own learning; become committed to their project; and develop a deep personal connection with the project or work (Wiley, 2009). During an interview, one individual explained that their communication with their Mentor Group during CCI was more than just "getting told what to do." Instead, the team engaged in decision making together, and as an intern they were involved in determining "how to actually tackle a question and how to use the tools at hand to answer it."

> *After about a week of getting my hands wet in the lab I felt like a researcher each day after that. This was due to the guidance and the responsibility my mentor gave me early on when it came to my project.*
>
> *I felt like an engineer every day… I felt especially engaged during my second internship when I designed a cable measurement system that [my] group could actually use to QA their windings with.*
>
> *I think what they did was give me just the right amount of freedom and flexibility to choose my own project, to make it more interesting … that just really piqued my interest … and then the combination of the two, kind of seeing what engineering and maybe structural engineering could look like … made me really want to continue pursuing engineering. It really shed a lot of light on what it all meant. And for me, it was just really inspirational to continue … this is what I wanted to do.*
>
> *It was clear to me early on that [my mentor] wasn't going to have me work on some random project for ten weeks … like, "you're an intern here, I need help scanning all of these transcription factors, you can do a lot of it every day." [Mine] wasn't just a project for ten weeks and that was it. It didn't feel like I was doing someone else's job.*

Experienced kindness from members of the LBNL community.

Scholars argue that – beyond being cordial – the expression of kindness in professional settings contributes to more socially equitable conditions, and can support recipients' academic goals and the motivation needed to pursue these goals (Niles et al., 2011; Pulsford, 2019). In both surveys and interviews 21/43 (49%) of CCI alumni described the kindness and socioemotional support they received from group members, program staff, and peers during the CCI program. In most cases, the kindness CCI interns received led to feelings of closeness, pride, engagement, and long-lasting positive feelings about the program and/or members of the LBNL community. Within the larger alumni group, 7/9 (78%) of Hispanic and/or Latinx CCI alumni shared examples of their experiences with kindness during the program. In addition to the aforementioned impacts expressed by other alumni, Hispanic/Latinx alumni shared how the receipt of kindness during CCI had a lasting impact on their impression of LBNL and their desire to work there again in the future.

> *I worked with a wonderful mentor … [we] would talk about everything … marriage, to religion and metaphysical questions, we'd talk about science, basically anything you can imagine! … [My mentor] was truly a friend.*
>
> *… [my mentor] told me about the process, that scientists read through the application … [he] read through mine and said, "I have to meet her" … I still have that email saved.*
>
> *… that summer [we had a death] in the family. [My mentor] told me I could take time off. She never made me feel pressured to do anything. That [made me] want to stay in research a lot … now I know what I should look for and expect in future mentors. I need someone I can resonate with.*
>
> *I really enjoyed working there. All of the people that I met, other interns and workers, were all kind and supportive. They always helped whenever I would ask for help and didn't make me feel bad that I didn't know certain things … it [would be] amazing if I ever had the chance to work there as a full-time employee in the future.*

Negative experiences with mentor support.

In contrast to the sentiments expressed by most CCI alumni, 5/43 (11%) reported that they did not receive adequate support from their mentors during the program. Each intern will have individual needs and perceptions about what an adequate level of support entails. However, in previous studies some common characteristics of inadequate or negative mentorship include those mentors who are “too busy” to provide support, infrequently communicate, are overly critical, or show no interest in student technical or professional development (Cooper et al., 2019b; Limeri et al., 2019; Tuma et al., 2021). For three individuals in this study, their mentors practiced a “hands-off approach,” were not approachable, assigned their interns “menial” tasks, and/or seemed frustrated when interns needed assistance. The other two individuals explained that their mentors were not present or available to meet regularly during the internship. Even though their few conversations with their mentor were positive, their overall impression of their working relationship was negative. All five alumni in this group commented on their STEM interest; four were still interested in STEM after the program, but not in the field/topic they worked on during CCI, and the fifth individual was no longer interested in pursuing a career in STEM following the CCI program.

> *I'm in that lab all day, and you know, [my mentor] is right there … she wasn't necessarily the easiest person to walk up and tap on the shoulder that often … She kept it pretty formal … I didn't want to bug her very much.*
>
> *... he was pretty serious about what he was doing, and so we talked shop, we talked work, we talked about the project … he was well respected by everyone and all of his colleagues, but it was very clear that he was there for a purpose … that's where all his energy was.*
>
> *I was a little disappointed in the work that was asked of us … they were utilizing their interns to do the work they did not want to do … we were only allowed to shadow [LBNL staff] … never work on a project with them or assist them in any way.*

STEM skills, knowledge, and interest level

Development of critical skills.

Through surveys and interviews, alumni expressed the benefits of working in an authentic environment, with access to “real” scientists and/or professionals in their STEM field of study. As a result of participating in the program, 38/43 (88%) of CCI alumni reported that they acquired skills that they perceive as valuable to their professional development. The three most common categories were science communication, research skills, and technical skills. Specifically, 30/43 (70%) of CCI alumni self-reported gains in scientific communication, related to the preparation of written technical or research reports, public speaking experience, or creating a narrative for group/poster presentations; 28/43 (65%) of CCI alumni self-reported gains in research skills, such as thinking like a scientist, organizing oneself for laboratory work, and analyzing data; and 27/43 (63%) of CCI alumni self-reported gains in technical skills, such as producing drawings in AutoCAD, carrying out laboratory protocols, and learning a new coding language. Some described how these new skills assisted them in their STEM coursework, through a deeper understanding of STEM content knowledge, or increased confidence when completing assigned projects or reports in school. One individual summarized a wide variety of technical experience they gained during the CCI program; they searched for the possible types of material best suited for their project, learned finite element analysis, and designed a piece of equipment. All of these skills were useful in their engineering studies and jobs after the program, as was the opportunity to create something “from scratch.” Another individual shared about how they learned more about the biological topics they were most interested in through their CCI project. The skills they gained related to working in a fume hood, maintaining cell cultures, and imaging techniques were all useful to designing their own projects in the years following their internship.

> *Unfortunately [my] community college doesn’t have a technical science writing class, so I had no idea what I was doing … I think coming out of that internship, having to write all of those abstracts, and all of those papers, I felt like I could actually write something technical.*
>
> *There’s [a] transition where you go from just looking at data, and you visit the location, and then you see the equipment, and you start to put pieces together and you’re like, "ohhhhh!" And, once you start to analyze your data, you learn to interpret that data, and once you finally start to see some bigger results, you start to understand more. So, there were a few different moments, these Aha! moments.*
>
> *The scientific writing part had the biggest impact because being able to communicate properly helped me to get my [master’s degree] and helps me every day at work.*
>
> *[CCI] taught me a lot about how to communicate my thoughts in science … that specific workshop [about presenting posters] taught me how to communicate a visual very quickly. I remember that being a huge and valuable experience because after that, that following fall, I told [my mentor] that I wanted to submit a poster to [a conference]. And after that, poster presentations became an addiction.*
>
> *I like doing hands-on things [more] than sitting in a lecture. It was the hands-on experience, actually getting to do research. You read things from a book, but it’s not the same thing! … Just*

> *working in a lab, and applying those skills and knowledge from class to what you're doing in lab. For sure, what impacted me the most during undergrad was internship experiences.*

Increased knowledge about STEM careers.

Social capital theory describes how a person's social network affords them valuable resources, and for students, this "social capital" could include information about possible career pathways in their field of interest (Lin, 2002). In Study 1, 28/43 (65%) of CCI alumni shared stories about how the program expanded their knowledge about STEM careers, in terms of what it's like to work in STEM, and how to be successful. This was especially impactful when they had conversations about STEM careers with their Mentor Group, in part, because they spent the majority of their time each week with these people. One individual explained that it was beneficial for them to observe the ways in which scientists and technicians in their group worked together each week at LBNL. These observations cleared up many of their previously held misconceptions about working in materials science and how people in different roles collaborate with each other.

Some CCI alumni explained that the program was impactful to them because they gained insights into *how* to be successful in their STEM field of interest. During interviews, several individuals recalled instances where members of their Mentor Group or other LBNL staff members shared information about being successful as a professional, and included personal details about their lives, as well. Beyond receiving information about how to be successful, these conversations seem to have been interpreted as microaffirmations that they could, for example, finish their degree or work at an institution like LBNL (Estrada et al., 2019). For example, one individual who began their studies at community college at a "non-traditional age" was deeply inspired by a scientist who shared about their experiences with taking time off from their career to care for their children. They came away from the conversation encouraged, with the knowledge that there is not "one way" to be successful in STEM. Other CCI alumni were interested in learning about how to find a STEM job or career path aligned with their personal goals and values. Previous work has shown that understanding the scientific and societal context of a project is an important aspect of student learning during science research experiences (Helix et al., 2022). Those students who are committed to the pursuit of a career that will allow them to "make a difference to people's lives" are likely to view these types of interactions as helpful in verifying that a STEM career will help them to meet this goal (Boucher et al., 2017).

> *So, she started talking to me about her private life a little bit … She didn't just magically decide that she was going to end up at Lawrence Berkeley National Lab, [but] sometimes life has a way of pushing you along, guiding you. It's just about you putting one foot forward and just persisting on your journey … that was really helpful.*

> *It allowed me to see if research was a good fit for me or not, and offered an opportunity to learn from other researchers/post-docs about a scientific career.*

> *It wasn't just work, there was that actual mentorship. It wasn't just like, "we're splitting cells today," or cleaning [something]. He was actually like, "this is my background, this is what I do. These are some things you could look into. Have you heard about this program?" … It wasn't just work.*

> *For sure, I didn't just gain technical skills, I learned new perspectives … I learned what a Ph.D. [is], how long does it take, [and] what are the options out there? It wasn't just how to use a pipette.*
>
> *STEM is hard. It's like gymnastics or going to the gym … It takes dedication ... mentors or professionals that basically look after women in STEM [are important] so that you don't constantly feel like you're struggling upstream alone.*

Lower interest in research or specific STEM field/topic.

After completing the program, 8/43 (19%) of CCI alumni reported that they were *less* interested in research, or the specific STEM field they were exposed to during CCI. One individual enjoyed working in STEM, but found a lack of alignment between their personal values and the values of those individuals they worked with in the research group. They concluded that they were not interested in working in that field/topic, though they were still interested in joining the STEM workforce. Originally interested in graduate school, another individual became less interested in Ph.D. programs after the CCI program, because they learned that there are many technical roles available that require less training. Due to the "slow pace" of research, two individuals explained that the program allowed them to make an informed decision not to work in research; one currently works in a health field, and the other works at a DOE national laboratory in STEM in a technical role that does not involve research. A third individual explained that they were less interested in research roles after CCI, due in part to the fact that their project was never well-described to them. As a result, they came away with a very superficial understanding of the work.

> *… the experience at Berkeley Lab was amazing, [but] it made me realize that research is not for me, … the outcome or results of research is too slow for me personally.*
>
> *I greatly enjoyed my work at the lab, but I decided that pursuing physics at higher levels [was not for me].*

STEM outcome expectations (during/after CCI); higher expectations of success

As compared with their experiences prior to participation in the program, **39/43 (91%) of CCI alumni** reported an increase in their expectations of success in STEM academic programs and careers; see "Low expectations of success in STEM" section for details. One individual shared that the CCI program helped them to "start" their career, while another explained how it motivated them to "go further" than their initial career goal. For others, they further developed their interests and felt confident and prepared to pursue their goals as a result of having relevant experience, access to a professional network, or a new sense of purpose. Regardless of the specific way in which the CCI program was impactful, alumni connected their experiences during the program with their academic and career trajectories in subsequent years.

Expectations related to entering the workforce.

The study participants possessed (and still possess) a wide variety of career goals, based on their own unique lived experiences, interests, and goals. Regardless, 37/43 (86%) of CCI alumni made a connection between the types of activities they engaged in during the program and their increased expectations of achieving their career goals. Alumni increased, broadened, and/or changed their career goals as a result of participation in the CCI program. In some cases, their change in perspective related to the types of work they believed they were capable of doing, while others explained that their goals were “higher” than before as a result of communication with members of the LBNL community. Some explained that – before the CCI program – they had identified jobs in the STEM workforce that they were interested in, but did not view themselves as potential candidates for these positions until their participation in the program. Similarly, 27/43 (63%) of CCI alumni explained that the program helped them to maintain or increase their interest in a research-based career, coupled with expectations of being successful as a researcher. Many CCI alumni explained this new interest in the context of “being exposed” to research, which involved learning about what research entails (i.e., what is it?), and gaining experience conducting research in an authentic setting.

> *I am planning to add in a career step [and study] at the U.S. base in Antarctica. The CCI program really opened up my eyes to the possibilities that I have in which I never [knew] were so close.*
>
> *My CCI [project] made a large impact on my career because it offered me the chance to participate in a small subset of my field. I learned about cooling systems and got a feel for what the construction and maintenance process is like. I eventually decided to pursue this side of mechanical engineering because … [of the] experience at Berkeley Lab.*
>
> *I didn't have many expectations for what research was like before the internship, … CCI was my first real hands-on experience with things I learned in the classroom. It made me pursue more academic research opportunities once I got accepted to university.*
>
> *… I [finally] had first-hand experience, and I could say, “Oh I did enjoy that. Okay, well this is something that may be valuable for me to explore as a profession now.” Whereas before I'd said, “Maybe I would enjoy that, so maybe it would be valuable for me to explore as a profession” but there's this frightening concept … I invest so many years into achieving whatever's required to do research, and getting there and being like, “oh, this isn't for me. Boy, that was a waste.” The biggest thing is that it cleared up a lot of uncertainty about the concept of research.*
>
> *It solidified my path to engineering because going into the program I wasn't sure if I fully wanted to pursue this … it made me look forward to completing my degree and being a part of a similar/same team in the future.*

Expectations related to academic achievement.

As community college students, some CCI alumni were certain of their desire to transfer to a baccalaureate granting institution prior to the CCI program, while others were not. 16/43 (37%) of CCI alumni linked their experiences in CCI with a new and/or strengthened desire to obtain a B.A./B.S. degree in their STEM field of interest. Some explained that their experiences made them more confident in transferring to particular universities or obtaining degrees in disciplines they had not previously considered. Workshops related to graduate school made an impact for some alumni, by demystifying the application process, financing a program, and preparing as an undergraduate. For 15/43 (35%) of CCI alumni, the idea of going to graduate school felt more attainable than it had before their participation in CCI. Even for those individuals who ultimately made the decision *not* to apply to graduate school, some reflected on having more confidence in their ability to be successful as a graduate student.

> *My experience with the lab made me want to continue to pursue a degree in civil engineering.*
>
> *At that point, I was actually thinking about [graduate school] more. I was confident enough that was what I wanted to do, I could do it … now I had an idea of something I wanted to do in the future. Since I had a crack at it, it was like, "Okay, this is something I can see myself doing, and feel confident doing."*
>
> *It motivated me to apply to [university name], and I am so thankful that I did.*
> *Before I participated in the CCI program, I did not like molecular biology because [of] my previous professor … Thanks to the CCI program opportunity, my PI and mentor were really helpful in explaining how the concepts of molecular biology were related to the research project. The opportunity changed my major decision.*
>
> *… before CCI, we were joking about how we were all going to get our Ph.D.s, but after, that was actually an option.*
>
> *Before [CCI], I didn't think about grad school much. And then, when I got here, and I met people in grad school, I definitely … that's when I realized, "Yes, I totally want to go to grad school, and … I feel like I could be successful doing it."*

Section 3. Additional considerations related to background, culture, and identity

In the field of undergraduate STEM education, many scholars have called for researchers to consider the ways in which students' multiple identities can result in unique lived experiences, versus the examination of experiences based solely on a single identity (e.g., Byars-Winston & Rogers, 2019; Ireland et al., 2018). The concept of "intersectionality" was first introduced by Crenshaw as a response to the unique marginalization of Black women, as opposed to the experiences of Black people of any gender, or women of any racial/ethnic background (Carbado et al., 2013; Crenshaw, 1989). Studies exploring intersectionality in STEM have highlighted the value of storytelling in empowering students to share about the ways in which they believe their identities and lived experiences have impacted their STEM trajectory (e.g., Avraamidou, 2020; Isler et al., 2021; Morton & Parsons, 2018; Sparks et al., 2023).

To add context to their academic/career experiences, 16/43 (37%) of CCI alumni shared stories about how their upbringing, group membership, or culture impacted their experiences in STEM. Although alumni referred to their multiple identities during interviews, one identity was usually the focal point when they were recounting a particular story. As described in the "methods" section, analysis for this theme was based only on the comments CCI alumni made about their background, and *not* from the demographic information they provided. The role of the mentor was a major theme present in both survey and interview data from alumni who self-identified as part of an "underrepresented" group. Despite being from a "different background," mentors and staff who deliberately dedicated time to connect with interns about their personal lives were remembered as critical to interns' positive experiences during CCI. This aligns with the concept of *personalismo* in Hispanic/Latinx culture, which describes how personal relationships are initially valued more than formal/institutional relationships, and critical to building trust (*confianza*) in an educational or professional setting (e.g., Kelley et al., 2020; Mireles-Rios & Garcia, 2019).

> *Yeah, my mentor was a White man, but for me … he was truly a friend. [We] would talk about everything, basically anything you can imagine.*

> *[My mentor] would sit you down, and he would tell you anything you wanted to talk about. … I told him, I feel inadequate. I don't know what I'm doing really, … And I remember he gave me a look, like he wasn't prepared, because typically the interns that he gets, they already had an idea as to what they want to do. … he was a little surprised and interested … So, he started talking to me about his private life a little bit, sharing about some of the things he did … That was really helpful. … I know he had a lot on his plate, he always did. But, he kept his door open. He literally kept his door open.*

> *Just because someone is a different color or background doesn't mean they can't have shared experiences. [I have] an example of a supervisor being himself and sharing his experiences. Ironically, I talk about improving diversity, but at this stage the only people I can identify with are White males. … I think it has to do with them having real conversations with me … we may not have had similar experiences, but we may have had shared emotional experiences. For instance, expectations from family members.*

Gender

During interviews, 5/12 (42%) of CCI alumni described how their identity as a woman impacted their academic and professional experiences in STEM and expressed the importance of having access to a "warm" social environment in which they could interact with other women at LBNL during the CCI program. This included peers, mentors, and other staff.

> *As a student I needed exposure to other STEM students who were equally as excited to do research, and CCI created that space during [group meetings]. Also, I needed [female] mentors since at my community college I was the only minority female in engineering.*

Despite professional experience, entry into the STEM workforce, or completion of graduate training, some women shared their long-term struggle with identifying as scientists or engineers. One woman with a STEM graduate degree explained that she has never felt comfortable using these terms to describe herself. However, when asked to compare her role in the scientific community to people she would describe as "scientists," she could not identify any differences between their professional activities and her own. She was comfortable with being called a "scientist" by non-scientists, but felt hesitant to use the term around others in the lab where she works.

> *I still struggle with the word "scientist." That's not uncommon for women who are doing science. I would definitely say I am still learning. I'm a learner … I think the thing with [the term] "scientist" is that it feels like a bar so high, it's something you're always striving for, where you're always being very careful about what you're doing, and reading everything, and being very diligent about marking down what you've done ...*

First-generation college students

Some of the alumni interviewed for Study 1 described how being the first in their family to attend college (first-generation college students) impacted their experiences as undergraduates, and made it more difficult to access professional development opportunities. During interviews, 4/12 (33%) of CCI alumni shared stories in which they connected their status as being first-generation college students with recurring struggles to feel comfortable learning and working in STEM, even after earning undergraduate and graduate degrees in STEM. This group of alumni are diverse in gender, race/ethnicity, and STEM field of interest. They all made references to the fact that they did not receive advice and/or support from their personal social network when making academic- and career-related decisions.

> *Being first-generation … there's no one really before me that can give me tips on how to navigate this world … At LBNL, I was feeling a little inadequate … Like, "I shouldn't be in a place like this. There's Nobel Prize winners around! We're developing special bacteria that can eat through plastics, detecting neutrinos, and all this fancy incredible stuff." … And I'm like, "I'm from a farming community." And I felt that. I told [my mentor], "I feel inadequate."*

Race and ethnicity

During interviews, 4/12 (33%) of the CCI alumni shared stories about how their racial or ethnic identities impacted their interpersonal relations with educators and STEM professionals. Some CCI alumni explained that the "diversity problem" in STEM made it challenging for them to envision being successful in STEM long-term. Several Hispanic/Latinx alumni explained how being "the only one" like them and facing racial discrimination led to lower confidence during school and when considering professional development opportunities.

> *You go into a research facility and you see that there's not too many people that speak like you, ... they're not Latino … when I went back to school, [I was dealing with] those negative thoughts.*
>
> *I remember not being sure how I'd be perceived [at my community college]. It was the first time taking classes and being valued by the professors. It was shocking. … Back then, my physical appearance was very different [from other students], so there was an intimidation factor. … when I got back my exam, I had the second highest score in the class. Then, people wanted to study with me … Of course, I had mentors and programs that supported me, but the first step was getting over my uncertainty of how I'd be treated from previous experiences of being traumatized.*

One individual, who is Latino, described their early interest in working as an engineer to build bridges. However, "those dreams dissipated" when they were repeatedly dismissed by most of their K-12 teachers, and became accustomed to frustration and disappointment in the classroom. The school would "separate the brown kids from the non-brown kids," and students like them were not presented with (nor selected for) the same educational opportunities afforded to their peers. They explained that there were simply too few encouraging teachers to ensure that Black and Hispanic/Latinx students had the same access to STEM-related activities. Another individual, who is Latina, shared how her early educational experiences inspired her to serve as a role model for others who may have experienced discrimination and bias, both in the classroom and from society. The quote below refers to microaggressions – "small acts of aggression" that can cause self-doubt and psychological harm to their recipients – which have been shown to make Latinx students feel as though they have "prove" that they belong in the STEM community (Camacho & Lord, 2011; Yosso et al., 2009).

> *I gotta identify myself as Latina … cultural identity is a part of me, full-time. As a Latina, it's important for me to represent. There's not a lot of people like me in this school … We feel a lot more pressure … I remember as a young high school student, comments from teachers saying*

> *that they were surprised I was doing so well. "You're a smart Mexican!" You hear that kind of crap … I don't want to make it sound like I'm doing something important, because I don't feel like I'm trying to be special … But, I am cognizant of the fact that, if I fail, or if I do poorly, I'm making it harder for people like me.*

She described the additional burden of being "the only" Latina in many academic and professional spaces, and the pressure to be high-performing and successful. This can be a heavy emotional toll to carry, and similar perspectives were expressed by multiple individuals in this study, often alongside a story where they experienced discrimination or racism, or were made aware of the harmful stereotypes held by others about "people like them." Several Hispanic and/or Latinx alumni in this study went on to explain how these experiences of racial discrimination in the classroom led to lower confidence during community college, influencing their confidence in coursework, interacting with others, and when considering professional development opportunities.

Table 1.5

Connections between findings and the Social Cognitive Career Theory (SCCT) model

Theme	Sub-theme	Connection to SCCT model
Pre-program social supports and barriers	Support from community college faculty, STEM groups, and peers	I propose that the support students receive from community college faculty, staff, and peers serve as **proximal contextual influences** in the SCCT model, contributing to their engagement in **learning experiences**. In practice, students who receive information, advice, and encouragement from the community at their school are *more* likely to seek out and submit applications to professional development opportunities in their STEM fields of interest. The data suggest that this can be true even when familial support is lacking and/or has a negative emotional impact on students. Previous studies have categorized familial or other forms of personal support (positive or negative) in the pursuit of extracurricular activities as a **background (distal) contextual influence** in the SCCT model (Lent et al., 2000). I imagine that the nature of an individual student's relationship with their family or personal network would influence the strength of this familial support on a student's academic or career decision-making. If a student perceives their family to have credible information and perspectives about STEM careers or regards the opinions of their family to be of utmost importance, familial influence may be stronger.
Pre-program social supports and barriers	Few opportunities for community college students	I propose that there are barriers to accessing STEM professional development opportunities for many community college students, which result in the student perspective that there are few opportunities "for them." These barriers serve as **proximal contextual influences** in the SCCT model, and can prevent community college students from engaging in **learning experiences** relevant to their STEM discipline of interest, despite their interest in these experiences.

Pre-program STEM interests and knowledge	Lack of knowledge about research, jobs, and careers in STEM fields	The study participants reported that the learning experiences they engaged in at their community college – typically in the form of STEM coursework – generally did not result in skill development or knowledge about STEM careers. Many studies address the benefits of course-based undergraduate research experiences (CUREs) for STEM majors, but study participants did not mention engagement in CUREs. Thus, I propose that participation in STEM coursework is not sufficient to a) prepare students in the development of skills relevant to student academic or career goals in STEM, or b) ensure that students understand what scientists, engineers, etc. do while employed in these roles.
Pre-program STEM outcome expectations; low expectations of success	Expectations of success in a STEM career; Expectations of admittance into the program	Regarding their experiences as community college students, the study participants reported having low **outcome expectations** of success in STEM careers and/or being admitted into the STEM internship program they applied to (i.e., the CCI program). The data suggest that these low outcome expectations are connected to low **confidence** as an applicant from a community college, lack of **knowledge about STEM careers**, and/or unfamiliarity with the concepts and methods used in real-world STEM projects. I propose that low **confidence**, lack of **knowledge about STEM careers**, and lack of **relevant skills** are factors with the capacity to *decrease* students' **outcome expectations** in the SCCT model.
Increased self-efficacy, confidence, and STEM identity	Self-efficacy and confidence; Feeling like a scientist or engineer (STEM identity)	Although CCI alumni recalled high levels of interest in their STEM field before the program, they also experienced lower confidence levels. In contrast, alumni reported increased **self-efficacy, confidence**, and **STEM identity** due to participation in CCI (a **learning experience**). This is aligned with previous studies that have applied SCCT to examine the impacts of research experiences on undergraduates' career-related outcomes, in which themes related to self-efficacy appear alongside themes of science identity and confidence (e.g., Frantz et al., 2017). A mediation model by Chemers and colleagues, and the SCCT model indicate that both self-efficacy and science identity mediate the relationship between a research experience and commitment to a science career, while science identity also mediates the relationship between self-efficacy and these intentions to "stay" in STEM (Chemers et al., 2010; Chemers et al, 2011). Although the term "science identity" is frequently used in educational research studies, and generally agreed upon as important to retention and success in STEM fields, there are numerous definitions of this concept. For example, Latinx students have been shown to leverage different types of capital (e.g., social, familial) in the development of STEM identity, which is important to their persistence in STEM (Rincón & Rodriguez, 2021). In both academic and professional settings, the opportunity to demonstrate competence, be recognized by others in the STEM community, present work, and author publications are all factors that support the development of STEM identity for women in STEM (Cabay et al., 2018). Thus, in the SCCT model, I propose that, as a result of participation in a **learning experience**, levels of **self-efficacy, confidence,** and **STEM identity** may increase for community college students who have a positive experience.

Social supports and barriers	Received support from and made connections with the LBNL community; Sustained network	As a result of participation in a **learning experience**, community college students may be introduced to and interact with members of the STEM professional community. I propose that support from and positive interactions with this professional network serve as **proximal contextual influences** to students in the SCCT model. Some of the data suggest that this support *during* the learning experience is important to student **knowledge about STEM careers**. Additionally, this support can enhance students' perceived value of that learning experience, increase their **self-efficacy** and **confidence**, and influence their **academic and career interests**, **goals**, and **actions**. During the learning experience, this support will likely be expressed mostly through interpersonal interactions, and conversations about academic/career pathways. *After* the learning experience, this support will likely be related to providing guidance and assistance to students as they take **actions** related to their academic/career interests and goals. In practice, students who receive support from members of the STEM professional community are *more* likely to be aware of relevant opportunities to advance their career, and have access to the resources they need to achieve their goals. This is especially true when that support is *sustained* following the completion of the learning experience. Mentors may, for example, write recommendation letters, introduce their previous student mentees to others in the professional community, or share information about job opportunities.
Social supports and barriers	Mentor Group supported their project ownership	As a result of the support they received from their Mentor Group during CCI, some study participants reported developing feelings of ownership over their assigned project. Comments by CCI alumni about their feelings of project ownership are relevant to this study, as previous work has connected a sense of ownership with student intentions to stay in scientific careers (Corwin et al., 2018; Hanauer et al., 2012). In the SCCT model, this further supports the relationship between **proximal contextual influences** (during **learning experiences**) and student **academic and career interests, goals,** and **actions**.
Social supports and barriers	Experienced kindness from others in the LBNL community	Unlike many of the resources needed to offer a professional development opportunity to students, kindness is free and readily available for all members of the STEM professional community to give to others. Although kindness is valued by all types of students, studies have shown that kindness cues in the form of macro- and microaffirmations can contribute to feelings of social inclusion, and persistence in STEM for Black, Hispanic/Latinx, Native American, and low-income students (Estrada et al., 2018a; Estrada et al., 2019). Two related studies that included more than 2,200 undergraduates majoring in life sciences attending baccalaureate granting institutions found that negative social interactions, feeling excluded or unwelcome, and witnessing unfair treatment – such as favoritism – were factors that led to students wanting to *leave* their group (Cooper et al., 2019b; Gin et al., 2021). For these students, a positive environment and experiencing kindness led to the opposite result, and they were more likely to *stay* with their group. Similarly, a study about female undergraduates majoring in engineering found that

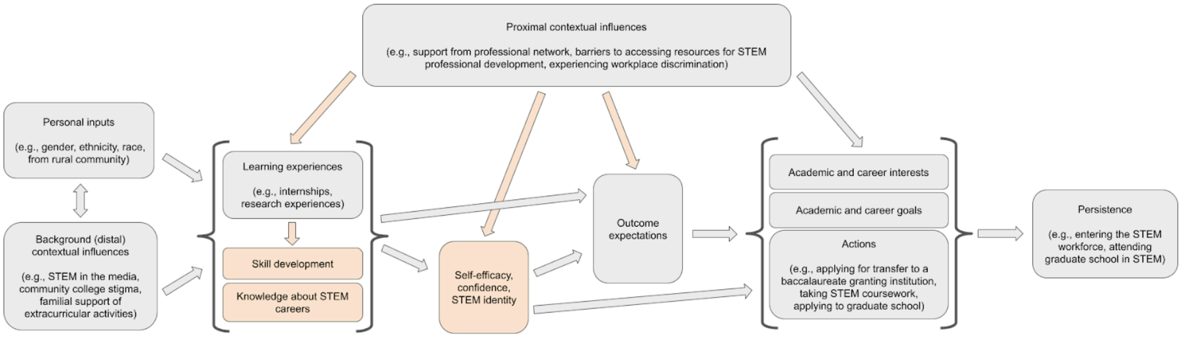
		microaggressions led to feelings of exclusion, frustration, and a desire to limit social interactions; examples included people showing surprise that a woman would study engineering; having to prove to others that they are qualified to be in engineering learning environments; tokenization as one of few women in engineering; and overhearing inappropriate jokes told by colleagues/peers (Camacho & Lord, 2011). In the context of STEM **learning experiences**, kindness shown to students is likely to increase their access, engagement, participation, and success in STEM careers. Additionally, for students and early career professionals in STEM, the absence of social cues that indicate welcoming, inclusion, and respect from mentors actively decreases engagement, confidence, and persistence in STEM careers (Camacho & Lord, 2011; Karalis Noel et al., 2022). In the SCCT model, this further supports the relationship between **proximal contextual influences** during **learning experiences**, student **confidence**, and their **academic and career interests, goals** and **actions**.
Social supports and barriers	Negative experiences with mentor support	I propose that the presence of a STEM professional – whose defined role is to serve in a teaching and mentoring capacity – who does not provide adequate support to their student during a learning experience is a **proximal contextual influence** that has a negative impact on student **academic and career interests** in the SCCT model.
STEM skills, knowledge, and interest level	Development of critical skills; Increased knowledge about STEM careers	As a result of participation in a **learning experience**, community college students may develop **new skills** (that they perceive to be beneficial to their academic and professional development) and increase their **knowledge about STEM careers**. I propose that these gains from the **learning experience** contribute to the development of student **self-efficacy, confidence, STEM identity,** and **outcome expectations** in the SCCT model.
STEM skills, knowledge, and interest level	Lower interest in research or STEM field/topic	The data suggest that there are a variety of reasons why a student's **interest** level in their STEM field or topic might decrease after completing a learning experience, including the following: not enjoying the nature of the work, having a mentor who provides inadequate support, and finding that their personal values are not aligned with those of the people they work with during the learning experience. These data are aligned with previous studies that have reported that undergraduates can clarify their **academic and career goals** as a result of participation in **learning experiences** such as research experiences or internships. In the SCCT model, this *may* also result in a decreased interest in STEM careers overall (versus a decreased interest in a specific type of work *within* STEM), but further exploration would be needed to make this connection.
STEM outcome expectations (during/after CCI); higher expectations	Expectations of achieving career goals; Expectations about working in research;	I propose that **outcome expectations** are impacted by the **learning experience** (including skill development and knowledge about STEM careers), **self-efficacy, confidence,** and **STEM identity** (resulting *from* the learning experience) and **proximal contextual influences** in the SCCT model. Further, these modified outcome expectations influence student **academic and career interests**, **goals**, and

of success	Expectations of graduating from a baccalaureate granting institution; Expectations of attending graduate school	**actions**. With respect to the data, the social support community college students received from the STEM professional community during and after their learning experience contributed to increased outcome expectations of being successful in achieving their career goals, working in research, obtaining a bachelor’s degree, and/or attending graduate school. In many cases, CCI alumni articulated their outcome expectations as meaningful to their overall academic and career trajectories, even if their goals related to a different outcome. In other words, a community college student might experience increased outcome expectations related to graduate school, even if they are *not* interested in pursuing graduate studies.
Additional considerations related to background, culture, and identity	Background, culture, and identity-related themes; Gender, Race/ethnicity, First-generation to college	I propose that **personal inputs** – such as race/ethnicity, gender, and being first-generation to college – influence community college perspectives and experiences prior to and during a **learning experience**, in the SCCT model. In context, students who identify as members of groups that have been historically excluded from STEM fields – and, as a result, are now underrepresented in the STEM workforce – generally have *less* access to opportunities for professional development, guidance, and support in their pursuit of a STEM degree and/or career.

Note. These findings suggest some modifications of the SCCT model to be more well aligned with the experiences of community college STEM majors engaged in learning experiences (i.e., STEM research experiences and internships).

Figure 1.2

Model of how Social Cognitive Career Theory (SCCT) influences participation in learning experiences and subsequent persistence in STEM fields



Note. This was developed for Study 1 based on the original model of how basic career interests develop over time (Lent et al., 1994) and later iterations applied to STEM learning experiences for undergraduates (Carpi et al., 2017; Fouad & Santana, 2017). Boxes highlighted in orange were added to previous models, based on data from CCI alumni in Study 1.

Discussion

Although there is a great deal of literature linking technical/research experiences to persistence in STEM fields, very few studies examine participant perspectives and/or outcomes beyond the first few years after such an experience (e.g., Dou et al., 2021; Trott et al., 2020). To address this gap in knowledge, my work in Study 1 connected the experiences of community college students – before, during, and after a STEM internship – with their academic and career activities in the years following the internship.

Internships at DOE national labs integrate students into the STEM community

Due to the striking underrepresentation of DOE national laboratories and community colleges in the higher education literature, I investigated both of these topics in Study 1. Learning, collaborating, and spending time with STEM professionals outside of their school was impactful to community college students who previously struggled to imagine what scientists and engineers “do” at work. Many of the CCI alumni in Study 1 recalled aspects of their experiences that are unique to working at LBNL — such as spending time in the cafeteria or riding the shuttle — that became important to them over the course of their internship. As these activities became familiar to the interns, so too did the idea that they were a part of the institutional community. Many of the CCI alumni in this study reflected on the unique opportunity to explore, learn, and work at a DOE national laboratory during their internship. Some found it valuable to collaborate with experts in their field while others reflected on the benefits of having access to specialized research centers and powerful technology.

Scholarship about "ownership of learning" suggests that certain learning environments can create or strengthen excitement and motivation about the topic of study (Wiley, 2009). In Study 1, most CCI alumni attributed an increase in their STEM identity to the novel experiences of being involved in the activities of a scientist or engineer, including opportunities to apply their newly-learned skills, present their work, and be recognized by others as colleagues. Some reported the importance of connecting their CCI projects to societal or scientific impacts, especially if they pursued a STEM career to make a positive impact on others. Some felt deep connections and commitment to their CCI projects when their Mentor Group gave them responsibility and ownership over some aspect of the work (Wiley, 2009). This aligns with previous work about how opportunities to showcase one's competence as a scientist through research progress and interactions with others can increase self-recognition as a scientist (Cabay et al., 2018; Trott et al., 2020); how STEM projects framed as beneficial to society can support STEM learning and retention for students with communal goals (Boucher et al., 2017; Helix et al., 2022); and the value to students in developing project ownership, a commitment and personal connection with a project (Wiley, 2009). The findings from Study 1 suggest that completing a STEM internship at a DOE national laboratory can produce outcomes that are comparable to other STEM research experiences or internships for undergraduates.

Many students are looking for opportunities close to home

Many community colleges are disconnected from the STEM professional community and promote employment over professional development opportunities that would support the development of STEM identity in students (Ayshford, 2022; Jain et al., 2020; Hewlett, 2018). At the time of their participation in CCI, more than 90% of the study population were residents of the same state where LBNL is located (California), and most were attending community colleges located within 100 miles of the LBNL Main Site in Berkeley. This aligns with previous findings about community college student preference for completing professional development opportunities located within a "comfortable distance" (Backes & Velez, 2015; Holland Zahner, 2022; Jabbar et al., 2017; Reyes et al., 2019).

Harmful stereotypes decrease student confidence

The study participants identified stereotypes about community college students, from the media or harmful "comments" made by others. The academic community perpetuates negative stereotypes about community college students, which can have harmful impacts on community college student retention and belonging in STEM fields (Busch et al., 2024). Similarly, television shows, films, and books produced in the U.S. rarely include depictions of community college students and/or inaccurately portray them as "mediocre" and "unmotivated" (Bourke et al., 2008; LaPaglia, 1993; Tucciarone, 2007). Although study participants did not agree with these negative depictions, these biases negatively impacted their confidence to apply to internships or other professional development experiences outside of school. Thus, the findings in Study 1 align with previous studies about the impact of negative narratives about community colleges on students' "thoughts, beliefs, values, and behaviors," even when they have positive perceptions about community colleges themselves (Choi, 2024; Hawk & Hill, 2016).

Application selection processes can be updated to increase access

The findings in Study 1 suggest that community college students feel that most opportunities for professional development are not "for them," especially when competing with students from more schools that provide more support with finding opportunities, writing personal statements, and obtaining recommendation letters. This aligns with previous work that has highlighted the unique challenges community colleges face with supporting their students to engage in STEM research, who are often unaware of research opportunities, believe that they are not qualified to apply, and are faced with implicit bias when they do apply for internships and research programs (Ayshford, 2022; Houser & Lemmons, 2018). Although many technical or research opportunities are offered to provide undergraduates with the chance to *gain* experience, studies suggest that "cultural biases of academic research" lead many STEM professionals to select those applicants who already *have* relevant experience or extracurricular activities for these positions (McDevitt et al., 2020; Park et al., 2023).

Kindness supports inclusion and persistence in STEM

For students and early career professionals, positive and supportive mentor-mentee relationships in a particular professional environment contribute to an increased desire to remain in a similar career pathway (Karalis Noel et al., 2022). Multiple scholars argue that Black and Hispanic/Latinx students and professionals do not receive adequate support needed to obtain their academic/career goals, and call for additional studies on the subject (Carales & López, 2020; García & Garza, 2016; Gaxiola Serrano, 2017; Ornelas & Solorzano, 2004; Singleton et al., 2021). This issue is only exacerbated in STEM disciplines, and Black, Hispanic, and Latinx students benefit from opportunities to interact with a supportive community, receive academic and social support, learn to publish and present work, and develop a sense of belonging within their STEM field of interest (Abrica et al., 2022; Cervantes, 2021; Jain et al., 2020; Morton, 2021; Singleton et al., 2021). Throughout this study, I have included examples of practices that led to community college students feeling as though they were capable, competent, and prepared to pursue a STEM degree or career. Previous studies about students from groups historically excluded from STEM have reported that a) mentoring relationships are necessary to retain these students in STEM careers, b) these students receive less mentoring overall, c) mentors with a similar background can be effective, but they are often over-burdened, and d) well-intentioned mentors can inadvertently harm these students through practices (e.g., biased selection of applicants, colorblind mentoring) that reproduce inequities faced by these groups in the past (Estrada et al., 2018a; Prunuske et al., 2013; Singleton et al., 2021). For example, "colorblind" mentoring approaches or color-evasion strategies are practices used in an attempt to treat all mentees equally – mentors may remark that they treat everyone the same regardless of background, they "do not see" skin color, or race/ethnicity does not impact the mentor-mentee relationship (Prunuske et al., 2013). This approach may leave students from diverse backgrounds feeling disempowered, erasing individuals' lived experiences, and promoting the idea that students should assimilate to the dominant culture in order to be successful in STEM. In contrast, professionals who establish a strong rapport with students support the Hispanic/Latinx cultural value of *personalismo*, and increase the chances that a student will form long-lasting ties to their mentors, colleagues, and institution (e.g., Mireles-Rios & Garcia, 2019; Sánchez et al., 2022).

Although kindness is valued by all types of students, studies have shown that kindness cues in the form of macro- and microaffirmations can contribute to feelings of social inclusion, and persistence in STEM for Black, Hispanic/Latinx, Native American, and low-income students (Estrada et al., 2018a; Estrada et al., 2019). Two related studies that included more than 2,200 undergraduates majoring in life sciences attending baccalaureate granting institutions found that negative social interactions, feeling excluded or unwelcome, and witnessing unfair treatment – such as favoritism – were factors that led to students wanting to *leave* their group (Cooper et al., 2019b; Gin et al., 2021). For these students, a positive environment and experiencing kindness led to the opposite result, and they were more likely to *stay* with their group. Similarly, a study about female undergraduates majoring in engineering found that microaggressions led to feelings of exclusion, frustration, and a desire to limit social interactions (Camacho & Lord, 2011). Examples of microaggressions in that study included: people showing surprise that a woman would study engineering, having to prove to others that they are qualified to be in engineering learning environments, tokenization as one of few women in engineering, and overhearing inappropriate jokes told by colleagues/peers (Camacho & Lord, 2011).

Advancing the SCCT framework

CCI alumni reported that **learning experiences** (including STEM coursework) they engaged with at their community college did not result in **skill development** or **knowledge about STEM careers**, and they had low confidence and outcome expectations. Their stories indicate that perceived barriers (e.g., biases against community college students, few opportunities) act as proximal contextual influences that reduce the likelihood of applying to a learning experience, but support from faculty, STEM clubs, and peers are proximal contextual influences that increase that likelihood. Many CCI alumni received a “nudge” to apply to the program from community college faculty, STEM club leaders, program staff, or peers, which was especially critical for those who experienced discrimination in K-12 educational settings or lacked familial support for their academic goals. A recent study identified types of individuals who influenced community college women of color during their pursuit of careers in STEM; family members, college faculty/staff, and K-12 educators were most commonly named as positive influences (Yap et al., 2024). Notably, two of their study participants named K-12 educators as negative influences, who “tried to block opportunities for them to advance their education,” which aligns with the findings in Study 1 (Yap et al., 2024). The original SCCT model and subsequent iterations did not include a link between **proximal contextual influences** and **learning experiences**, but the data connect these two concepts. In other words, many of the students who participated in the CCI program would have been less likely to apply to the program without the support from their community college network.

Recent studies about the SCCT model suggest an indirect effect of **proximal contextual influences** on goals related to STEM careers through **self-efficacy** and

outcome expectations, and other potential modifications to the model in its original form (Lent et al., 2018; Sheu et al., 2010). Nearly all of the CCI alumni surveyed in Study 1 reported the two largest gains from participating in a STEM internship as a community college student to be a) the connections they formed with members of the STEM professional community (**proximal contextual influences**) they interacted with during the internship, and b) increased expectations that they would be successful in their academic or professional pursuits (**outcome expectations**). This professional community allowed students to learn more about STEM careers during CCI; supporting them in achieving their goals; and provided kindness – all of which resulted in increased student self-efficacy and confidence. These findings allow us to extend the SCCT model by including a direct link between **proximal contextual influences** and **self-efficacy** and/or **confidence**.

Mentors, colleagues, peers, and program staff continued to take actions to provide support in the form of advice, recommendations, additional internships and jobs, future collaborations, publishing papers together, etc. As described in the "Study Population" section, of the 38 CCI alumni in this study who have entered the workforce, 36 (95%) are working in STEM fields. Further, those who stayed in contact with the LBNL professional community after the CCI program were regularly reminded of their ability to be successful. These **actions** were thus connected to STEM **persistence**. Additionally, alumni reported that learning new research and/or technical skills and developing proficiency in science communication during CCI were beneficial to their academic and career trajectories and feeling like a scientist or engineer. Previously, the SCCT model did not include **skill development** or **knowledge about STEM careers**, although these are well-known outcomes of professional development opportunities for students. They have been added to the SCCT model in this study, because the data suggest that these are critical to increased **self-efficacy, confidence, identity,** and **outcome expectations**. Although I understand them to be individual concepts, there are a large number of studies that link **self-efficacy, confidence,** and **STEM identity** together (e.g., Bottia et al., 2021; Chemers et al., 2011; Frantz et al., 2017; Hernandez et al., 2018b; Syed et al., 2019), and the data suggest that all three of these factors are closely related. Thus, I have grouped these three concepts together in my proposed updates to the SCCT model, as applied to community college STEM majors who completed a STEM internship.

Some alumni expressed frustration when they felt like "the only" person from a particular background/identity in a particular group/setting, especially when this situation repeated itself over time. However, those mentors from a different race/ethnicity than their mentees who created space to have conversations about personal topics created feelings of trust and closeness. Aligned with the concept of "authentic care," the findings in Study 1 indicate that mentors who were perceived to prioritize the care of mentees over project-related outcomes (e.g., finishing tasks, generating data) made a deep and long-lasting impact on their mentees (Valenzuela, 2005). Women who participated in the CCI program reported the benefits of experiencing a "warm" social environment and opportunities to interact with other women. Some Hispanic/Latinx alumni shared stories about the discrimination they experienced from K-12 educators and schools, which negatively influenced their **confidence** to apply to the CCI program and their expectations of success in a STEM career. Combined with knowledge from previous studies about SCCT (e.g., Carpi et al., 2017; Fouad & Santana, 2017), the data suggest that **personal inputs** (e.g., race/ethnicity, socio-economic status; first-generation to college) play a role in the pursuit of a STEM degree or career, and in their overall perspectives before, during, and after a **learning experience**.

Community college students may be actively exploring and negotiating their relationship to STEM as a career pathway. Thus, a STEM internship has the ability to a) expose them to new academic and career options, b) provide them with the self-efficacy and confidence to succeed, and c) integrate them into the STEM community at a critical time in their undergraduate studies. The findings in Study 1 reveal that – years after completing the program – students who received quality mentoring and support retained positive memories and associations regarding their experience.

Recommendations

Partnerships with community colleges

Many community colleges are disconnected from the STEM professional community, have less access to engagement in internships and research experiences for their students, and promote employment over professional development opportunities that would support the development of STEM identity (Jain et al., 2020; Hewlett, 2018). Programs that involve partnerships between community colleges and other institutions can be an effective way to support student success during “the transitions from one part of their career pathway to another” (Myran et al., 2023). Aligned with the call to action by Hampton-Marcell and colleagues (2023) to support Black students through partnerships between schools and DOE national laboratories, I recommend that laboratories establish strategic partnerships with community colleges to provide students with “early exposure” research opportunities. Considering previous findings about community college student preference for academic/career opportunities within a “comfortable distance,” I recommend that DOE national laboratories engage in outreach efforts that include community colleges in the surrounding geographic area (Backes & Velez, 2015; Holland Zahner, 2022; Jabbar et al., 2017; Reyes et al., 2019). Additionally, DOE national laboratories can communicate with program alumni to share information about future opportunities to enter the DOE workforce and engage in outreach efforts that include schools in the surrounding geographic area, to provide opportunities to both students and faculty at community colleges (Bellis et al., 2022; DOE SC, 2020).

Applicant evaluation and selection

Broadening the scope of possible ways to evaluate program applicants is one way to address the disparities in resources across different student populations and ensure that a diverse new generation of STEM professionals is trained and supported to succeed from the undergraduate level and beyond. Programs should also consider the bias that may be present in their eligibility requirements, application structure, selection criteria, and/or recommendation letters against those student populations with less access to STEM careers. For example, an applicant’s GPA may not be reflective of their disposition and interest in working on research/technical projects (Carpi et al., 2017). Programs could reduce bias by the use of a standardized recommendation letter, which would produce “a similar description for each student” applicant (Houser & Lemmons, 2018). Those involved in reviewing applications could consider the potential impact such an opportunity might have for a student with limited access to those opportunities. The Level Playing Field Institute in Oakland, California and the Biology Scholars Program at the University of California, Berkeley consider factors such as “distance traveled.” Rather than previous achievements, *distance traveled* examines an applicant’s trajectory, including the resources and support they had access to and what hurdles they have overcome to arrive at their current academic/career stage (Craig, 2015; Estrada et al., 2021; Martin & Scott, 2013; Matsui, 2018). Similarly, McDevitt and colleagues suggest a two-step approach, in which program directors first review and narrow the applicant pool based on project needs, program goals, etc., and then mentors select students from this pool based on skills and their “potential to gain additional value” from the program (McDevitt et al., 2020).

Practices in support of community college students

For students and early career professionals, positive and supportive mentor-mentee relationships in a particular professional environment contribute to increased desire to remain in a similar career pathway (Karalis Noel et al., 2022). Creating a positive and supportive working environment is beneficial to all parties in the short-term, and can have long-term impacts on students, as well. Mentors will best serve all students by being aware of the possible ways in which background, culture, and identity can impact students’ academic/career experiences and perspectives. Unlike many of the resources needed to offer a professional development opportunity to students, kindness is free and readily available for all members of the STEM professional community to give to others. Although it is common to associate professional development opportunities with productivity and career advancement, mentors whose practices also include kindness, attention, and trust can have many positive impacts on their mentees years into the future.

Mentors, counselors, and staff can expose and challenge negative stereotypes about community colleges, to support students’ pride in their educational pathways and identities and increase the likelihood that they will persist and complete their studies (Brower et al., 2021; Choi, 2024; Varty, 2022). I recommend that those individuals involved in the recruitment, training, and education of community college and transfer students learn about these issues and take active steps to empower these students.

Conclusions and future work

Based on my in-depth communication with individuals who were interested in STEM disciplines as community college students, I now understand some of the reasons why they reported that they initially held low expectations of being successful in the STEM workforce: they did not understand what science/engineering entailed, and/or they did not have the support to pursue their interests in these disciplines. Additionally, to retain students in STEM career pathways, it is not enough to recruit them into technical or research experiences. The ways in which STEM professionals, program staff, guest speakers, and other members of the community interact with students are critical to their professional development and perception that they are capable of completing STEM degrees and entering the STEM workforce.

Study 1 made use of the existing SCCT model, which helped me to interpret my findings in the context of previous scholarship about STEM research and technical experiences. Indeed, CCI at LBNL serves as a SCCT-aligned learning experience for community college students, influencing their academic/career interests, goals, and actions. I propose several additions to the SCCT model, to better reflect the supports and barriers to STEM persistence for community college students. Further research is needed to determine if this updated model is reflective of the experiences of community college participants at other DOE national laboratories

I urge more scholars to contribute to knowledge about STEM professional development for community college STEM majors by publishing studies that describe program elements and participant outcomes (Hora et al., 2017; Lucero et al., 2021). Additionally, I encourage faculty and scholars with ties to community colleges to be involved in studies about the experiences of community college students, interventions beneficial to them, and the development of new approaches to support STEM learning and workforce development (De Leone et al., 2019; Hewlett, 2018; Jensen et al., 2020; Schinske et al., 2017). Considering the rare mention of programs at DOE national laboratories in the research literature, I advocate for collaborations between STEM professionals and those with training and expertise in educational research and social sciences to study this topic (Collins, 2023; NASEM, 2023). Scholarship in this area has the potential to influence policy, funding, and the adoption of new ideas for impactful and inclusive learning environments.

Chapter contributions

My co-authors for this work are Seth Van Doren, Astrid Zamora, Julio Jaramillo Salcido, Esther Law, Gabriel Otero Munoz, Aparna Manocha, Colette Flood, and Anne Baranger. Thanks to Laura Almaguer, Christine Beavers, Christopher Chen, Jerica Duey, Katie Dunne, Brett Heischmidt, Chris Martinez, Melissa Meikle, and Daniel Ramos for supporting this project during its early development. Dianna Bolt, Sean Burns, Chris Byrne, Christel Cantlin, Joseph Crippen, Nakeiah Harrell, Lady Idos, and Christina Teller assisted with records and information. Finally, thanks to Sean Burns, Krista Cortes, Amanda Dillon, Ali Esmaili, Max Helix, Megan Hochstrasser, Kelsey Miller, Rey Morales, Erin Murphy-Graham, Sinéad Griffin, Lloyd Goldwasser, Kris Gutiérrez, Jennifer King Chen, Ingrid Ockert, Miguel Órdenes, Colette Patt, Christopher Payne, Laura Pryor, Michael Ranney, Renee' Schwartz, Angy Stacy, Elisa Stone, Alice Taylor, Matt Traxler, Karen Villegas, Michelle Wilkerson, Brieanna Wright, Rachel Woods-Robinson, Sandra Zuñiga-Ruiz, and the Spring 2022 EDUC 209 class at the University of California, Berkeley for their feedback. Finally, I would like to acknowledge the role that Rey Morales, Eduardo Cervantes, and Darlene Del Carmen played in "nudging" students (like me) at Gavilan College to apply to professional development opportunities.

CHAPTER 2

Where are they now? Academic and career trajectories of national laboratory STEM internship alumni from community colleges, compared to those from baccalaureate granting institutions (Study 2)

For students attending baccalaureate granting institutions, it is well-established that participation in research experiences or internships hosted by colleges and universities can support retention in STEM degree programs. However, limited research has been published about these opportunities for community college students and/or hosted by the DOE national laboratories. Data was collected from individuals who participated in the Community College Internship (CCI) and Science Undergraduate Laboratory Internship (SULI) programs between 2009 and 2016, at Lawrence Berkeley National Laboratory (LBNL). The CCI and SULI programs are part of a suite of programs hosted at DOE national laboratories designed to expose students and recent graduates to career opportunities at these institutions. Of the CCI alumni, 94% transferred to a baccalaureate granting institution, 90% graduated with a STEM bachelor's degree, and 88% are on a STEM career pathway. Based on what is known about graduation and transfer of community college students in the U.S., CCI alumni transferred and graduated with bachelor's degrees at higher rates than expected. Of the SULI alumni, 91% graduated with a STEM bachelor's degree, and 71% are on a STEM career pathway. These findings suggest that – as compared to students attending baccalaureate granting institutions – community college students who engage in STEM professional development activities are likely to persist in STEM careers at similar rates. Additionally, participation in STEM professional development activities may increase the likelihood that community college students complete their academic degrees in STEM disciplines.

Introduction

For the past decade, increasing the number of trainees to work in STEM fields in the United States (U.S.) has been featured prominently in federal calls to action (America COMPETES Act of 2022, 2022; President's Council of Advisors on Science and Technology (PCAST), 2012, 2021). In recent years, there has been an increasing amount of attention on the "aging workforce" in STEM[8], both because of the anticipated shortage of STEM-trained professionals, and the collaborative advantages of teams with members from various career stages and backgrounds (Blau & Weinberg, 2017; Byrd & Scott, 2018; Conway & Monks, 2017; Lim et al., 2017; Sinnott et al., 2021; Smith-Doerr et al., 2017; White et al., 2018; Zerhouni et al., 2016). Critical to the DOE, the energy and manufacturing sectors may not have enough staff to meet workforce demands, considering the anticipated number of retirees in the coming years (Energy Workforce Opportunities and Challenges, 2019; National Research Council, 2015). The DOE national laboratory system anticipates loss of institutional knowledge across all STEM fields, through the impending retirement of a large proportion of its workforce (DOE, 2017). One strategy for addressing this issue involves offering internships and other professional development opportunities for students at DOE national laboratories and facilities across the U.S., and taking steps to retain some of these students as employees in the following years (DOE, 2017, 2022; DOE SC, 2020). In Study 2, I examined a) the academic and career trajectories of individuals who completed internships at a DOE national laboratory as community college students, and b) compared these to the trajectories of individuals who completed a similar internship as students attending baccalaureate granting institutions. It is a deliberate choice not to refer to community colleges as "2-year" schools or baccalaureate granting institutions as "4-year" schools, because undergraduates may spend more or less time at these institutions in pursuit of their academic goals (Complete College America, 2014; Jain et al., 2020; Ocean et al., 2022).

Literature review

Benefits of STEM research experiences and internships

Students who feel that they have participated in activities that led to learning and personal growth and established positive relationships with faculty and/or professionals in their field are more likely to have a positive view of their undergraduate education and career prospects (Andrade et al., 2022; Johnson & LaBelle, 2022; Coté et al., 2023). There is agreement across numerous studies that participation in a mentored internship or research experience decreases degree completion time, and increases academic achievement, STEM degree completion rate, interest in completing a STEM graduate degree, and persistence in STEM, especially for individuals from groups who have been excluded in STEM based on factors such as race, ethnicity, gender, and/or socioeconomic status (Chemers et al., 2011; Eagan Jr et al., 2013; Hernandez et al., 2018b; Hewlett, 2016; Jelks & Crain, 2020; Nerio et al., 2019; Prunuske et al., 2016;

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[8] The term "silver tsunami" is a widely used metaphor to describe the fact that many individuals born between 1946 and 1964 (referred to as "baby boomers") have retired, or are approaching this career stage. However, I recognize this as an "ageist" term often used in conversations about changing population demographics (White et al., 2018).

Romero et al., 2023). Many first-generation to college, low-income, Black or African American, Hispanic or Latinx, Native American, and Alaska Native students need to work during their undergraduate studies to fund their education, and are *less* likely to participate in professional development when it requires them to volunteer their time (Coté, 2023; Pierszalowski et al., 2021; Pratt et al., 2019; Drake et al., 2019). Educational programs and opportunities that offer financial compensation to students can increase their self-esteem, self-efficacy, feelings of being valued by the sponsor, interest in participation, and likelihood of staying in school (Coté et al., 2023; Minasian, 2019; Pratt et al., 2019; Romero et al., 2023). Studies about the experiences of community college students who participate in STEM research experiences report student gains such as perceived improvement in research skills and increased self-confidence, STEM career interest, transfer rates, likelihood of graduating with a bachelor's degree, and entry into the STEM workforce (e.g., Gamage et al., 2022; Higgins, 2013; Hirst et al., 2014; Leggett-Robinson et al., 2015; McIntyre et al., 2020; Nerio et al., 2019).

Gaps in the literature about STEM research experiences and internships

There have been a large number of studies about science research experiences published in the past few decades, though these focus primarily on the experiences and outcomes of students enrolled at baccalaureate granting institutions (Krim et al., 2019; Linn et al., 2015; National Academies of Sciences, Engineering, and Medicine (NASEM), 2017). Although nearly half of all students with STEM degrees in the U.S. attend a community college at some point during their education, there is little research about internships and/or research experiences for community college students (Creech et al., 2022; Krim et al., 2019; Lucero et al., 2021; Linn et al., 2015; Mooney & Foley, 2011; NASEM, 2017; NSF, 2011; Tuthill & Berestecky, 2017; Tsapogas, 2004). For studies collecting data from students attending a baccalaureate granting institution, it is generally unknown what proportion of the study population may have transferred from a community college prior to data collection (Linn et al., 2015).

Additionally, many studies designed to measure the impacts of research experiences on student success and persistence in STEM are merely descriptive in nature and/or do not track student success beyond the acquisition of an undergraduate-level degree (Estrada et al., 2018b; Krim et al., 2019). In fact, there is little tracking of STEM majors' ultimate career pathways in existing literature, as few studies report long-term impacts beyond 4 years after a research experience (Dou et al., 2021; Trott et al., 2020). Commonly, studies about the impacts of "science training programs" rely on short-term outcomes such as levels of motivation, interest, and intention to stay in STEM, which are important, but would be more powerful when coupled with longitudinal data about academic and career activities (Estrada et al., 2021).

Programs hosted at DOE national laboratories are unique and understudied

In collaboration with over 450 academic institutions across the U.S. and Canada, DOE national laboratories spend over $500 million each year to support students, recent graduates, postdoctoral fellows, and faculty members through sponsored research experiences, though these institutions are almost entirely missing from the extensive body of educational research literature published about such programs (DOE, 2017; Krim et al., 2019). To the best of my knowledge there is only one previous project – a doctoral capstone – that examined how DOE internships compare to other federally funded programs and examined program outcomes (Foltz et al., 2011). Conducted in partnership with DOE Office of Science (SC) Office of Workforce Development for Teachers and Scientists (WDTS) staff members, this project collected survey data from alumni of the Science Undergraduate Laboratory Internship (SULI) and the joint NSF and National Institute of Standards and Technology (NIST) Summer Undergraduate Research Fellowship (SURF) programs. However, these findings have not been published in a peer-reviewed journal.

As compared to the typical internship or research experience highlighted in the literature, programs at DOE national laboratories are unique in that a) they are not situated at a college or university, b) individuals who participate as mentors are predominantly scientists, engineers, and postdoctoral researchers rather than faculty and graduate students, c) some projects give students access to large-scale interdisciplinary research facilities beyond the capability of the typical faculty-led research group housed at a college or university (https://nationallabs.org/). Similar to Research Experiences for Undergraduates (REU) programs funded by the National Science Foundation, internships at DOE national laboratories collectively engage thousands of participants each year, from colleges and universities across the U.S., in a variety of disciplines (Foltz et al., 2011). Although less is known about STEM industry internships from the literature, some (but not all) industry internships have dedicated mentors appointed to oversee interns' work. When there are dedicated mentors in industry internships, they are STEM professionals, as opposed to faculty or graduate students. To my knowledge, there are no peer-reviewed publications that include *both* a) data from DOE national laboratory program participants and b) documentation of human subjects committee review/approval at the host institution. This limits the visibility and representation of the impact of DOE national laboratories on STEM education in the U.S., and the ability of scholars from other institutions to *locate* and *add to* this information and *engage with* DOE national laboratories on the subject.

Overview of Study 2

Previous work by Foltz and colleagues (2011) calls for the evaluation of DOE program outcomes related to “educational advancement and workforce development,” collecting data about “long-term outcomes,” and maintaining communication and engagement with program alumni. Similarly, more recent reports from the DOE have called for the collection of quantitative data to assess the impact of its “educational and community outreach efforts,” engage in longitudinal tracking of program participants, determine program participant entry into the DOE workforce, and determine the success of programs in promoting careers in STEM (DOE, 2022; DOE SC, 2020). In Study 2, I address these recommendations by examining academic and career activities in the years following undergraduate students’ participation in DOE internships.

Considering the many studies published about STEM research experiences each year, and the sizable proportion of undergraduates attending community colleges, Study 2 responds to a) the lack of research published about community college students’ academic and career pathways in STEM fields and b) the call from many scholars to show data about the long-term activities of community college STEM majors *beyond* their undergraduate studies (Bahr et al., 2017; Crisp et al., 2016; Hagedorn & Purnamasari, 2012; Hernandez et al., 2018b; Lucero et al., 2021; Starobin et al., 2013). ***Research Question 1:*** *What are the academic and career trajectories of Community College Internship (CCI) alumni in the years following their participation in the program?* For example, I wanted to examine what percentage of CCI alumni a) graduated with A.A./A.S. degrees, b) graduated with B.A./B.S. degrees, c) entered graduate programs, d) joined the STEM workforce, e) are currently working at a DOE national laboratory or facility, and f) are interested in working at LBNL and/or another DOE national laboratory or facility in the future. ***Research Question 2:*** *How do the academic and career trajectories of CCI alumni compare with those of a similar program, the Science Undergraduate Laboratory Internship (SULI) alumni?* As described in the “Study Population” section, I have constructed a comparison group from a subset of SULI alumni for this study.

Description of Programs

In support of the DOE mission – to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions – DOE SC WDTS collaborates with DOE national laboratories and other facilities to sponsor and manage a suite of internship programs. Two of these, the **Community College Internship (CCI)** and **Science Undergraduate Laboratory Internship (SULI)**, are the focus of this study. The goal of the CCI program is to encourage community college students to enter technical careers relevant to the DOE mission by providing technical training experiences at DOE laboratories across the United States. The SULI program aims to encourage undergraduates and recent graduates (i.e., post-baccalaureates and graduate students who have obtained a bachelor’s degree within 2 years) to pursue STEM careers by providing research experiences at DOE laboratories. These programs are regarded as opportunities for “fostering diversity” within the DOE workforce, and DOE national laboratories engage in outreach efforts to increase the likelihood that students and recent graduates from various backgrounds apply to participate (Hampton-Marcell et al., 2023; DOE SC, 2020).

During both CCI and SULI, students and recent graduates selected for participation work on research or technical projects that use the specialized instruments or facilities at the host laboratory in support of the DOE mission. Each year, applications for these programs are solicited for three separate internship terms; spring, summer, and fall. Although the eligibility requirements differ slightly between programs, the applicant should: be 18 years or older at the time the program begins, be enrolled as a “full-time” student in an undergraduate institution, have a minimum Grade Point Average of 3.0 on a 4.0 scale, have completed at least six credit hours of STEM coursework, and have completed 12 hours of coursework toward a degree. Full details can be accessed online at https://science.osti.gov/wdts/.

These programs are hosted by DOE national laboratories across the United States, but this study focuses on one laboratory in particular, Lawrence Berkeley National Laboratory (LBNL). At LBNL, Workforce Development & Education (WD&E) serves as the host for several internships, including CCI and SULI. Once selected for participation in either program, students and recent graduates are referred to as "interns." Each intern is placed with a Mentor Group, which consists of those individuals responsible for the daily supervision, teaching, and mentoring of interns and their colleagues. Altogether the team may consist of permanent staff, temporary staff, postdoctoral scholars, and/or graduate students, though the structure of these teams varies widely. In support of intern development from novice to expert, these Mentor Groups engage in both teaching (e.g., technical skills training) and mentoring (e.g., conversations about STEM careers, sponsorship) over the course of the internship term (Helix et al., 2022; Zalaquett & Lopez, 2006).

Interns attend an Orientation and regularly scheduled meetings and training sessions throughout the term. An internship coordinator facilitates check-in meetings to discuss interns' experiences, address any issues, and connect them with resources at LBNL. They have opportunities to attend optional enrichment activities, such as tours and seminars. Interns also attend "Peer Poster Presentations," during which they learn about effective presentation and communication techniques and then have the opportunity to practice these skills. Throughout the program, interns complete a technical report or research paper and poster, and present at a poster session during the final week of the program. The interns complete pre- and post-surveys administered by WDTS, and one exit survey administered by WD&E at LBNL.

WD&E provides interns with textbooks about technical writing and research ethics, and the Mentor Group provides each intern with access to a desk, phone, and computer, to be used during the internship. Additionally, interns receive a stipend and housing supplement, and are reimbursed for travel costs to and from LBNL. They are eligible to receive these funds by submitting any required "onboarding" paperwork, dedicating 40 hours a week to the internship for the duration of the program, participating in mandatory events, and completing written deliverables. Between 2009 and 2016, the amount of financial compensation paid to interns during the internship term (stipend and housing supplement) increased, based on data collected from interns by WD&E through the aforementioned exit survey. Prior to 2013, interns received $500 per week, which included both stipend and housing. In 2013, interns received a stipend of $16.25 per hour ($650 per week) and $150 per week for housing costs. In 2016, interns received a stipend of $20.00 per hour ($800 per week) and $300 per week for housing. For comparison, the minimum wage in California was $8.00 per hour in 2013, $9.00 per hour in 2014, and $10.00 per hour in 2016 (State of California Department of Industrial Relations, 2023).

Methods

Author expertise and background

As an undergraduate biology major, I (L.E.C.[9]) attended multiple community colleges in California and completed the CCI program in 2007 and the SULI program in 2008 and 2009. I worked with the same Mentor Group at LBNL during these internships

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[9] In this dissertation I am using the Method Reporting with Initials for Transparency (MeRIT) approach as described by Nakagawa and colleagues (2023). For Study 3, L.E.C. = Laleh Cote, C.L.F. = Colette Flood, A.M.B. = Anne Baranger, E.W.L. = Esther Law, J.J.S. = Julio Jaramillo Salcido, S.V.D. = Seth Van Doren, A.M. = Aparna Manocha, A.N.Z. = Astrid Zamora, and G.O.M. = Gabe Otero Munoz.

and for an additional 2 years as a Research Assistant. Both C.L.F. and L.E.C. have over a decade of experience working with various internship programs hosted by WD&E at LBNL, including CCI and SULI. A.M.B. has 27 years of experience working with and studying STEM UREs. L.E.C. and A.M.B. have worked together for 7 years, studying this topic, generating curricula for training workshops about teaching and mentoring undergraduate researchers, and working to improve undergraduate-level courses in biology and chemistry. The authors of this work include women, men, Asian, Black, Hispanic, Latinx, mixed race, and White individuals. As student assistants and/or staff, E.W.L., J.J.S., and S.V.D. worked at LBNL with WD&E internship programs. A.M., A.N.Z., and G.O.M. contributed to this project as undergraduate and graduate research assistants through partnerships with the University of California, Berkeley.

Data collection

For Study 2, my primary mode of communication with the study population was email. However, the email addresses for some individuals were missing, inactive, or temporary email addresses from undergraduate institutions. The remaining members of the study population were contacted using online platforms such as Facebook and LinkedIn. I administered consent forms and surveys to potential study participants through Qualtrics. Data about academic and career activities and interest in working at a DOE national laboratory was collected from CCI alumni (the study population) and SULI alumni (the comparison group), and engaged in follow-up communication with alumni of both programs between 2018 and 2021. As described in the “Study Population and Comparison Group” section, these methods resulted in data collection from 86 CCI alumni (out of a total of 93 individuals who completed CCI during 2009-2016) and 90 SULI alumni (out of a total of 99 individuals who completed SULI during 2009-2016).

As shown in **Figures A2.1 and A2.2**, CCI and SULI alumni were asked to respond to survey questions about their professional activities across the DOE complex in the years following their internship at LBNL, and interest in working at a DOE national laboratory or facility. These methods were approved by the Institutional Review Board at LBNL (Protocol ID: Pro00023065) with the University of California, Berkeley as the relying institution (Reliance Registry Study #2593). All contributing researchers completed training in the responsible and ethical conduct of research, administered through LBNL or the University of California, Berkeley.

Table 2.1

Gender, ethnicity, and race of study participants

Demographics	CCI group		SULI[a] group	
	n	%	*n*	%
Total	86	100	90	100
Gender				
Female	27	31	36	40
Male	58	67	54	60
Unknown[b]	1	1	0	0
Ethnicity/race				
Asian	24	28	24	27
Black or African American	5	6	2	2
Hispanic or Latinx	19	22	5	6
Native American	0	0	1	1
Two or more races	7	8	6	7
White	26	30	50	56
Unknown[b]	5	6	2	2

Note. This table includes demographic information for the Community College Internship (CCI) and Science Undergraduate Laboratory Internship (SULI) participants who completed their program at LBNL between 2009 and 2016. [a] This is a subset of all 2009-2016 SULI participants at LBNL. This group includes only those who were first- and second-year undergraduates during their first SULI term and did not attend a community college at any time prior to their participation in SULI. [b] For both gender and ethnicity/race data, the "unknown" group includes both "decline to state" responses and missing data.

Study population and comparison group

There are two groups of alumni represented in Study 2. Motivated by the lack of research studies about academic and career pathways for community college STEM majors, my goal was to study the 93 individuals who completed the CCI program at LBNL between Summer 2009 and Fall 2016; this group is the **study population** for Study 2. Each of these individuals was a community college student at the time of their participation, and they were enrolled in schools in Alabama, Arizona, California, Florida, Illinois, Massachusetts, Nevada, New York, and Washington. I collected data about academic and career trajectories from 86 individuals who attended community colleges in the following locations: 77 (90%) in California and the remaining 9 (10%) in Alabama, Arizona, Florida, Illinois, Massachusetts, Nevada, New York, and Washington. Nearly 50% of CCI alumni attended the following six community colleges, listed in descending order: Contra Costa College, Diablo Valley College, City College of San Francisco, College of Marin, College of San Mateo, and Hartnell College. My original intention was to have a control group for this study, perhaps by studying community college STEM majors who applied to the CCI program at LBNL but were *not* admitted. However, this was not possible[10], so the second group represented in this study is my **comparison group**, made up of individuals who participated in the SULI program.

As community college students taking lower division courses, CCI interns are defined as taking coursework equivalent to that of first- or second-year undergraduates at baccalaureate granting institutions, even if they spent more than 2 years taking lower division coursework. To create as many similarities as possible between the study population and comparison group, I included only those SULI participants who were first- or second-year undergraduates at the time of their participation in SULI at LBNL. From the years 2009 to 2016, there were approximately 500 SULI participants at LBNL, and I had access to program records which include information such as the undergraduate institutions previously attended, current undergraduate institution, and educational level (i.e., academic year of study) at the time of their application to SULI. The comparison group constructed for this study includes the 99 individuals who a) participated in the SULI program at LBNL in 2009 to 2016, b) were in the first or second year of their undergraduate studies at the time of their first internship term in SULI, and c) did not begin their studies at a community college. I collected data about academic and career trajectories from 90 individuals, who attended baccalaureate granting institutions in the following locations: 36 (40%) in California, 9 (10%) in Massachusetts, 7 (8%) in New York, 5 (6%) in Pennsylvania, 4 (4%) in North Carolina, and the remaining 29 (32%) in Colorado, Florida, Idaho, Illinois, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nevada, New Jersey, Ohio, Oregon, Puerto Rico, Rhode Island, Tennessee, Texas, Vermont, Virginia, and Washington. Nearly 40% of SULI alumni attended the following seven baccalaureate granting institutions, listed in descending order: University of California, Berkeley; University of Southern California; Princeton University; State University of New York at Stony Brook; University of California, Los Angeles; University of North Carolina, and University of Pennsylvania.

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[10] When I designed this study, I submitted a protocol to the LBNL Institutional Review Board with my plans to study community college STEM majors who applied to the CCI program at LBNL, including those who were admitted and those who were not admitted. However, this protocol was not approved after a review, and the board asked me to remove my plans to study those individuals who were not admitted into CCI.

Of the CCI alumni who attended California Community Colleges, 60/77 (78%) attended a community college in the Bay Area, which consists of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma counties (U.S. Census Bureau, n.d.). At the time of data collection for this study, the LBNL Main Site was located in Alameda County, and off-site LBNL offices were located in Alameda and Contra Costa counties. Considering previous findings about community college student preference for academic/career opportunities within a “comfortable distance,” I compared the race and ethnicity of CCI participants with Bay Area census data from a similar time frame (Backes & Velez, 2015; Holland Zahner, 2022; Jabbar et al., 2017; Reyes et al., 2019), as shown in **Figure 2.1**. Additionally, SULI alumni data was included to compare how the CCI and SULI programs differ based on race and ethnicity of participants. As described in the “Data collection” section, the group of 41 CCI alumni who responded to the survey questions about the DOE complex were 44% female, 54% male, and 2% unknown gender; and 29% Asian, 22% Hispanic or Latinx, 7% two or more races, 37% White, and 5% unknown race/ethnicity. The group of 57 SULI alumni who responded to these questions were 21% female and 36% male; and 16% Asian, 2% Black or African American, 7% Hispanic or Latinx, 7% two or more races, 67% White, and 2% unknown race/ethnicity.

Differences in school type and resources between groups

I have attempted to construct a comparison group (SULI alumni) that is as similar as possible to the study population (CCI alumni). As mentioned in the “Description of Programs” section, the SULI program is a DOE program similar to the CCI program in many aspects. The primary difference between SULI and CCI is that all U.S. undergraduates and post-baccalaureates (up to 1 year after graduation from a baccalaureate granting institution) are eligible to apply to SULI, while only U.S. community college students are eligible to apply to CCI. Many of the CCI and SULI alumni represented in this study interacted with each other at LBNL, attended the same group meetings, and/or worked in the same Mentor Groups. However, there are some salient differences between the two groups.

Many U.S. colleges and universities have endowments that can be used to support many types of activities, including student financial aid and stipends, professional development programs, research supplies and facilities (ACE, 2021). Approximately 40% of public and 42% of private baccalaureate granting institutions have endowments larger than $50 million, and all of the SULI alumni in this study attended schools in this category (ACE, 2021; NACUBO, 2022). Only 6% of public and 5% of private baccalaureate granting institutions have endowments larger than $50 million, and 68 (76%) of SULI alumni attended schools in this category (ACE, 2021; NACUBO, 2022). There are eight baccalaureate granting institutions that make up the “Ivy League” in the U.S. – Brown University, Columbia University, Cornell University, Dartmouth College, Harvard University, Princeton University, University of Pennsylvania, and Yale University (U.S. News, 2022). These schools are highly selective in their undergraduate admissions, and have some of the largest endowments in the U.S. In total, 14 (16%) of SULI alumni attended one of these Ivy League schools (ACE, 2022; NACUBO, 2022).

Of the SULI alumni who make up the comparison group in this study, 75 (83%) attended schools in the 80th to 100th percentile of selectivity among all baccalaureate institutions, 73 (81%) attended schools classified as “research institutions,” 68 (76%) attended doctoral universities with “very high research activity,” 39 (43%) attended private schools, and 15 (17%) attended minority-serving institutions (ACE, 2022). Of the group of CCI alumni in this study, 74 (86%) attended minority-serving institutions, and none attended private schools, schools with large endowments, or schools that would be considered to have high levels of “research activity” (ACE, 2022). The California Community College system has an endowment of $76 million, but this is shared between 116 colleges (Foundation for California Community Colleges, n.d.).

At the time of their participation in CCI at LBNL, the study population (CCI alumni) attended public community colleges with little to no opportunity for undergraduates to conduct research on campus. Many individuals in the comparison group (SULI alumni) were students at some of the most selective, well-funded, and research intensive baccalaureate granting institutions. Based on the differences between the schools attended by members of each group – especially in terms of resources available to support student professional development and success – I would expect to see major differences in academic/career activities between groups. However, Study 2 found high rates of degree attainment, retention in STEM majors, and entry into the STEM workforce from both CCI and SULI alumni. I acknowledge that there are likely many differences between the two groups of students studied, but believe that the results from Study 1 about the impacts of CCI at LBNL (Coté et al., 2023) coupled with the career pathway data presented in Study 2 illustrate the benefits of offering discipline-specific professional development opportunities to community college students.

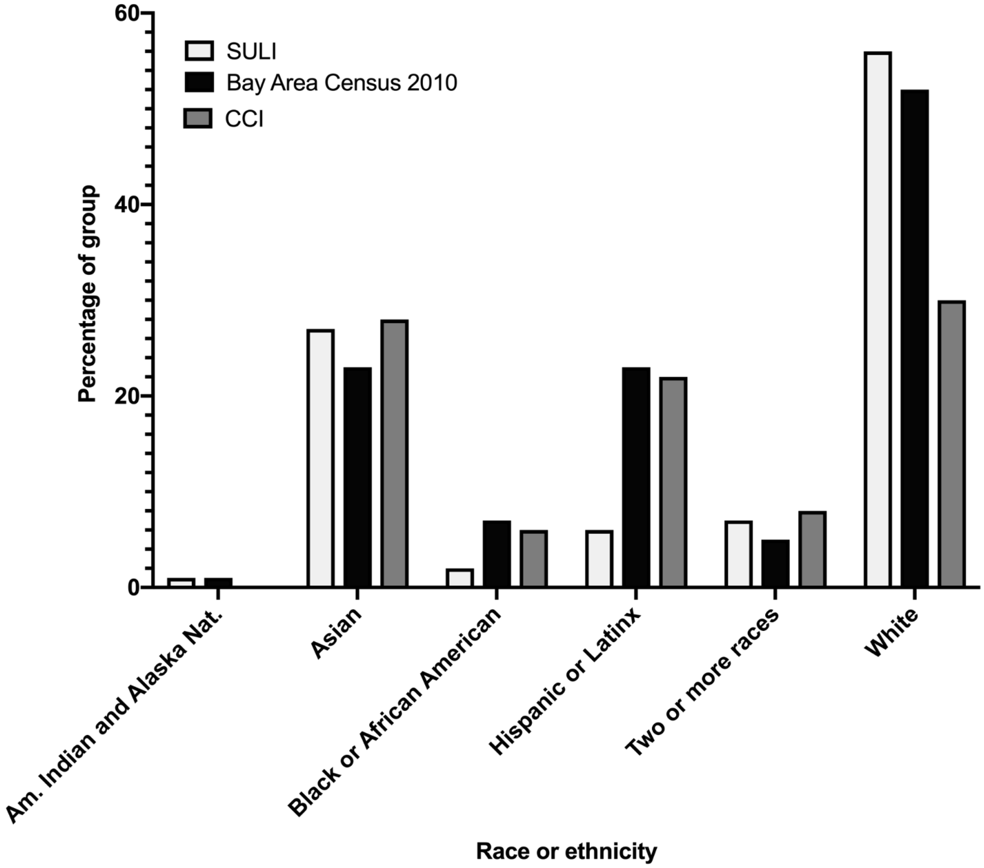
Data analysis

As described in the “Data collection” section, I collected academic and career “activity” data, which illustrates previous accomplishments, current employment, or current engagement in graduate studies. For example, did CCI participants obtain an A.A. or A.S. degree? Did they transfer to a baccalaureate granting institution? Did they graduate with a B.A. or B.S. in STEM? Beyond their undergraduate studies, how many joined the STEM workforce? Information related to the academic and career “trajectories” of both CCI and SULI alumni were organized by A.M., A.N.Z., L.E.C., J.J.S., and S.V.D. to show how many individuals from each group are on a specific career pathway; STEM, health, or non-STEM. This method of analysis was also used in my previous study about the CCI program (Coté et al., 2023). These categories were created to determine the proportion of each group that persisted in STEM, or are currently engaged in graduate-level training to support a STEM career. All authors identified and discussed the themes, and the data representation was refined for accuracy and clarity throughout the study.

Throughout Study 2, I refer to the “STEM workforce” and the majors, degrees, and pathways related to students preparing to enter this workforce. In my analysis, I followed the guidance provided by the NASEM (2018) and National Science Board (2016), using what they refer to as “science and engineering occupations” and “science and engineering-related occupations.” Examples of the first category are computer scientists, mathematicians, life scientists, physical scientists, and engineers. Examples of the second category are laboratory managers, science and engineering teachers, and lab technicians.

Figure 2.1

Comparison of race and ethnicity data between study participants and the 2010 Bay Area Census



Note. Based on the 2010 Census, the Bay Area population was 0.7% American Indian and Alaska Native, 23.3% Asian, 6.4% Black or African American, 23.5% Hispanic or Latinx, 0.6% Native Hawaiian and Other Pacific Islander, 10.8% some other race, 5.4% two or more races, and 55.6% White in 2010 (U.S. Census Bureau, n.d.). During the 2009-2016 time frame, the CCI participants were 27.9% Asian, 5.8% Black or African American, 22.1% Hispanic or Latinx, 8.1% two or more races, 30.2% White, and 5.8% unknown; and the SULI participants were 1.1% American Indian and Alaska Native, 26.7% Asian, 2.2% Black or African American, 5.6% Hispanic or Latinx, 6.7% two or more races, and 52.5% White, and 2.2% unknown.

Results

Academic and career trajectories for CCI alumni

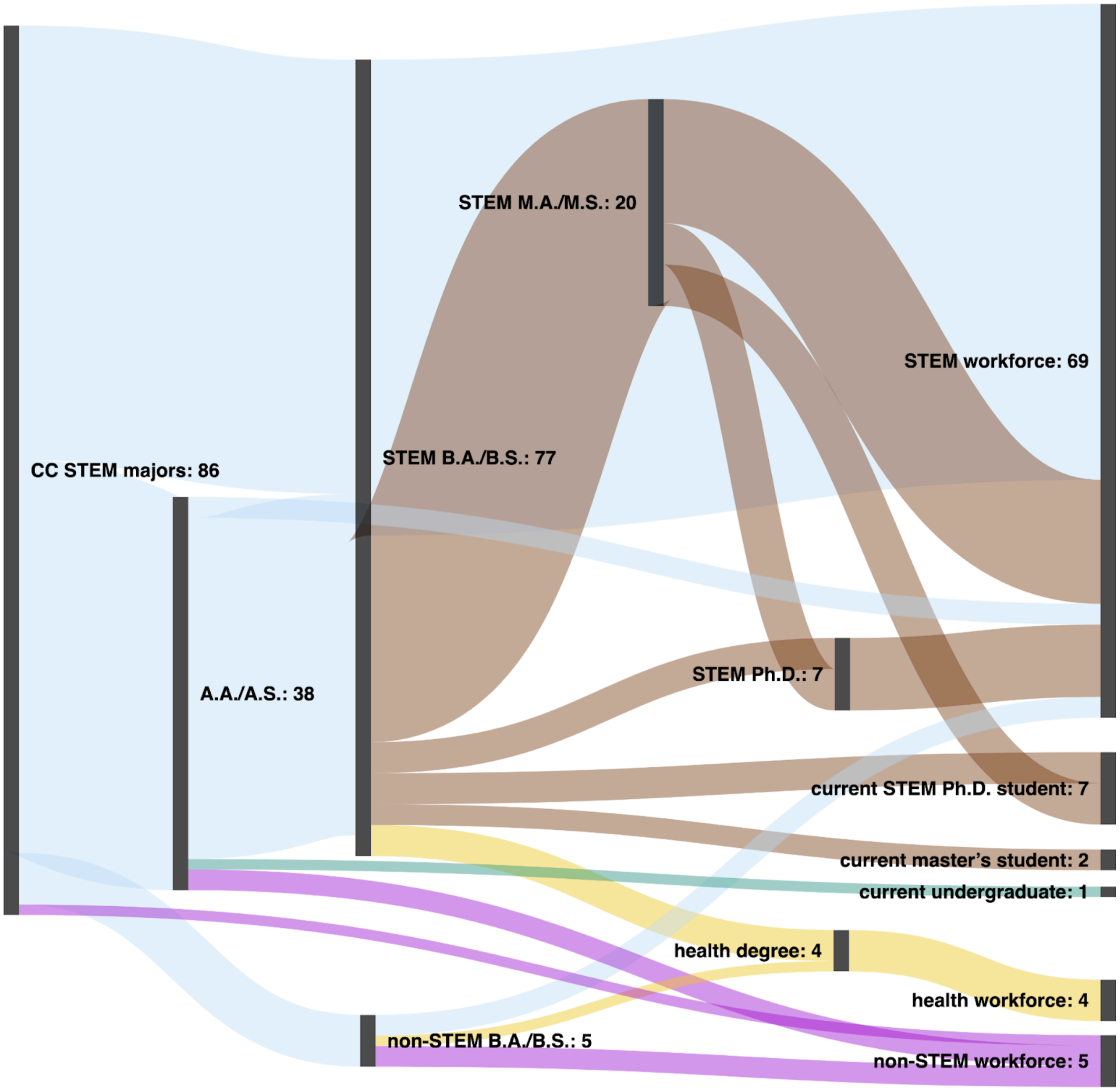
In total, I collected data about the academic and career activities of 86 CCI alumni, as shown in **Table 2.2,** between 5 and 12 years after their participation in the CCI program at LBNL. As shown in **Figure 2.2**, all (100%) of these 86 CCI alumni were STEM majors attending a community college at the time of their participation, 38 (44%) obtained one or more A.A./A.S. degrees, 77 (90%) obtained a STEM B.A./B.S., 5 (6%) obtained a non-STEM B.A./B.S. degree, and 1 (1%) is currently an undergraduate student. Nearly all CCI alumni (81; 94%) transferred from a community college to a baccalaureate granting institution; 46 (53%) transferred *without* first obtaining an A.A./A.S. degree; and 35 (41%) transferred *after* obtaining one or more A.A./A.S. degrees. After completing their CCI internship term at LBNL, 14 (16%) alumni participated in the SULI program at LBNL, 5 (6%) participated in a different internship at LBNL, and 9 (10%) participated in an internship at another DOE national laboratory.

Of the 77 CCI alumni who obtained a STEM B.A./B.S., 73 (95%) entered a STEM field through the workforce or graduate studies, 4 (5%) joined the health workforce and none (0%) joined the non-STEM workforce. In comparison, of the 5 individuals who obtained a non-STEM B.A./B.S. degree, 2 (40%) joined the non-STEM workforce, 2 (40%) joined the STEM workforce, and 1 (20%) joined the health workforce. Of this group of CCI alumni who obtained a STEM B.A./B.S., 20 (26%) obtained a STEM M.A./M.S. degree, 2 (3%) are currently enrolled in a STEM M.A./M.S. degree program, 7 (9%) obtained a STEM Ph.D. degree, 7 (9%) are currently enrolled in a STEM Ph.D. program, 3 (4%) obtained a health degree (e.g., D.D.S., M.D., Pharm.D.), 65 (84%) are currently part of the STEM workforce, and 3 (4%) are currently part of the health workforce.

In 2022, Allison and colleagues reported that some of the community college students in their study population, aged 25 years or older, had obtained a non-STEM B.A./B.S. degree before enrolling in community college courses with the ultimate goal of entering the STEM workforce. Similarly, I found that 5 (4%) CCI alumni graduated with a B.A./B.S. degree in a non-STEM subject *and* joined the non-STEM workforce before enrolling in a community college to take STEM coursework.

Figure 2.2

Academic and career trajectories of Community College Internship (CCI) alumni



Note. In this Sankey diagram, the academic and career trajectories of Community College Internship (CCI) alumni (n=86) who participated in the program at LBNL between 2009 and 2016 are shown. The numbers next to each node indicate the number of individuals within the larger group of CCI alumni. For example, of the original 86 STEM majors (shown on the left side of the diagram), 38 obtained an A.A./A.S. degree, 77 obtained a STEM B.A./B.S. degree, and 5 obtained a non-STEM B.A./B.S. degree.

Table 2.2

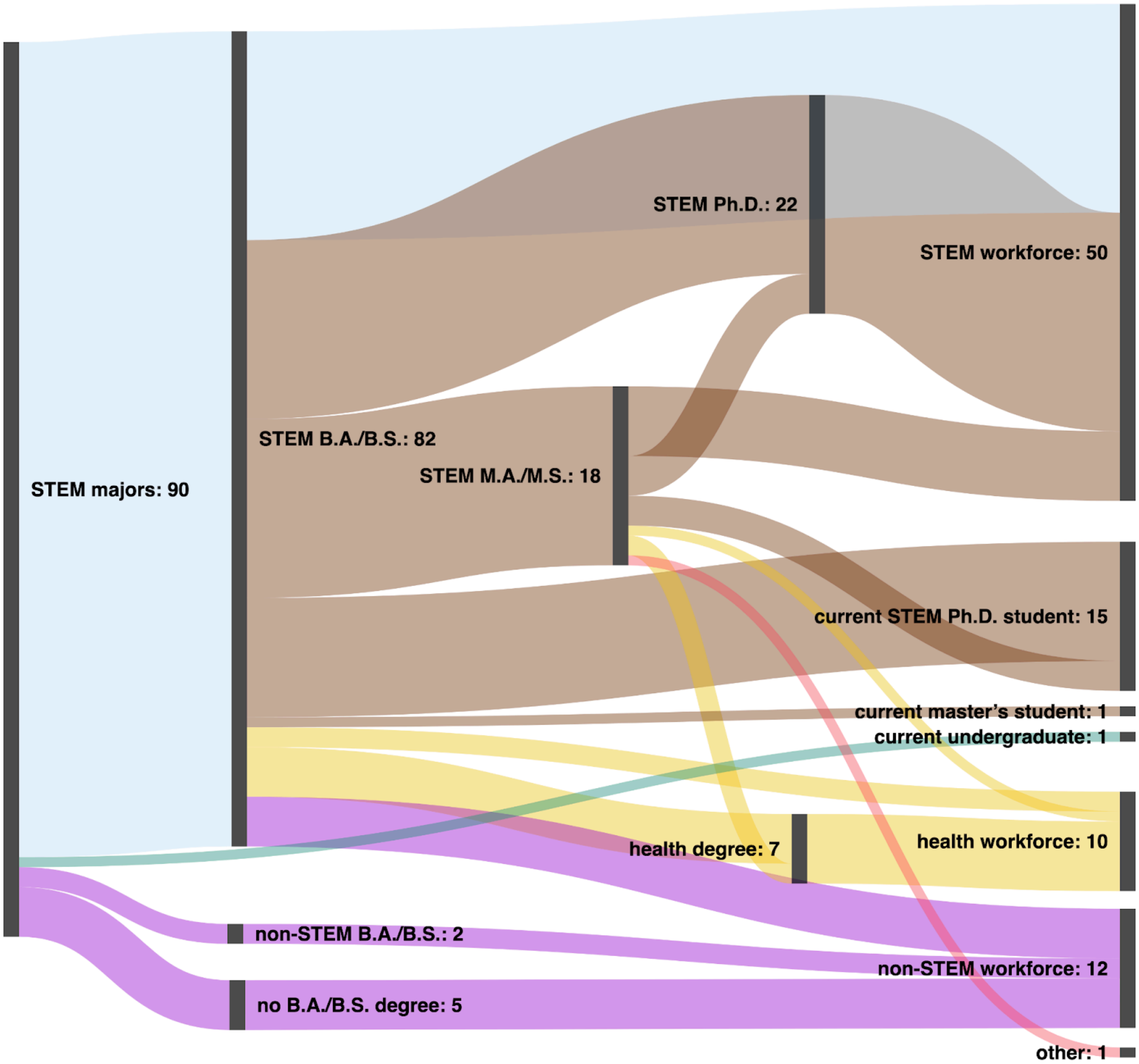
Current academic and career activities of study participants

Academic or career activity	CCI alumni		SULI alumni		CCI/SULI alumni combined	
	n	*%*	*n*	*%*	*n*	*%*
Total	86	100	90	100	176	100
Undergraduate or post-baccalaureate program (STEM)	1	1	1	1	2	1
Master's program (STEM)	1	1	0	0	1	0.6
Master's program (other)	1	1	1	1	2	1
Ph.D. program (STEM)	7	8	14	16	22	12.5
Ph.D. program (other)	0	0	1	1	1	0.6
STEM workforce	69	80	50	56	118	67
Health workforce	4	5	10	11	14	8
Non-STEM workforce	5	6	12	13	17	10
Other	0	0	1	1	1	0.6

Note. This information is current as of December 2021. The academic or career activities of participating individuals may be described by more than one category. For example, two CCI alumni joined the workforce and started an academic program without leaving their professional positions.

Figure 2.3

Academic and career trajectories of Science Undergraduate Laboratory Internship (SULI) alumni



Note. In this Sankey diagram, the academic and career trajectories of Science Undergraduate Laboratory Internship (SULI) alumni (n=90) who participated in the program at LBNL between 2009 and 2016 are shown. The numbers next to each node indicate the number of individuals within the larger group of SULI alumni. For example, of the original 90 STEM majors (shown on the left side of the diagram), 82 obtained a STEM B.A./B.S. and 2 obtained a non-STEM B.A./B.S.

Academic and career trajectories for SULI alumni

I collected data on academic and career activities for 90 SULI alumni (who were first- or second-year undergraduates at the time of their internship) between 5 and 12 years after they participated in the CCI program at LBNL. As shown in **Figure 2.3**, of the 90 SULI alumni in this study, 82 (91%) obtained a STEM B.A./B.S., 2 (2%) obtained a non-STEM B.A./B.S. degree, 5 (6%) did not obtain a B.A./B.S. degree in any subject, and 1 (1%) is currently an undergraduate student. Of the 82 SULI alumni who obtained a STEM B.A./B.S. degree, 66 (80%) entered a STEM field through the workforce or graduate studies, 10 (12%) joined the health workforce, and 5 (6%) joined the non-STEM workforce. All (100%) of the individuals who obtained non-STEM B.A./B.S. degrees *or* did not obtain B.A./B.S. degrees have entered the non-STEM workforce. Of the 82 SULI alumni who obtained a STEM B.A./B.S., 18 (22%) obtained a STEM M.A./M.S. degree, 1 (1%) is currently enrolled in a STEM M.A./M.S. degree program, 22 (27%) obtained a STEM Ph.D. degree, 15 (18%) are currently enrolled in a STEM Ph.D. program, 7 (9%) obtained a health degree (e.g., D.D.S., M.D., Pharm.D.), 50 (61%) are currently part of the STEM workforce, 10 (12%) are currently part of the health workforce, and 5 (6%) are currently part of the non-STEM workforce.

Comparing the trajectories of CCI and SULI alumni

As described in the “Data analysis” section, I used three categories to identify those individuals who are currently working and/or attending school in a discipline related to STEM, health, or non-STEM. As opposed to the current academic and career activities data shown in **Table 2.2**, the data in **Figure 2.4** combines the data from individuals in the workforce with those enrolled in graduate programs to produce STEM, health, or non-STEM “career pathways” categories. For example, the number of individuals working in the health workforce as medical staff, dentists, or physicians have been combined with the number of individuals currently enrolled in nursing, dental, or medical degree programs to produce a single “health career pathway” group. Based on the “career pathways” data: **88% of CCI alumni and 71% of SULI alumni are currently on a STEM career pathway**; 6% of CCI alumni and 13% of SULI alumni are currently on a health career pathway; and 6% of CCI alumni and 16% of SULI alumni are currently on a non-STEM career pathway. **80% of CCI alumni and 56% of SULI alumni have joined the STEM workforce**; 5% of CCI alumni and 11% of SULI alumni have joined the health workforce; and 6% of CCI alumni and 13% of SULI alumni have joined the non-STEM workforce (see **Table A2.3** for details).

As shown in **Table A2.3**, I collected data about the academic achievements of program alumni and found that 90% of CCI alumni and 91% of SULI alumni have completed a STEM B.A./B.S. degree; 23% of CCI alumni and 20% of SULI alumni have completed a STEM master’s degree; and 8% of CCI alumni and 24% of SULI alumni have completed a STEM Ph.D. degree. Of those who completed degrees outside of STEM: 6% of CCI alumni and 2% of SULI alumni have completed a non-STEM B.A./B.S. degree; and 5% of CCI alumni and 7% of SULI alumni have completed a health or non-STEM graduate degree. As shown in **Table 2.2**, 1% of CCI alumni and 1% of SULI alumni are currently completing their undergraduate studies; 2% of CCI alumni and 1% of SULI alumni are completing a master’s degree; and 8% of CCI alumni and 17% of SULI alumni are completing a Ph.D. degree.

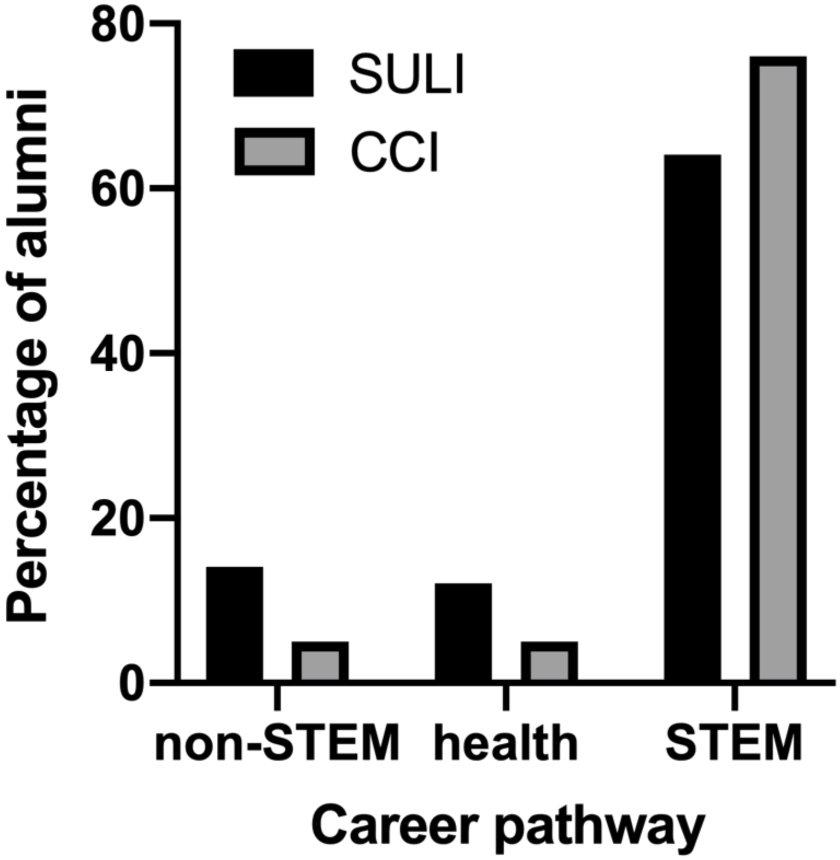
Alumni experience and interest in working at national laboratories

The CCI and SULI programs are part of a suite of programs hosted at DOE national laboratories designed to expose students and recent graduates to career opportunities at these institutions (DOE, 2022). Alumni from these programs are thus considered to be candidate pools from which DOE national laboratories can “recruit new permanent hires” (DOE SC, 2020). As described in the “Limitations” section, a smaller set of program alumni responded to survey questions about their interest in working at LBNL or another DOE national laboratory or facility in the future. Since their participation in CCI or SULI at LBNL, 19/41 (46%) of CCI alumni and 17/57 (30%) of SULI alumni worked at LBNL in some capacity; and 26/41 (63%) of CCI alumni and 21/57 (37%) of SULI alumni (from the comparison group) worked at any of the U.S. DOE national laboratories or facilities in some capacity. Most commonly, program alumni worked at a DOE national laboratory (including LBNL) or facility after completing an additional internship program. Currently, 8/41 (20%) of CCI alumni and 5/57 (9%) of SULI alumni who responded to these survey questions work at one of six different DOE national laboratories. Their roles include analysts, engineers, postdoctoral scholars, research assistants, research associates, and scientists. They work in various disciplines, including chemical engineering, chemistry, environmental science, materials science, mechanical engineering, nuclear engineering, nuclear science, operations, and physics.

Additionally, 33/41 (80%) of CCI alumni and 29/57 (51%) of SULI alumni reported their interest in working at LBNL in the future, and 15/41 (37%) of CCI alumni and 24/57 (42%) SULI alumni reported their interest in working at a *different* DOE national laboratory in the future. Combining the CCI and SULI alumni together, **13/98 (13%) of alumni currently work at one of the DOE national laboratories**, and 64/98 (65%) of alumni are interested in working within the DOE complex now or in the future.

Figure 2.4

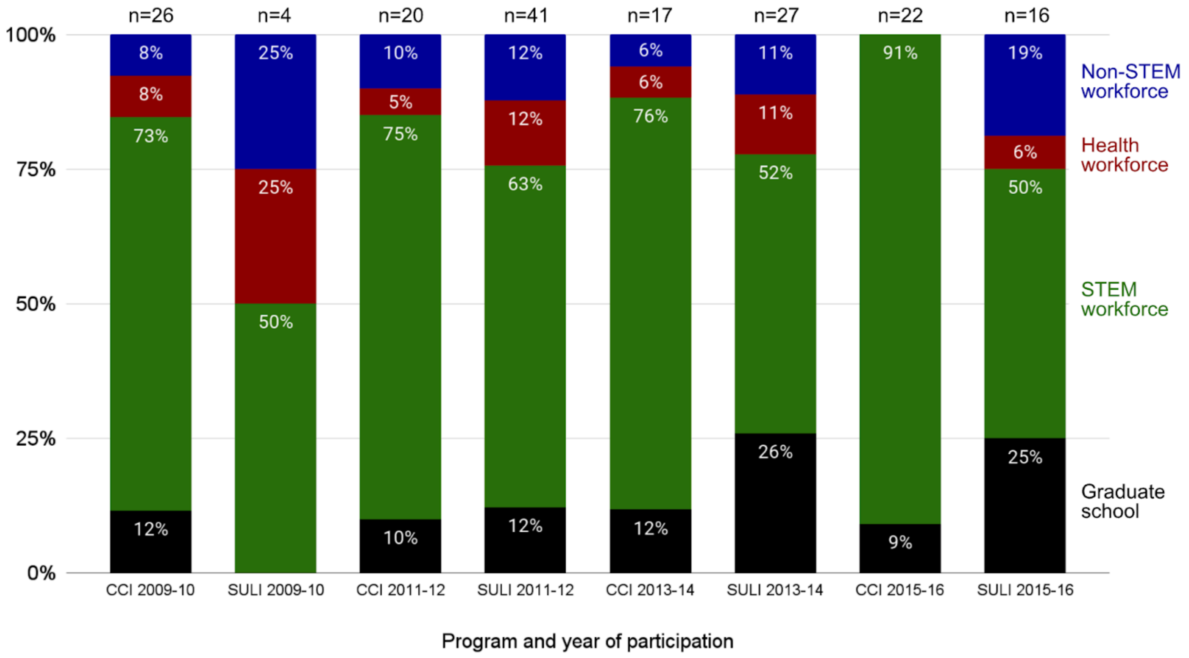
Career pathways for study participants by program



Note. For SULI alumni – who were first- or second-year undergraduates attending baccalaureate granting institutions at the time of their internship – 64 (71%) are on a STEM career pathway, 12 (13%) are on a health career pathway, and 14 (16%) are on a non-STEM career pathway. For CCI alumni – who were community college students during the internship – 76 (88%) are on a STEM career pathway, five (6%) are on a health career pathway, and five (6%) are on a non-STEM career pathway.

Figure 2.5

Current academic and career activity for study participants by time frame and program



Note. The graph shows which percentage of the CCI and SULI participants from a 2-year time frame are currently attending graduate school (any program type), or employed in the STEM, health, or non-STEM workforces. The time frames included are 2009-2010, 2011-2012, 2013-2014, and 2015-2016.

Limitations

Selection bias

It is common for “selection bias” to be cited as a limitation of studies that examine the impacts of internships and UREs. This concept refers to a scenario in which the students who apply to and/or participate in a program are among the students who have a greater than average chance of academic and professional success. For example, students who participate in a STEM internship may have (on average) higher grades, relevant experience, and knowledge of STEM careers than their peers. I do not claim that participation in the CCI or SULI programs directly caused the academic or career activities of alumni in the years after they completed these programs. Instead, Study 2 builds on many previous studies that connect participation in mentored internships and research experiences with increased confidence and interest in STEM, higher rates of STEM degree completion, and persistence in STEM fields (e.g., Eagan Jr et al., 2013;

Gamage et al., 2022; Hernandez et al., 2018b; Higgins, 2013; Hirst et al., 2014; Jelks & Crain, 2020; Leggett-Robinson et al., 2015; Nerio et al., 2019; Prunuske et al., 2016).

Demographic data collection

During the initial collection of demographic information from program participants, individuals were given the opportunity to select only one option related to race/ethnicity, including "two or more races," which is a commonly used demographic category on many academic and professional records, surveys, etc. However, this category is not descriptive enough to allow for accurate separation of all participants into the commonly used "underrepresented minority" category, which generally includes individuals from the following groups: Alaska Native, Black/African American, Hispanic/Latinx, Native American, Native Hawaiian or other Pacific Islander (e.g., Robnett et al., 2015). Without this information, the individuals in the "two or more races" category are aggregated together, limiting the accuracy of data analysis related to race/ethnicity.

Survey response rate

As part of the data collected for this study, CCI and SULI alumni were asked to respond to survey questions, but "nonresponse error" – where not all of the individuals in the study population have provided a response – is one limitation of Study 2 (Ponto, 2015). Out of the individuals included in this study, 41 out of 86 (48%) CCI alumni and 57 out of 90 (63%) SULI alumni responded to survey questions about their interest level in working for LBNL or another DOE national laboratory or facility in the future. A 2019 study by Hendra and Hill suggests that a response rate of 80% (often used in federal reports) may not be necessary to ensure generalizable results. However, I recognize that "response bias" may limit the generalizability of these findings, because the smaller group of program alumni who responded to questions about their interest level in working for LBNL or another DOE national laboratory or facility may not be representative of the perspectives of all program alumni.

Although not all of the program alumni responded to these survey questions, the groups who did respond have a demographic makeup (as described in the "Data collection" section) to the full group (shown in **Table 2.1**). Although my goal was to get the highest response rates possible, the demographic similarities between groups reduces the likelihood that the responses would be different if every individual had responded (Hendra & Hill, 2019).

Discussion

Academic and career trajectories of community college STEM majors

In the U.S., the majority of STEM professional development opportunities for undergraduate students are a) hosted by baccalaureate granting institutions, or b) involve partnerships between community colleges and baccalaureate granting institutions located near each other (Draganov et al., 2023; Nerio et al., 2019). The findings from Study 2 suggest that – as compared to students attending baccalaureate granting institutions – community college students who engage in STEM professional development activities are likely to persist in STEM careers at similar rates.

I found that CCI alumni transferred and graduated with bachelor's degrees at *higher* rates than expected. Based on data collected from students who attended U.S. community colleges during the time frame studied, an estimated 20-30% graduated with an associate degree and 9-16% graduated with a bachelor's degree within 6 years (CCSSE, 2021; Horn & Skomsvold, 2011; Juszkiewicz, 2020; Sansing-Helton et al., 2021; NCES, 2019). In comparison, 44% of the CCI alumni in Study 2 graduated with an associate degree, and 96% graduated with a bachelor's degree. One-third of alumni were *more* interested in graduating with a bachelor's degree after their participation in the CCI program at LBNL (Coté et al., 2023). These findings add to previous studies that connect STEM UREs with academic and attitudinal benefits for community college participants (e.g., Gamage et al., 2022; McIntyre et al., 2020; Nerio et al., 2019).

Previous studies have shown that few students who enroll in community colleges to obtain a STEM degree have the support to accomplish this goal, especially for Alaska Native, Black/African American, Hispanic/Latinx, Native American, female, first-generation to college, and low-income students (e.g., CCSSE, 2021; Chen, 2013; Hill et al., 2010; Huang et al., 2000; Kokkelenberg & Sinha, 2010; Sansing-Helton et al., 2021; Varty, 2022). More than two-thirds of STEM majors attending community colleges end up "leaving STEM" by selecting a non-STEM major or dropping out of their undergraduate institution (Chen, 2013). The findings in Study 2 suggest that CCI at LBNL has effectively achieved the program goal of supporting students to enter technical careers through retention in STEM academic and career pathways, and at higher rates than SULI. Overall, 88% of CCI alumni and 71% of SULI alumni are on a STEM career pathway.

Longitudinal data about program alumni

A primary goal for this study was to focus on the career pathways of STEM majors attending community colleges, but I found that most alumni from *both* the CCI and SULI programs were retained in STEM through degree programs and/or the workforce. Collectively, 80% of SULI/CCI alumni are on a "STEM career pathway," 77% completed a STEM bachelor's degree, 20% completed a STEM master's degree, and 16% completed a STEM Ph.D. Taken together, the results from Study 2 support previous findings that undergraduates who complete STEM internships and/or research experiences are more likely to *stay* in a STEM major, transfer to a baccalaureate granting institute (if attending a community college), graduate with one or more STEM degrees, and enter a career in STEM (e.g., Amelink et al., 2015; Chang et al., 2014; Dong et al., 2021; Draganov et al., 2023; McDaniel & Van Jura, 2022).

These findings are helpful in understanding the academic and career activities of alumni years after their participation in CCI or SULI, but – like many studies – this is not a "complete picture" of their activities. I was unable to communicate with every individual who completed the CCI or SULI program at LBNL during the 2009-2016 time frame, because much of the contact information on file was outdated at the time of my data collection efforts. This was especially true for those individuals who participated in the program in earlier years (2009-2011). Some individuals were only accessible to us through *temporary* email addresses associated with a college or university that expired once those students were no longer enrolled. Inspired by the National Science Foundation Survey of Earned Doctorates (an annual exit survey of all U.S. doctoral graduates), I recommend that programs administer post-surveys to past participants to a) collect personal email addresses, b) track the completion of higher education degrees, and c) gather information about academic and career activities. To further enhance access to information about academic and career trajectories, I encourage programs to learn more about how their study populations use professional networking websites, such as LinkedIn.

The data in Study 2 about alumni interest in working at a DOE national laboratory is relevant to efforts across the DOE complex to train a diverse group of students and recent graduates through internships and retain some of these alumni as permanent staff at DOE national laboratories and facilities (DOE, 2022; DOE SC, 2020). Based on survey data collected about the career activities and perspectives of past program participants, 65% of alumni expressed interest in working at a DOE national laboratory or other DOE facility, but only 13% of alumni are currently employed at one of these institutions. Although it is impossible to foresee the *future* career activities of the CCI and SULI alumni in Study 2, these findings appear to conflict with a previous estimate that “roughly 50 percent of program participants eventually work at a national laboratory” (Foltz et al., 2011). Thus, there is an opportunity to engage with this population about jobs at DOE national laboratories through long-term communication and engagement.

Conclusions

Improvement of processes for data collection

Although reporting retention and/or graduation rates can be useful in understanding student success at an undergraduate institution, many researchers neglect to distinguish between community college students who "drop out" of school (i.e., leave their undergraduate studies without obtaining any degree), transfer between community colleges, and those who transfer without first obtaining an associate degree (Bahr, 2012; Porter, 2003). In Study 2, if data had not been collected about transferring (versus graduation), and/or the students in the study population were not tracked *beyond* their attendance in community college, it would be possible to conclude that 46 (53%) of CCI alumni “did not graduate.” Instead, 81 (94%) of CCI alumni completed their studies at a community college (with or without obtaining an associate degree), and 78 (96%) of these transfer students completed their studies at a baccalaureate granting institution (by obtaining one or more bachelor’s degrees).

In the “Limitations” section, I addressed data collection related to race/ethnicity related to the “two or more races” category. When this item is selected on a multiple-choice survey question (for which respondents select no more than one choice), respondents do not specify which race(s) they refer to as part of their “two or more races” response. If a program would like to report on the number of participants from racial/ethnic groups historically excluded from (and thus underrepresented in) STEM fields, the “two or more races” data cannot accurately be included in *or* excluded from that count. One alternative is to include a checkbox question (for which respondents select one or more choices), allowing respondents to select the exact combination of categories they choose to report. In the future, it would be useful to collect more descriptive data regarding participants’ identities (e.g., ethnicity/race, gender, LGBTQIA, first-generation to college, disability) and lived experiences, considering the breadth of educational literature published about the role of intersectionality and personal experiences in STEM identity development (e.g., Ellis-Robinson, 2021; Ibourk et al., 2022; Mattheis et al., 2020; Sparks et al., 2023).

Call to action

Collectively, many federal calls to action, DOE reports and strategic plans, and STEM education studies about professional development opportunities for undergraduates include recommendations to collect data about outcomes related to retention in STEM majors, graduation rates, and entry into the STEM workforce. However, most studies do not distinguish between outcomes for students who began their studies at a community college versus a baccalaureate granting institution. Beyond this, what is publicly known (i.e., published in scholarly journals) about the academic and career trajectories of STEM internships and research experiences almost always involves programs hosted at baccalaureate granting institutions. Thus, I encourage educational researchers and scientists from other disciplines to partner with each other to conduct and *publish* work about internships and research experiences hosted at community colleges, DOE national laboratories, companies, and other types of institutions (Collins, 2023; Hora et al., 2017; Lucero et al., 2021). I also advocate for the establishment of partnerships between community colleges and other institutions to provide community college students – who make up nearly half of the undergraduate population in the U.S. – with opportunities to learn about careers in STEM.

Chapter contributions

My co-authors for this work are Astrid Zamora, Julio Jaramillo Salcido, Seth Van Doren, Aparna Manocha, Gabriel Otero Munoz, Esther Law, Colette Flood, and Anne Baranger. Thanks to Laura Armstrong, Katie Blackford, Dianna Bolt, Sara Bourne, Beatriz Brando, Sean Burns, Chris Byrne, Christel Cantlin, Joseph Crippen, Michelle Douskey, Ping Ge, Lloyd Goldwasser, Kris Gutiérrez, Ibrahim Hajar, Nakeiah Harrell, Max Helix, Lady Idos, Terry Johnson, Geri Kerstiens, Kelsey Miller, Laura Pryor, Michael Ranney, Alexis Shusterman, Christina Teller, Matthew Traxler, Michelle Wilkerson, Brieanna Wright, and the Baranger (ChemEd) Research Group at the University of California, Berkeley for their assistance and feedback on this work.

CHAPTER 3

Development of the *Berkeley Undergraduate Research Evaluation Tools Teaching and Mentoring (BURET-TaM)* instrument to identify practices used by scientists with undergraduate researchers (Study 3)

It is common practice for undergraduates in STEM degree programs to participate in discipline-specific research experiences to gain new skills and knowledge, and to explore STEM careers. Similarly, many graduate students are expected to collaborate with undergraduates on a research project, which requires a combination of teaching and mentoring practices. Studies have shown that teaching and mentoring practices can vary dramatically between individuals, and these differences impact the overall experience for undergraduates, for better or worse. However, the details provided in previous studies about STEM research experiences make it difficult to determine which teaching or mentoring practices are being used in a particular learning environment, by whom, and how often. Many scholars have described benefits of understanding how teaching and mentoring activities differ from each other, which supports student learning and well-being, communication between research team members (including undergraduates), and the evaluation of teaching/mentoring quality in STEM research experiences. Study 3 describes the new *Berkeley Undergraduate Research Evaluation Tools Teaching and Mentoring (BURET-TaM)* instrument, which I developed collaboratively with research team members to identify the teaching and mentoring practices used in STEM research experiences. Additionally, I provide definitions for teaching and mentoring for UREs relevant to this new instrument that are informed by the literature and can be used by educational researchers, students, and practitioners alike. I applied the *BURET-TaM* instrument to written reflections from and interviews with 46 graduate students working with undergraduate researchers in faculty-led research teams at the university and/or at the nearby DOE national laboratory, and generated a list of teaching and mentoring practices used by this group. My findings suggest that a) teaching and mentoring practices are often intertwined in this context, b) teaching scientific concepts and processes can support undergraduate learning about how new scientific knowledge is created, and c) research environments can impact student learning, well-being, and success. In the future, departments or research teams could use the *BURET-TaM* instrument to implement training sessions or materials to support scientists and professionals in learning how to teach/mentor undergraduate researchers, or to improve their skills in these areas.

Introduction

For undergraduates taking coursework and/or majoring in STEM, research experiences can provide opportunities to learn new skills and content knowledge, and explore STEM career pathways. This form of active learning in STEM has been found to improve performance for all students, and decrease the achievement gap between Black, Hispanic/Latinx, Native American, Native Hawaiian, Pacific Islander, and low-income students and their peers (Freeman et al., 2014; Theobald et al., 2020). Gains attributed to STEM research experiences can include learning (e.g., content knowledge, laboratory skills), psychosocial (e.g., confidence, identity, self-efficacy), and professional development (e.g., awareness of STEM careers, leadership) outcomes (Krim et al., 2019). There are many different approaches to engaging undergraduates in STEM research experiences, and a distinction has been made between course-based undergraduate research experiences (CUREs) and other types of undergraduate research experiences (UREs). Typically, CUREs take place in a classroom setting that include components of lecture and/or laboratory courses. CUREs include, the following design features considered to contribute to their impact: Use of scientific practices; Discovery; Broadly relevant or important work; Collaboration; and Iteration (Auchincloss et al., 2014, Dolan, 2016; Krim et al., 2019). UREs that are *not* CUREs take place in research settings outside of the classroom, which may include laboratories, field sites, offices, or other physical/virtual collaborative workspaces. Both UREs[11] and CUREs involve students in learning about research through direct engagement in research practices.

A large number of studies in the past few decades have focused on identifying the teaching practices that are most effective for supporting STEM learning and producing desirable outcomes for STEM majors, but, many faculty and scientists do not understand how to distinguish between teaching, mentoring, advising, and supervising (Amundsen & McAlpine, 2009; Ruben, 2020; Titus & Ballou, 2013). If scientists so often juggle these different roles, how can they determine if their **teaching** practices in UREs are effective?

Mentoring during STEM research experiences can impact undergraduate belonging, confidence, identity, interest, and motivation (e.g., Goodwin et al., 2023; Olimpo et al., 2016; Pearce et al., 2022; Romero et al., 2023; Vasquez-Salgado et al., 2023). However, scholars have made the case that mentoring for students and professionals is not well-defined as a concept (e.g., Crisp & Cruz, 2009; Ehrich et al., 2004; Gershenfeld, 2014; Jacobi, 1991; Merriam, 1983). For example, definitions of mentoring are often different between studies, and in some cases conflict with each other (Jacobi, 1991). Without clear definitions and expectations, mentoring theory cannot be applied effectively to research studies and mentor-mentee relationships will be less impactful (Dawson, 2014; Fletcher & Mullen, 2012; Jacobi, 1991). How can scientists expect to provide high-quality **mentoring** to students in pursuit of STEM careers if the concept is not well defined?

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[11] From this point on in the study, the acronym “URE” will be used to describe undergraduate research experiences (UREs) that are not course-based undergraduate research experiences (CUREs), though I recognize that CUREs are one type of URE.

Overview of Study 3

This work is part of the *Berkeley Undergraduate Research Evaluation Tools (BURET)* initiative, which includes multiple projects led by researchers A.M.B., C.N.S., E.M.S., L.E.C., and M.R.H. and colleagues to understand and improve STEM research experiences. Our previous study includes the development of four *BURET Indicators* that describe areas where an undergraduate is expected to integrate their understanding of scientific content and practices during their research experience; and several instruments and scoring guides which assess multiple aspects of undergraduates' poster presentations and written student reflections about the progress of their research project. The *BURET* tools were used to characterize the progression of undergraduate researchers' expertise over the course of their STEM research experience (Helix et al., 2022).

For more experienced researchers, collaborating with undergraduates on a research project requires a combination of teaching and mentoring practices. In this context, it is important for the experienced scientists as well as undergraduate researchers to understand how teaching and mentoring activities differ from each other in order to clarify responsibilities, improve communication, increase the chances of achieving desired outcomes, and support assessment of an undergraduate's progress (Shanahan et al., 2015; Steneck, 2006; Titus & Ballou, 2013). Additionally, clarification and study of the teaching and mentoring provided to Black, Hispanic/Latinx, and Native American students – who receive less career support and mentoring than their peers – is crucial for promoting equity in and access to STEM careers (e.g., Lane, 2016; Morton, 2021; NASEM, 2019; Rainey et al., 2019; Singleton et al., 2021).

As part of Study 3, the new *Berkeley Undergraduate Research Evaluation Tools Teaching and Mentoring (BURET-TaM)* instrument was developed to a) identify teaching and mentoring practices used in UREs and CUREs, and b) support undergraduate learning and scholarship about the impacts of research experiences on undergraduate success. To address the lack of widely used definitions by URE and CURE scholars, I provide definitions for teaching and mentoring for UREs relevant to this new instrument that are informed by the literature and can be used by educational researchers, students, and practitioners alike. In Study 3, I examined the following research questions:

1. Guided by these new definitions[12]*, does the new instrument distinguish between teaching and mentoring of undergraduate researchers?*

2. While working with undergraduate researchers, what teaching and mentoring practices do graduate students use?

3. While working with undergraduate researchers, what barriers to implementing these practices, if any, do graduate students report?

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[12] See "Step 1. New definitions to support research and practice" in the Methods section

Teaching, mentoring, and learning in UREs and CUREs

This review of the literature on UREs and CUREs examines: I) distinguishing features of UREs and CUREs, II) how teaching and mentoring in research experiences support students, III) which teaching and mentoring practices are used in research experiences, and IV) how teaching and mentoring are defined in the literature. Using the Google Scholar and Web of Science search engines, I used the following terms in various combinations to generate a list of published studies that might be relevant for this study: "advise," "advisor," "curriculum," "instruct," "instruction," "instructor," "taught," "teach," "teacher," "teaching," "learn," "learned," "learning," "mentee," "mentor," "mentored," "mentoring," "pedagogy," and "protégé." Two sets of papers were selected for review: 1) highly-cited papers, which are those papers that have been cited the highest number of times, according to the counts generated by Google Scholar, and 2) recently-published papers, which are papers about UREs or CUREs published between 2022 and 2024. From these two groups, papers were excluded if they were only descriptive in nature, and did not include one or more of the following: data from participants about their experiences or perspectives; measurement of learning (or other outcomes); or analysis of previous work. Additional papers were added to the literature review while reading papers in the aforementioned groups, though papers published in the past 5 years were prioritized, to include information about current practices and perspectives. My goal was to leverage what is already known about UREs and CUREs to develop the *BURET-TaM* instrument, which can be used to identify practices used in both UREs and CUREs.

I. Distinguishing features of UREs and CUREs

Who teaches and mentors in research experiences?

Many studies about UREs or CUREs have focused on faculty as instructors and mentors of undergraduate researchers, though it is common for faculty and other STEM professionals to assign graduate students and postdoctoral scholars responsibilities associated with training, guiding, and supervising undergraduate researchers (Aikens et al., 2016; Ann Mabrouk & Gapud Remijan, 2023; Bradley et al., 2017; Dolan & Johnson, 2010). This "multi-mentoring team" has the potential to a) provide undergraduates with *more* support and unique benefits, b) relieve pressure from primary investigators (PIs) to spend more time with undergraduates than they have available; and c) prevent undergraduates from feeling as though they are working on projects with too little direction (Bourne et al., 2021; Bradley et al., 2017; Eagan Jr et al., 2011; Limeri et al., 2019; Mireles-Rios & Garcia, 2019; Sorte et al., 2020). I argue that, in order to accurately study the impact of UREs or CUREs, it is important to know who is involved in teaching and mentoring, what practices they are using, and how these relate to the intended learning and career-related goals of the experience.

The terminology to describe the individuals involved and the practices used during research experiences differs between studies about UREs and CUREs. Many studies describe scientists as "mentors" while working with undergraduate researchers as part of a research team and "instructors" or "teachers" when working with undergraduates as part of a research-based course, or highlight this as a perspective of their study population (e.g., Auchincloss et al., 2014; Bangera & Brownell, 2014;

Buchanan & Fisher, 2022; DeChenne-Peters & Scheuermann, 2022; Gerringer et al., 2023; Shortlidge et al., 2016).

In studies about UREs, the individuals who work with undergraduate researchers are usually identified as faculty, professionals, postdoctoral scholars, graduate students, and other undergraduates (e.g., Coté et al., 2023; Dolan & Johnson, 2009; Lopatto, 2004; Romero et al., 2023). By far, “mentor” is the most common term used in the literature about UREs to refer to those individuals who advise, collaborate with, mentor, supervise, support, teach, train, and work with undergraduate researchers on research projects. Some studies use multiple terms to describe this relationship during UREs, highlighting its complexity (e.g., Lopatto, 2007). For example, some postdoctoral and graduate students who worked with undergraduate researchers described “teaching” students during UREs, but still framed their “mentoring” activities during UREs as being separate and supportive of their “teaching” activities in a classroom setting (Dolan & Johnson, 2009). In STEM classroom settings, undergraduates may perceive their instructors to be “mentors” when they offer emotional support beyond their teaching role (Atkins et al., 2020).

In studies about CUREs, the individuals who interact with undergraduates enrolled in the course are usually faculty and graduate students (e.g., Auchincloss et al., 2014; Freeman et al., 2023; Goodwin et al., 2023; Shortlidge et al., 2016). An influential paper published in 2014 describes the nature of collaboration in a CURE as being between students, teaching assistants, and course instructors, as compared to collaboration in a research internship (a type of URE), which is between students and mentors in a research group (Auchincloss et al., 2014). A 2016 study by Shortlidge and colleagues about the perspectives of faculty who have developed and taught CUREs includes some description about teaching practices and activities used, and the benefits of CUREs for faculty. Nearly one third of the faculty they interviewed expressed the unique challenge of “juggling” multiple roles of instructor, advisor, and mentor while teaching a CURE (Shortlidge et al., 2016). It is possible that graduate teaching assistants – who are responsible for much of the laboratory-based instruction at baccalaureate granting institutions – feel a similar way (Kepple & Coble, 2020). Freeman and colleagues (2023) make the case that it would be challenging to integrate mentoring into CUREs because of the limited time instructors have to engage in mentoring activities.

Taken together, this separation of terms based on the learning environment described is one possible reason why CURE literature is heavily focused on teaching practices while the literature about research experiences outside the classroom primarily uses language related to mentoring. Although results from many studies indicate that teaching activities occur in classroom settings, CUREs, and UREs, the term “mentoring” is typically used by authors as a “catch-all” term to include a variety of activities, including both mentoring and teaching practices.

Group size

Generally, in a CURE there are few instructors teaching an entire class of students, and in a URE one or more people from a single research group works with a small number of students (e.g., Auchincloss et al., 2014; Jordan et al., 2014). For example, the lab sections of a chemistry CURE enrolled 16-20 undergraduates, who were taught by one faculty instructor and two graduate teaching assistants (Bixby & Miliauskas, 2022). In a microbiology-focused data science CURE, 60 undergraduates were taught by 2 instructors and 4 graduate teaching assistants with disciplinary expertise (Sun et al., 2022). Most studies about UREs do not specify the number of research team members working with a particular undergraduate, though it is common knowledge that the number of team members varies between groups. In the event that an undergraduate researcher works “daily” with a PI or postdoctoral researcher, for example, the other team members may also engage in practices to guide, mentor, supervise, support, teach, or train them (e.g., Aikens et al., 2016; Ann Mabrouk & Gapud Remijan, 2023; Hayward et al., 2017).

Time on task

Many chemistry CUREs engage students in a cohesive research project for 4 to 5 weeks, which gives students between 12 and 20 hours of “lab work” (Kerr & Yan, 2016). In a biology CURE, Freeman and colleagues (2023) reported that “students only spent 23 hours working in the lab” over the course of one semester. A cancer biology CURE engaged undergraduates in a research project for 4 hours each week, for 10 weeks (Brownell et al., 2015). In a data science CURE, students reported spending an average of 5 to 6 hours per week on their research projects, for 4 consecutive weeks (Sun et al., 2022).

In general, formal UREs that span one semester have a duration between 8 and 10 weeks in summer terms, and 14 to 16 weeks in spring and fall terms (Tan et al., 2022). Although many UREs engage undergraduates in activities for 20 to 40 hours a week, some programs include other activities to support learning and career development, such as field trips, lectures/seminars, programming tutorials, training workshops, (Tan et al., 2022). Studies have shown that a higher weekly time commitment and duration in UREs contributes to STEM degree completion, entrance into the STEM workforce, and graduate school attendance (e.g., Chamely-Wiik et al., 2023; Hernandez et al., 2018b). Undergraduates who participated in a URE for longer than one semester were more confident in their technical skills, data interpretation, communicating research results to others, and working in a professional environment (Haeger & Fresquez, 2016). Engineering majors who participated in a URE for 4 or more semesters viewed their research experience as “extremely important,” and they found that students who participated in research for a shorter duration rated their research experience as less important (Zydney et al., 2002).

The large time commitment required by faculty and professionals is often cited as a challenge to the implementation of both UREs and CUREs, though a close working relationship between faculty/professionals and students is believed to produce positive outcomes when there is a good rapport between them (e.g., Bixby & Miliauskas, 2022; Freeman et al., 2023; Nolan et al., 2020; Zydney et al., 2002). Some studies about CUREs describe access to mentors as a major benefit to undergraduates, in support of their resilience, development as scientists, retention in STEM, and ability to navigate challenges faced during their studies (Auchincloss et al., 2014; Buchanan & Fisher, 2022). Framed as “an important challenge for the CURE research community,” Freeman and colleagues (2023) remark that CURE instructors will generally not have enough time to implement mentoring practices, especially if offered as a “large-enrollment introductory" course. Similarly, a study about an analytical chemistry CURE described the decision to limit the amount of time spent discussing CURE projects in class, to allow enough time for "regular instruction of standard labs" (Kerr & Yan, 2016). This trade-off between laboratory instruction and research project planning highlights a potential challenge for CURE implementation.

Proximity to existing research agendas

In the natural sciences, CUREs are generally expected to involve undergraduates in "discovery," and projects should be a) connected to a larger discipline-specific body of knowledge, b) novel, and c) relevant or interesting to external stakeholders (e.g., Auchincloss et al., 2014; Buchanan & Fisher, 2022; Dolan, 2016). This is one of five major components of CUREs identified and agreed upon by influential scholars in the field, and addressed in subsequent studies about CUREs in a variety of STEM disciplines (e.g., Auchincloss et al., 2014; Cooper et al., 2019a; Corwin et al., 2015a; Deka et al., 2023; Spence et al., 2022; Sun et al., 2022). The biology CURE studied by Brownell and colleagues (2015) provided undergraduates with a research goal – to characterize mutant versions of the transcription factor p53 that were previously identified in human tumors – and multiple research questions to explore. The answers to these research questions are unknown, and they are unrelated to any faculty research at the institution (Brownell et al., 2015). During the SEA-PHAGES course, undergraduates engage in research projects that allow them to isolate bacteriophages, visualize them with electron microscopy, annotate the genome of one bacteriophage, and make predictions about protein function (Jordan et al., 2014). This topic is well-suited for undergraduates, because bacteriophages are easy to isolate from field samples, have small genomes (making sequencing and annotation simple), are genetically diverse, and scientists "know remarkably little about them" overall (Hanauer et al., 2017; Jordan et al., 2014). Thus, undergraduates have a high likelihood of studying a previously undiscovered bacteriophage, and CURE instructors are not constrained by the agendas of research faculty at their institution (Jordan et al., 2014).

In a study about the development of CUREs in pure mathematics, the authors describe some challenges with implementing the "discovery" component (Deka et al., 2023). They make the case that it is important for undergraduates to "make discoveries" about mathematical concepts beyond what is covered during undergraduate coursework, though these discoveries would "not [be] new to the mathematical community" (Deka et al., 2023). Similarly, there are some CUREs in which undergraduates develop their own novel research projects in alignment with the content knowledge and/or research methods taught during the course. In the *General Chemistry and Quantitative Analysis* CURE, pairs of undergraduates develop their own unique research project, and then conduct experiments, collect results, write a report, and present a poster for this project (UC Regents, 2023). In the *Passion-Driven Statistics* CURE, undergraduates identify a topic of interest and then complete a literature review to refine their research questions, with the goal of identifying a question that has yet to be answered by the scientific community (Spence et al., 2022).

The majority of UREs, on the other hand, engage undergraduates in activities that advance an established research project, or a new project that was planned prior to recruiting the undergraduate (e.g., Ann Mabrouk & Gapud Remijan, 2023; Romero et al., 2023; Tan et al., 2022; Trott et al., 2020). It is common for undergraduates to develop their own research project in the the social sciences and humanities, while the majority of UREs in science and mathematics engage undergraduates in new or existing projects developed by faculty-led research groups (Craney et al., 2011). In the Quantitative Sciences Undergraduate Research Experience (QSURE) program, faculty "proposed a quantitative research project" that was appropriate for an undergraduate who had completed one statistics course, and could be completed in eight to ten weeks (Tan et al., 2022). A steering committee selected which QSURE applicants would be placed with these faculty members, after considering faculty input and applicant skills and interests (Tan et al., 2022). In a study about a chemistry/chemical biology research experience for undergraduates (REU) – a well-established URE program funded by the National Science Foundation – undergraduates selected for participation worked on "well-defined research projects" (Ann Mabrouk & Gapud Remijan, 2023). In this case, faculty advisors determined which of their graduate students would work with a particular undergraduate, based on a "match" between interests, availability, and graduate students' current projects (Ann Mabrouk & Gapud Remijan, 2023).

A smaller number of URE studies reported that undergraduates were tasked with creating their own research projects. In a study about UREs for pre-service teachers (PSTs), a professor of curriculum and instruction guided the PSTs to develop their own STEM curricula, and assessment tools "validated by three science education experts" (Pearce et al., 2022). To study the impacts of their curriculum, the PSTs collected and analyzed their own data and presented their results at a state conference (Pearce et al., 2022). In a study about a URE focused on the environment, STEM majors from two different institutions designed their own research projects and collaborated on these projects remotely for 12 weeks (Mathieu et al., 2023).

II. How do teaching and mentoring in research experiences support students?

Increasing knowledge of STEM content

In most cases, studies about UREs include data about undergraduates' own perceptions of the content knowledge they learned, though some studies use direct measures such as quizzes or exams (e.g., Haeger et al., 2020; Tan et al., 2022). For example, Tan and colleagues (2022) found that most undergraduates believed that they learned content knowledge related to genetics/genomics, cancer, epidemiology, and ethics from a quantitative sciences URE. Two instruments have been developed to assess undergraduate skill in applying content knowledge to a research project, assessed through written responses and poster presentations (Helix et al., 2022). In a study about a statistics URE, students reported their belief that they learned more about statistical methods and skills through completion of "real-world" projects (Nolan et al., 2020). Multiple studies have reported a positive impact of UREs on undergraduates' grade point averages (GPAs), especially for those with multiple semesters of experience (Brown et al., 2020; Chamely-Wiik et al., 2023; Slovacek et al., 2012).

When compared to "traditional" laboratory courses, CUREs can be an effective way to teach undergraduates content knowledge, and connecting this knowledge to technical skills and real-world applications (Bixby & Miliauskas, 2022; Freeman et al., 2023; Kerr & Yan, 2016; Olimpo et al., 2016). Similarly, Freeman and colleagues (2023) argue that traditional laboratory courses may not be sufficient to support learning of scientific content. At the University of California, Berkeley, the second semester of *General Chemistry and Quantitative Analysis* is a CURE that introduces new content such as chemical kinetics, stoichiometry, thermochemistry, quantum theory (UC Regents, 2023). Studies most often investigate undergraduate learning of content knowledge by comparing scores on quizzes, mid-terms, exams, and other in-class assessments between "matched" groups of students based on factors such as school, course subject, academic level, major, gender identity, race/ethnicity, and first-generation to college status (e.g., Freeman et al., 2023; Jordan et al., 2014, Olimpo et al., 2016).

Learning technical and research skills

Undergraduates can be motivated to participate in STEM research experiences by the desire to learn new technical and research skills on new or existing research projects (Craney et al., 2011; Coté et al., 2023). Examples of research and technical skills commonly described as being taught to undergraduates during UREs are: proficiency in laboratory or research techniques, data analysis, interpretation of results, searching for relevant literature, understanding how to read and apply primary literature, experimental design, technical writing, and presenting at meetings or poster sessions (e.g., Bauer & Bennett, 2003; Craney et al., 2011; Kardash, 2000; Linn et al., 2015; Lopatto, 2004; Vasquez-Salgado et al., 2023; Zydney et al., 2002). Through interviews, the authors of a longitudinal study found that some undergraduates learned technical skills during a geosciences URE that were helpful in their subsequent graduate studies or jobs, such as computer modeling and data analysis (Trott et al., 2020). Through structured surveys about a URE designed to train undergraduates in quantitative methods, all undergraduates believed that they were highly competent in data analysis and coding skills by the end of the program (Tan et al., 2022). One study compared the impacts of structured and unstructured UREs, and found that the structured URE – which required undergraduates to write a research proposal and these and give formal research presentations to peers and faculty – and found that these differences may have enhanced undergraduate development of skills related to presenting, reading relevant literature, and interpretation of scientific findings (Zydney et al., 2002). To support undergraduates "who may not otherwise participate in research," some institutions offer courses about research proposal development and discipline-specific methods, as preparation for UREs (Cobian et al., 2024).

Typically assessed through self-report data from undergraduates, some studies document the research and technical skills undergraduates learn during CUREs (e.g., Bixby & Miliauskas, 2022; Borlee et al., 2023). Examples of new skills taught during CUREs are: experimental design, laboratory techniques – such as micropipetting, pH measurement, redox titration – problem-solving, data analysis, and data visualization (Brownell et al., 2015; Helix et al., 2022; Jordan et al., 2014; Kerr & Yan, 2016; Olimpo et al., 2016). During the first 10 weeks of an analytical chemistry CURE, instructors taught students to perform laboratory techniques (e.g., pH measurement, redox titration) and then students completed their laboratory activities in pairs (Kerr & Yan, 2016). A key focus of the year-long *Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science* (SEA-PHAGES) course was to teach undergraduates research methods, experimental design, and how to analyze data, and focused *only* on the biological content knowledge necessary to advance the research projects (Jordan et al., 2014). After completing a chemistry CURE, undergraduates reported increased skills in data analysis, supporting claims with evidence, and scientific writing, all of which were “supported by notable improvement in lab report scores” (Bixby & Miliauskas, 2022). Undergraduates who completed a cancer biology CURE believed that course activities involving data analysis and collaboration were *most* helpful to learning how to think like a scientist (Brownell et al., 2015).

Understanding what it means to “do” STEM research

One of the key elements of UREs that confers benefits to undergraduates is the “immersive” nature of the experience, which can increase their understanding of what it’s like to conduct scientific research (e.g., Gamage et al., 2022). Through regular collaborative interactions with more experienced scientists in their workspaces, laboratories, or facilities, undergraduates learn discipline-specific practices in context (Krim et al., 2019; Robnett et al., 2015; Trott et al., 2020). The idea of “legitimate peripheral participation” from situated learning theory describes the way in which people learn through engagement in the sociocultural practices of a particular community (Lave & Wenger, 1991).

In a 2007 study, faculty articulated the role of UREs in supporting undergraduates to “become” scientists through the development of new attitudes and behaviors that would contribute to their success in science (Hunter et al., 2007). Traits associated with “thinking and working like a scientist” include understanding how scientific knowledge is created; making connections between content from science courses and research projects; and scientific problem-solving skills (Hunter et al., 2007). In a 2020 study by Faber and colleagues, undergraduates conceptualized research and traits of researchers as: research results in discovery (e.g., creating new knowledge, studying the unknown); research includes dissemination (e.g., presentations to others, publishing studies); research findings are integrated into society (e.g., better humanity, improve a process); and researchers demonstrate self-regulation (e.g., desire to learn, working independently).

In a biology CURE, undergraduates were taught to carry out research protocols, collect data and visualize data, and connect project data to “important scientific questions” (Freeman et al., 2023). When compared to students who completed a “traditional” laboratory course, the CURE students better understood “what doing science entails” at the end of the semester (Freeman et al., 2023). A series of brainstorming sessions were integrated into a cancer biology CURE to enable undergraduates to contribute to the overall strategy for answering a research question, and “experience the benefits of having multiple people working together to solve a problem” (Brownell et al., 2015). Additionally, there were three group discussions – facilitated by instructors – during which undergraduates compared data collected from the same p53 mutants, drew conclusions, discussed possible sources of error, and determined which data would be classified as outliers (Brownell et al., 2015). These and other activities were included in the CURE to teach students to “think like a scientist,” and they found that students who completed the course exhibited more expert-like views about what it means to think like a scientist (Brownell et al., 2015). After completing a biology CURE, students reported (through open-ended survey responses) that they had increased appreciation for and insight into what it means to “do” science (Olimpo et al., 2016).

Many studies about CUREs have used the Laboratory Course Assessment Survey (LCAS), which was developed by Corwin and colleagues (2015b) to measure the extent to which undergraduates perceive that collaboration, discovery and relevance, and iteration are present in a particular CURE. Each of these activities are common features of STEM research – addressing new questions through generating and testing hypotheses (discovery); working on projects of interest to the larger scientific community (relevance); working with others to solve complex problems (collaboration); and the process of trying out new problem solving strategies, failing, and re-trying (iteration) – though there are discipline-specific nuances between fields (Auchincloss et al., 2014). For example, the following is a question on the LCAS about collaboration: *In this course, I was encouraged to discuss elements of my investigation with classmates or instructors* (Corwin et al., 2015b). All undergraduates who completed a data science CURE reported weekly communication with others about their research project, but some felt that they had few opportunities to provide “constructive criticism” to their peers (Sun et al., 2022).

Influencing attitudes toward STEM

Many recent studies about the impacts of UREs and CUREs have included findings about the socioemotional impacts of these experiences on undergraduates. For example, some undergraduates who participated in a geosciences URE felt more confident, independent, and prepared for their career (Trott et al., 2020). In a study about a bridge program that includes undergraduate research, Black, Hmong, Latinx, and mixed race program participants learned about the positive benefits of mentoring and were inspired to mentor others themselves (Luedke et al., 2023). Transfer students who participated in a geosciences URE reported feelings of confidence, excitement, self-efficacy, and responsibility for their projects (Gamage et al., 2022).

A study about SEA-PHAGES focused on the role of graduate teaching assistants as both teachers and mentors, and examples of practices associated with both roles are described (Goodwin et al., 2023). They found that positive support from graduate students during a CURE is likely to lead to increased interest, motivation, and more positive experiences for undergraduates overall (Bradshaw et al., 2023; Goodwin et al., 2023). Over the course of a semester, undergraduates enrolled in a biology CURE reported larger gains in enjoyment, career motivation, self-determination, and self-efficacy than their peers in a “traditional” laboratory course in the same subject (Olimpo et al., 2016). As a result of participating in a chemistry CURE, most students found the CURE project to be interesting and exciting (Kerr & Yan, 2016). Most undergraduates who developed and carried out their own research projects as part of a CURE felt *more* likely to participate in research activities following the course (Kerr & Yan, 2016). Additional studies reported student gains in undergraduate STEM self-efficacy, STEM identity, and positive feelings about STEM following their completion of a CURE (e.g., Bixby & Miliauskas, 2022; Borlee et al., 2023; Vater et al., 2020).

Making connections between research projects, culture, and society

In support of undergraduate success, Cobian and colleagues (2024) make the case that institutions can support inclusion in science by adopting culturally relevant approaches to "science training activities." For example, some of the institutions featured in their study focused on leveraging students' previous experiences and areas of interest when engaging them in research activities (Cobian et al., 2024). Two related studies examine the impacts of BUILD PODER, a biomedical URE funded by the National Institutes of Health (NIH) designed to support undergraduates at California State University, Northridge from groups historically excluded from STEM based on race/ethnicity, disability status, and socioeconomic status (Camacho et al., 2021; Vasquez-Salgado et al., 2023). A unique feature of this multi-year URE is the implementation of a culturally affirming curriculum for undergraduates and faculty, designed to teach participants about "structural, cultural, and gender inequities in science," and provides undergraduates with opportunities to incorporate their cultural assets into program activities and deliverables (Camacho et al., 2021). This curriculum design aligns with previous research about leveraging students' culture, identity, knowledge, and experiences with new information in a learning environment (e.g., Denton & Borrego, 2021; Esteban-Guitart & Moll, 2014; Wilson-Lopez et al., 2016). As first-year undergraduates, there were no differences in science identity levels between groups, but by senior year the science identity of undergraduates who completed BUILD PODER were significantly higher than those with a faculty mentor outside the program and those with no faculty mentor (Camacho et al., 2021).

Supporting the achievement of students' academic and career goals

Aligned with STEM majors' exploration of their discipline, many are compelled to participate in a research experience because of their curiosity about graduate schools and/or careers in a particular field (e.g., Coté et al., 2023; Trott et al., 2020). As compared to their peers with similar backgrounds and academic achievement, undergraduates who participate in UREs are more likely to graduate with a bachelor's degree and pursue a Ph.D., especially when researchers share information with them about graduate school and career pathways (Camacho et al., 2021; Haeger et al., 2024; Romero et al., 2023; Trott et al., 2020; Wilson et al., 2018). Latinx undergraduates who participated in a biomedical URE for 2 years were more likely to report their intention to pursue a career in science than undergraduates with access to a faculty mentor outside of a URE (Camacho et al., 2021). For those undergraduates who establish a strong rapport with their research mentors and team members, one major benefit of participating in UREs is the collection of interpersonal relationships that undergraduates can leverage to support their academic and career goals (Romero et al., 2023; Trott et al., 2020; Zydney et al., 2002). This network of professionals can be called on multiple times over the course of an individual's career, if communication is maintained over time.

Studies about CUREs typically focus on the ways in which these courses impact undergraduate academic success, which is likely due to the emphasis on teaching in these learning environments. A study about the Freshman Research Initiative (FRI) found that, As compared to peers with similar backgrounds, undergraduates who completed the Freshman Research Initiative (FRI), a three-course CURE program, were more likely to graduate with a STEM bachelor's degree (Rodenbusch et al., 2016). The findings from a recent study suggest that – for Black, Latinx, and Native American undergraduates – participation in a one-semester CURE may increase the likelihood that they complete a STEM degree (Bradshaw et al., 2023).

Although longitudinal studies about the impacts of CUREs are less common than those about UREs, there have been some studies about the career-related impacts of CUREs. Several studies showed that academic/career goals and "clarification" of careers were some of the topics least emphasized or impacted by completing a CURE (Bixby & Miliauskas, 2022; Goodwin et al., 2022; Martin et al., 2021). The authors of a study about a microbiology CURE did not record gains in STEM career interest over the course of a semester, but noted that undergraduates *entered* the course with high interest levels (Borlee et al., 2023). In a study about a SEA-PHAGES CURE, some undergraduates believed that their university hosts CUREs for self-serving reasons, to obtain additional funding and use undergraduates as "free labor" to advance research (Goodwin et al., 2022). These findings highlight the importance of communication between instructional team members about course goals (Goodwin et al., 2022).

Summary

Each of these potential outcomes for undergraduates can be achieved through the use of effective teaching and mentoring practices during UREs and CUREs, and aligns with at least one the codes contained in the instrument developed for Study 3 (see **Table 3.4**). Although outcomes from STEM research experiences come from a combination of teaching, mentoring, and other factors, the following are some – but not all of the – connections between the literature in this section and the instrument developed as part of Study 3: undergraduates learn **STEM content knowledge** through teaching in the Conceptual Domain, learn **technical and research skills** through teaching in the Procedural Domain, learn **what it means to "do" research** in STEM through teaching in the Epistemic Domain and career development mentoring, develop their **attitudes toward STEM** through student-centered teaching and psychosocial development mentoring, make **connections between research projects, culture, and society** through teaching in the Epistemic and Social Domains and psychosocial development mentoring, and progress toward **achieving their academic/career goals** through career development mentoring.

III. Characterizing teaching and mentoring practices used in research experiences

Overall, undergraduates are receiving benefits from research experiences, in terms of their discipline-specific content knowledge, attitudes toward STEM, academic success, and STEM persistence. However, the information included in most studies about CUREs and UREs makes it difficult to determine which teaching or mentoring practices are being used in a particular learning environment, by whom, and how often. For example, one longitudinal study found that more than half of the individuals who participated in the Undergraduate Research Program (URP) at the University of Delaware reported that this experience was important to their decision to attend graduate school (Zydney et al., 2002). It is likely that most research teams participating in the URP engaged in teaching practices, based on students' perception that they learned *new* skills associated with giving presentations, understanding scientific findings, etc. However, it is unclear what mentoring practices were used during URP and with which students. Although mentoring is a key component of BUILD PODER, practices associated with teaching the curriculum and applying this content to participants' own projects is a salient feature of this URE (Camacho et al., 2021; Vasquez-Salgado et al., 2023). From case studies about Latinx undergraduates' experiences in BUILD PODER, study participants most often attributed their progress with learning new skills (e.g., project development, research methods, technical writing, publishing papers) to their science identity level (Vasquez-Salgado et al., 2023).

Varied effects of teaching and mentoring practices on students

Regardless of the learning environment, it is clear from the literature that teaching and mentoring practices can vary dramatically between individuals, and these differences impact the overall experience for undergraduates. Not only can the chosen approach support or hinder STEM learning, but it can also impact undergraduate confidence, enjoyment, engagement, and interest in STEM (Linn et al., 2015). A 2015 review article summarized findings from empirical studies about research experiences and found that the "form of mentoring varies substantially" between UREs (Linn et al., 2015). They describe some aspects of "successful mentoring" when working with undergraduate researchers, including supporting students to: make connections between experimental design, data collection, analysis of results, and science communication; learn content knowledge related to the general topic of study and methods used in the project; develop science identity, confidence, and resilience; learn about the culture of the lab; prepare for their career path of interest (Linn et al., 2015). Other studies document how undergraduates from groups historically excluded from STEM fields have less access to research mentors and UREs than their peers, and mentoring practices differ enough between individuals that they can impact the quality of an undergraduate's experience during a URE (Atkins et al., 2020; Fries-Britt & Holmes, 2012; Pierszalowski et al., 2021). For example, a 2019 study by Limeri and colleagues reported the following "negative" mentoring practices as described by undergraduate researchers: absenteeism, abuse of power, interpersonal mismatch, lack of career support, lack of psychosocial support, misaligned expectations, and unequal treatment. Other studies have identified mentoring practices that have a negative impact on undergraduates during and after UREs, such as being inflexible, unapproachable, unavailable, unkind, or not providing mentees with sufficient guidance (Coté et al., 2023; Gin et al., 2021; Haeger & Fresquez, 2016; Houser et al., 2013; Limeri et al., 2023). In contrast, multiple studies provide examples of mentoring practices that result in positive outcomes for undergraduates pursuing STEM degrees and careers, but report that only *some* people employ these practices. Thought to support undergraduates' development as competent researchers, "active mentoring" is characterized by engagement with mentees at every stage of the research process, including: support with selecting a research project; encouragement to communicate ideas and ask questions; constructive feedback; and offering assistance when needed (Davis & Jones, 2017). Both socioemotional and cultural mentoring practices (e.g., exhibiting friendly behavior, serving as a role model, understanding how mentees' background influences their academic experiences) support undergraduates in refining their STEM-focused academic and career goals (Haeger & Fresquez, 2016). Mentors who share similar values as mentees; discuss diversity; connect mentees' academic interest to their community/culture; provide opportunities for mentees to present at research conferences and co-author papers; and interact frequently with mentees can have a positive impact on Hispanic/Latinx undergraduates' interest in STEM graduate programs and careers (Delgado-Guerrero & Gloria, 2023; Morales et al., 2021; Pedersen et al., 2022). Several studies have illustrated how Black undergraduates develop meaningful relationships with faculty and staff after they perceive a "shift in faculty behavior" characterized by affirmation, closeness, interest, personal connection, and/or trust (Atkins et al., 2020; Fries-Britt & White-Lewis, 2020).

In the STEM education literature, it is common for studies to evaluate the impact of a particular program or activity (e.g., working in faculty labs at a particular institution, a CURE administered for 2 consecutive years, a formal summer internship program). In some of these studies, student learning and psychosocial gains are attributed to the teaching efforts of the faculty, graduate students, postdoctoral scholars, or other STEM professionals associated with the program or activity. However, there is evidence to suggest that teaching practices vary widely between individuals, and have the potential to create different outcomes. Studies about teaching approaches used in STEM classrooms have found that a) exposure to less interactive courses contributes to undergraduate desire to drop the course and/or leave STEM altogether, and b) active-learning teaching practices support STEM retention and undergraduate perception that their instructors care about them (Ellis et al., 2014; Harper et al., 2019; Rainey et al., 2019). While active learning was desired by the highest number of undergraduates, it was also the teaching approach that was encountered least often (Rainey et al., 2019). Through interviews with graduate teaching assistants in biology and science literacy courses, Smith and colleagues (2023) found that those individuals with higher levels of self-efficacy as a teacher used more student-centered than teacher-centered approaches. One study about the impacts of a CURE did not collect detailed information about the teaching practices used by course instructors, but the authors have observed "very different teaching styles" between instructors (Brownell et al., 2015). Their analysis of student responses from different semesters suggest that certain teaching practices led to higher gains in students "thinking like a scientist" than others (Brownell et al., 2015). In a CURE using the SEA-PHAGES curriculum, both first-time and experienced graduate teaching assistants received the following support: training at the beginning of a term about the rationale for teaching a CURE and data about the impacts of these courses on students; training on lab techniques used in the CURE, weekly training and discussion meetings, and access to faculty and lab coordinators for "instructional support, advice, assistance, and mentorship" (Goodwin et al., 2022). Despite this level of support, undergraduates reported that some graduate teaching assistants were not proficient in creating a "positive learning environment," while others were effective at supporting undergraduate collaboration, enjoyment, and productivity (Goodwin et al., 2022). Multiple studies about STEM classroom experiences have shown that some faculty are discriminatory, dismissive, insincere, presumptuous, or unwelcoming during interactions with Black and Hispanic/Latinx students, or employ harmful "color-blind" practices (Fries-Britt & Holmes, 2012; Fries-Britt & White-Lewis, 2020; King et al., 2023; Leyva et al., 2021; Russo-Tait, 2022). As a result, Black students spend time and energy to cope with and/or push back against this exclusionary behavior, which reduces the amount of time they spend on studying and other academic activities (Fries-Britt & Holmes, 2012). These findings support previous studies about "teacher effect" about how different teachers produce measurable differences in K-12 students' self-efficacy and attitudes toward math, motivation, attendance, and academic advancement (Blazar, 2018; Jackson, 2018; Yagan, 2021).

IV. How are teaching and mentoring defined in the literature?

Focus on teaching approaches

There is a general consensus that activities that involve active learning, inquiry, and exploration are important components of science education, though they are not inherently incorporated into all settings in which undergraduates learn science (Freeman et al., 2014; Gill, 2011; Kuh, 2008; Wieman, 2014). A 2018 report from the National Academies of Sciences, Engineering, and Medicine (NASEM) called for the implementation of evidence-based teaching approaches to improve undergraduate STEM education, especially during undergraduates' first two years of college. However, scholars have documented the discrepancy between what is known about impactful teaching in STEM fields and the teaching practices commonly used in undergraduate research settings, experiential projects, and classrooms (Dancy et al., 2014; NASEM, 2016; Tormey et al., 2021; VanWyngaarden et al., 2024).

Wieman (2015) argues that evaluating the quality of teaching requires a clear articulation of the desired outcomes for students, rather than a teacher's values or traits. In national reports and individual studies, scholars more commonly define concepts such as "effective teaching," "inclusive teaching," or discuss teaching approaches thought to enhance the efficacy of STEM coursework, professional development experiences, and learning in various contexts (e.g., NASEM, 2018). Some scholars argue that the definition of "teaching" should be expanded beyond activities during lecture and laboratory courses, to include research and other creative projects that undergraduates can engage in (e.g., Hu et al., 2008). Taken together, I believe that a working definition of "teaching" in the context of scientific UREs and CUREs would support student learning, communication between students and teachers, and evaluation of teaching quality in these learning contexts.

Developing a consensus about what "mentoring" means

For decades reports and articles have argued that having a clear definition of the term "mentoring" would support creation of new tools to assess mentoring, development of expectations and training for mentors, research to determine the impact of specific mentoring practices on desired outcomes, and formal recognition of excellence in mentoring (e.g., Fletcher & Mullen, 2012; Jacobi, 1991; Mullen & Klimaitis, 2021; NASEM, 2019; Pfund, 2016). However, many peer-reviewed publications that focus on mentoring as a key component of their study design do not offer readers a definition of this concept. Many publications about UREs provide some examples of mentoring practices or cite existing mentoring models, but most do not define mentoring in this context (e.g., Hernandez, 2019; Kardash, 2000; Linn et al., 2015; Lopatto, 2007;

Mohamad Nasri et al., 2023; Pearce et al., 2022; Russell et al., 2007; Vasquez-Salgado et al., 2023; Zydney et al., 2002). Studies about mentoring do not ask study participants to provide a working definition of mentoring, and so it is challenging to compare these perspectives to each other across different contexts (Mullen & Klimaitis, 2021). Sometimes concepts such as “effective mentoring” are introduced and/or defined, but the lack of agreement between studies presents challenges in assessing the impact of mentoring efforts (NASEM, 2018). Many studies describe the skills and abilities that are “taught” to or “learned” by undergraduates during UREs, and it is implied that undergraduates learned these skills as a result of teaching practices used by their “mentors” (e.g., Kardash, 2000; Mathieu et al., 2023; Romero et al., 2023; Vasquez-Salgado et al., 2023; Zydney et al., 2002). Although Kardash (2000) does not provide a definition of mentoring, the author references an assumption about UREs by Hakim (1998) that the interactions between undergraduate researchers and faculty mentors are focused on “the student’s learning.” A 2009 study pushes back against the definition of a mentoring relationship as one in which an “older, more experienced mentor and a younger, less experienced” mentee interact for the benefit of advancing the mentee’s career (Dolan & Johnson, 2009; Ragins & Verbos, 2017). The authors make the case that postdoctoral scholars and graduate students who mentor during UREs are likely engaged in “relationships that are reciprocal and mutual in nature” with undergraduate researchers (Dolan & Johnson, 2009; Fletcher & Ragins, 2007).

As the use of the term “mentoring” becomes more common in literature about higher education, STEM education, and learning sciences, the number of definitions has also increased (Crisp & Cruz, 2009; Mullen & Klimaitis, 2021; Pfund, 2016; Shuler et al., 2021). In Study 3, I hope to address this challenge through the contribution of a working definition of “mentoring” in UREs and CUREs, to support training and evaluation of mentoring quality, and students’ well-being, researcher identity, and long-term retention in STEM.

Theoretical framework

Inquiry-based science education

Study 3 is grounded in an inquiry-based teaching framework, which centers active engagement of students as they learn science, as opposed to relying solely on “passive” participation strategies, which are comparatively ineffective and inequitable (Bradforth et al., 2015; DeHaan, 2005; Kuh, 2008; Theobald et al., 2020; Varty, 2022). To push back against classroom teaching approaches that required students to “memorize facts” as the primary method for learning science, inquiry-based teaching was developed as a way for students to learn that aligned with the ways in which new scientific knowledge is produced, including critique, curiosity, investigation, observation, and revision (Riga et al., 2017).

As an educational concept, “inquiry” is based on constructivism, a philosophical way of thinking about how people learn. Constructivist theorists posit that in order to learn something, individuals construct new knowledge by engagement in activities that include social interaction to produce “shared meaning,” replacement (or integration) of previous knowledge with new knowledge, targeted attention on a specific topic, and the organization of related concepts (Bada & Olusegun, 2015; Fosnot & Perry, 1996;

Gordon, 2009; Mintzes et al., 1997).

Despite the value of inquiry, its exact definition, strategies to support inquiry-based learning, and the most appropriate ways to assess its presence or impact are framed differently depending on the context (e.g., Furtak et al., 2012; Grob et al., 2017; Kogan & Laursen, 2014; Lazonder & Harmsen, 2016; Liu et al., 2008). For example, many assessments used to determine the efficacy of teaching in the undergraduate-level science classroom do not distinguish between the presence of procedural versus conceptual teaching, both of which are valuable in the context of STEM research experiences (Rodriques & Bond-Robinson, 2006). Inquiry is generally regarded as a way to promote the development of students as they learn to “think and act scientifically,” by engaging them in the activities of scientists (AAAS, 1994; National Research Council, 2000). Instead of expecting students to learn science through memorization of facts and principles, inquiry-based approaches provide ways for students to learn through engagement in the types of activities that scientists do, such as making observations, generating research questions, and collecting data.

> Engaging students in kit-based science or lab investigations in and of itself is not inquiry … The kind of inquiry I want us to consider is that which occurs when students examine how scientists have come to know what they believe to be scientific knowledge and why they believe this knowledge over other competing knowledge claims (Duschl, 2003).

Integrated Domains of Scientific Knowledge in teaching

A major goal of Study 3 was to produce an instrument capable of identifying teaching (and mentoring) practices used in UREs and CUREs, and I leveraged the inquiry-based teaching framework as a foundation in developing the teaching themes for this purpose. Based on an analysis of cognitive psychology, learning sciences, and educational research scholarship, Duschl (2003, 2008) presented three “integrated domains” to guide science education (and assessment of learning) efforts: cognitive processes and *conceptual* structures used in scientific reasoning; *epistemic* frameworks requires to create and evaluate scientific knowledge; and *social* processes and contexts that influence communication, representation, and argumentation. Duschl (2003) made the case that assessment of inquiry is made possible through the creation of a learning environment that supports students to engage in inquiry themselves, and includes design elements informed by the three aforementioned domains. For example, a classroom set up to assess inquiry aligned with the Social Domain will provide opportunities for students to make their thinking “visible” through verbal, writing, and visual representations of concepts associated with the inquiry. In this case, a teacher could “ask each student … upon completion of an investigation, to place their data into a class data table on [the] board” (Duschl, 2003).

Having published extensively on inquiry-based teaching and learning, formative assessments, equity in the classroom, and curriculum development, Furtak and colleagues have made recommendations to support the work of educators, researchers, and policymakers (e.g., Ruiz-Primo & Furtak, 2006; Furtak et al., 2008). In a 2009 meta-analysis, Furtak and colleagues presented a framework to describe inquiry-based science teaching that extended the use of Duschl’s initial three domains for assessment of inquiry. The original *epistemic* domain was interpreted to contain two distinct themes, both of which are important to learning science: the process of learning how scientific knowledge is produced, and the “physical things that scientists do,” such as asking scientific questions, collecting data, making graphs, etc. (Furtak et al., 2009). Grounded in the cognitive and social processes students engage in while learning science in an inquiry-based environment, the four Domains of Scientific Knowledge include the *conceptual*, *procedural*, *epistemic*, and *social* domains (Furtak et al., 2012). Additionally, inquiry is supported by the following conditions: student-centered learning; student guidance; making students’ ideas and ways of thinking visible; teacher-designed assessments for learning and providing feedback; and opportunities for students to learn that integrate the domains of inquiry (Duschl, 2003; Furtak et al., 2012; Lazonder & Harmsen, 2016; Linn, 2006).

In Study 3, I use the four domains as named and described by Furtak and colleagues (2012), to describe inquiry-based teaching practices that can be used to support STEM learners. The **conceptual domain** describes teaching practices that engage students with science as a body of knowledge; the **procedural domain** describes teaching practices that utilize the methods of discovery; the **epistemic domain** describes teaching practices that engage students in learning about how scientific knowledge is generated; and the **social domain** describes teaching practices that engage students in discussions with others about the project or work.

Application of inquiry to support teaching and learning

As a body of knowledge, inquiry has been used extensively to create instructional materials to support K-12 science learning (Minner et al., 2010; Riga et al., 2017). Investigations about the efficacy of inquiry-based teaching approaches have focused on improving standardized test scores, increasing students’ conceptual understanding of scientific concepts, and closing the achievement gap between students from different backgrounds (Minner et al., 2010). The four Domains of Scientific Knowledge have most often been applied to science learning in K-12 classroom environments (e.g., Franco & Munford, 2020). Inquiry-based teaching practices and activities that support learning associated with the Epistemic Domain have been widely documented across many educational studies, but less is known about the practices associated with the other domains (Soares & Trivelato, 2019). While teaching scientific concepts is a norm in STEM classrooms, and teaching processes is a norm in laboratory-based courses, neither of these practices is sufficient to engage students in learning aligned with the Epistemic Domain (Furtak et al., 2012; Stroupe, 2015; Ko & Krist, 2019).

As learning environments, STEM research experiences are well-suited for teaching and assessing inquiry-based learning, as they have the potential to involve students in activities that promote inquiry, such as: investigations over extended periods of time; process skills in context; management of ideas and information; and applying the results of experiments to scientific arguments and explanations (Duschl, 2003; National Research Council, 2000). There are a wide range of assessment types educators can use in their “everyday” interactions with undergraduate researchers, in order to support student learning, identify knowledge gaps, and strengthen their working relationship with the student. In the context of UREs, many assessment tools commonly found in STEM classrooms would feel “out of place” and overly formal - administering an exam, for example. In research environments – including laboratories or workspaces – informal formative assessments may be more appropriate, as they can be integrated into collaborative work, progress updates, or other communication between undergraduates and research team members. One such approach to informal formative assessment has been described as an “assessment conversation,” in which educators *elicit* information from students to make their understanding visible or explicit; *recognize* student thinking by evaluating their responses, explanations, or mental models; and *use* information generated from this conversation to support student learning (Ruiz-Primo & Furtak, 2007). If I apply the ideas from Ruiz-Primo & Furtak, (2006, 2007) to a URE setting, the following is an example of an assessment conversation: a) a scientist tasks an undergraduate researcher with *presenting a short update about their latest research data/results at a group meeting*, and the undergraduate gives the presentation; b) the scientist *considers the content of the presentation, and has a conversation with the undergraduate researcher* to address the areas where they have performed well and those areas where improvement is needed - this conversation should explicitly connect the goals of the project and team members, and provide opportunities for the undergraduate to ask clarifying questions and share their perspectives; c) with an understanding of their next steps and goals, the scientist and undergraduate researcher continue to *work together to generate new data/results and/or make progress in the areas they defined* during the conversation, with the goal of promoting understanding and confidence to produce new ideas, data, results, etc.

Study 3 makes several novel contributions to this topic in inquiry-based science teaching, including: a) the application of the Domains of Scientific Knowledge to the context of STEM UREs, b) identification of teaching practices aligned with all four domains that have been used, and c) recommendations to support the implementation of teaching practices across all four domains.

Methods

The development of the *Berkeley Undergraduate Research Evaluation Tools Teaching and Mentoring (BURET-TaM)* instrument involved several stages of work. 1) After summarizing literature about UREs and CUREs, I examined what is known about teaching and mentoring to produce new definitions of these terms that can be applied to STEM research experiences. 2) Members of the research team collected data from graduate students in STEM disciplines who train, collaborate with, and oversee the work of undergraduate researchers in UREs, to learn more about what teaching and mentoring practices they use. 3) The research team reviewed this data, to create themes associated with teaching and mentoring that informed the development of the *BURET-TaM* instrument. The goals were to produce an instrument that distinguished between teaching and mentoring in UREs and CUREs, ensure that the codes were general enough to apply to any STEM discipline, and use this new instrument to analyze data and produce a set of teaching and mentoring practices that have been used with undergraduate researchers.

Step 1. New definitions to support research and practice

Teaching in STEM research experiences

A definition of teaching in UREs and CUREs should consider the desired student learning outcomes, to ensure that evaluation of teaching quality is aligned with these goals (Wieman, 2015). Two major goals of having undergraduates participate in scientific research are to learn science and participate in “doing science.” *Science* is a method by which humans gather and organize information “to understand the natural world,” *learning* is a process that results in “change in [one’s] knowledge, beliefs, behaviors, or attitudes” (and can be done with or without a teacher), and *teaching* practices are used with the intention of “bringing about learning” (Ambrose et al., 2010; Hirst, 1971; National Research Council, 1996). Scientists engage in “doing science” by applying previous knowledge, gathering new information, and generating new knowledge (National Research Council, 1996). Thus, I argue that the act of “teaching science” should include activities that result in student learning about a) the type of information scientists use (content knowledge), and b) the activities through which scientists collect new information and create new knowledge (scientific practices).

I recognize that there are many differences between STEM research experiences, impacted by factors such as discipline, project type, career stage of individuals involved, financial resources, physical or virtual space, institution type, length of time, frequency of interactions between individuals, and overall goals. These differences will impact learning goals, teaching strategies, and outcomes for participants. Additionally, undergraduates themselves will have unique goals, interests, and priorities that will influence the learning environment in UREs and CUREs. With all of these factors in mind, I believe that the following definition is aligned with the literature presented in this study, and is simple enough for scholars, students, and practitioners to use. In general, someone **teaching during a STEM research experience** will be using practices that will result in undergraduate learning about existing scientific content knowledge, the process of collecting new information through discipline-specific methods, and the generation of new knowledge.

Mentoring in STEM research experiences

The conceptualization of mentoring as a development relationship with four stages – initiation, cultivation, separation, and redefinition – is well-aligned with the typical relationship that undergraduates engage in with others as part of a STEM research experience (Kram, 1983, 1988). Of these, the “cultivation” stage most resembles the portion of a STEM research experience during which undergraduates are meeting regularly with the individuals who train and collaborate with them on a research project (Kram, 1983; Mullen & Klimaitis, 2021). During summer research, for example, the cultivation stage is the 8- to 10-week period of time designated to working on the project. This stage of the mentoring relationship involves two major goal-oriented components; **career development** activities that support mentees in refining their career interests, developing themselves as professionals, and achieving their career goals; and **psychosocial development** activities in which address the “psychological and social-environmental” aspects of learning and working in STEM (Ehrich et al., 2004; Fletcher & Mullen, 2012; Kram, 1983).

Undergraduates are motivated to participate in research based on their interest in a scientific field, desire to pursue a research-oriented job or career, goal of making a positive impact on society, etc. – an effective mentor can support undergraduates in exploring these possibilities (e.g., Coté et al., 2023; Gin et al., 2021; Smith et al., 2014). I recognize that each mentor-mentee relationship is unique and influenced by different supports and barriers, such as the presence of a formal agreement, program details, duration and intensity, career stage of individuals, level of closeness, and shared interests. However, someone **mentoring during a STEM research experience** will be engaged in activities to support the career and psychosocial development of undergraduate researchers.

Table 3.1

Definitions of teaching and mentoring generated in Stage 1 of Study 3

Term	Definition
teaching	During a STEM research experience, effective teaching involves practices that will result in undergraduate researchers learning about existing scientific content knowledge (e.g., previously published work, what is known about the topic), the process of collecting new information through discipline-specific methods, and the generation of new knowledge.
mentoring	During a STEM research experience, effective mentoring involves activities to support the career development (e.g., professional development, steps toward achievement of career goals) and psychosocial development (e.g., confidence, identity, self-efficacy) of undergraduate researchers.

Step 2. Data collection

Setting and study participants

Members of the research team collected data from 45 doctoral students and 1 postdoctoral scholar from two institutions located in Berkeley, California: the University of California, Berkeley (UC Berkeley) and Lawrence Berkeley National Laboratory (LBNL). UC Berkeley is a research-intensive public land-grant university with approximately 31,000 undergraduates and 13,000 graduate students enrolled in the 2021-2022 school year (UC Berkeley Office of Planning and Analysis, 2022). LBNL is one of 17 DOE national laboratories located across the country (DOE, n.d.). The University of California manages LBNL for the DOE Office of Science, and at the time of this writing there were approximately 240 faculty, 640 postdoctoral researchers, and 400 students (both undergraduate and graduate) associated with both LBNL and the

University of California (LBNL, n.d.).

Although there is a single postdoctoral scholar in the study population for Study 3, I will hereafter refer to study participants as “graduate students,” as this is a more accurate descriptor of this group. The graduate students’ primary areas of research are as follows: 21 in biology, 20 in chemistry, 4 in physics, and 4 in engineering, 2 in STEM education, and 1 in chemical engineering. Several individuals conduct research that spans more than one discipline. This group is mixed in terms of gender identity, race, ethnicity, and year of study.

Data collection and preparation

In Study 3, members of the research team collected written reflections and interview data from graduate students about their experiences working with undergraduate researchers. Written reflections were generated by graduate students during a workshop about teaching and mentoring undergraduate researchers, which will be described in detail in a future study about the impacts of the workshop. Between two and seven months after the workshop, we (B.B., L.E.C., L.T., and M.R.H.[13]) conducted semi-structured interviews with only those graduate students enrolled as study participants about the teaching and mentoring practices they used with undergraduate researchers. Consisting of both the written reflections and interviews, the combined “transcripts” were reviewed and compared to audio files by B.B., J.K., L.T., L.E.C., and M.R.H. to correct errors and anonymize names of graduate students, collaborators, and other identifiable information. Researchers B.B., C.N.S., J.K., L.E.C., L.T., M.R.H., and Y.W. were involved in the collection, organization, and management of data. The methods used in this study have been approved by the Committee for Protection of Human Subjects (CPHS) at the University of California, Berkeley, under Protocol ID number 2016-02-8360.

Step 3. Data analysis and instrument development

Initial review of data and development of codes

Members of the research team uploaded de-identified transcripts into a shared folder as Google Documents, to allow researchers to review, apply comments (e.g., codes, questions, level of agreement with other coders), and discuss the data in real-time. First, we (A.M.B., E.M.S., L.E.C., and M.R.H.) met as a group to discuss the content of the data collected, and generated initial themes based on information provided by study participants (Braun & Clarke, 2019). For example, some transcripts contained descriptions of the process of training undergraduates in laboratory techniques and data analysis, which we initially coded as “teaching.” Other transcripts detailed how graduate students supported undergraduates who were interested in graduate school, by teaching them about technical writing for publication and editing their application essays, which we initially coded as both “teaching” and “mentoring.” During this stage in the process, we determined as a group that some sections of a

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[13] In this dissertation I am using the Method Reporting with Initials for Transparency (MeRIT) approach as described by Nakagawa and colleagues (2023). For Study 2, L.E.C. = Laleh Cote, B.B. = Bridget Brown, L.T. = Lillian Tian, M.R.H. = Max Helix., C.N.S. = Christiane Stachl, J.K., = Jiho Kim, Y.W. = Yongbo Wang, A.M.B. = Anne Baranger, and E.M.S. = Elisa Stone.

transcript should be coded as teaching or mentoring “goals,” especially for data that was collected early in the semester, when graduate students and undergraduates had only been working together for a short period of time (Kram, 1983; Mullen & Klimaitis, 2021).

Using a combination of inductive and deductive logic, I generated a series of teaching and mentoring codes for the *BURET-TaM* instrument (a codebook), based on the initial themes we constructed, previous work by the *BURET* team about STEM research experiences, literature about UREs and CUREs in STEM, inquiry-based science education, the four Domains of Scientific Knowledge, and the major components of the cultivation stage of mentoring (Auchincloss et al., 2014; Ceyhan & Tillotson, 2020; Creswell & Poth, 2016; Dolan & Johnson, 2009; Duschl, 2003, 2008; Ehrich et al., 2004; Fletcher & Mullen, 2012; Furtak et al., 2012; Helix et al., 2022; Kram, 1983; Krim et al., 2019; Shanahan et al., 2015; Walkington et al., 2020). Researchers A.M.B., E.M.S., L.E.C., and M.R.H. individually reviewed and identified sections of transcripts that described aspects of teaching and mentoring. As a group, we met to discuss the set of *BURET-TaM* codes produced, and discussed our rationale for interpreting specific codes. This allowed us to identify themes mentioned by study participants that were missing from the definitions of each code, but important to the research questions for Study 3.

Finalization of instrument and coding

We (A.M.B., E.M.S., L.E.C.) coded the full transcripts for a subset of study participants and we met as a group to discuss and revise codes until we reached consensus. As part of this process, we labeled sections of text that required discussion between researchers and refined the instrument to align with our interpretation of the literature, theory, or data collected from graduate students (Bloomberg & Volpe, 2018). After the instrument was finalized, I coded all of the transcripts using the final version of the instrument. In some studies, after a codebook or instrument is finalized, researchers will engage in “retroactive coding” to update the original (and now outdated) codes assigned to data sets (e.g., Hemmler et al., 2020). However, as a research team we used Google Documents to produce the codes, and I used MAXQDA[14] to assign finalized codes to each of the 46 transcripts. During this process, the coded Google Documents were consulted if needed, but this often coincided with a real-time discussion with researchers A.M.B. and E.M.S. to determine what code to assign to a particular section of text in a transcript. I used this process of coding the data to generate the themes presented in the Results section, and the final list of teaching and mentoring practices shown in **Tables 3.5 and 3.6**.

Reliability and trustworthiness

These qualitative data sets were coded with the *BURET-TaM* instrument, so I measured “intercoder reliability,” the extent to which two researchers (A.M.B. and L.E.C.) assigned similar codes to the same selection of text (MacPhail et al., 2016). Intercoder reliability is one method used in science education studies to validate coding by calculating the degree of agreement when two researchers apply codes to qualitative data sets (Cheung & Tai, 2021; Gwet, 2014). This method requires a minimum of two

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[14] MAXQDA is a data analysis software program: https://www.maxqda.com/

researchers to apply codes to a subset of the data, and supports the study goal that both coders are “applying the coding frame in consistent ways” (Campbell et al., 2013; O’Connor & Joffe, 2020).

I measured the level of agreement between codes assigned by me (L.E.C.) and one of the other researchers who developed the codes that make up the *BURET-TaM* instrument. This was done by calculating Cohen’s *kappa* (κ) to determine the level of agreement between L.E.C. and A.M.B. Thus, after the codes for the *BURET-TaM* instrument were finalized through discussion with the larger team of researchers, A.M.B. and L.E.C. individually coded a single transcript. κ was calculated for that transcript as 0.60 – indicating that 60% of their assigned codes matched. For example, if A.M.B. coded a segment of text as “teacher-centered” and L.E.C. coded it the same way, this would be marked as an instance of *agreement*. After this, the two researchers had a discussion about how to interpret the final version of the instrument (definitions for specific codes) to code the data. This process was completed for three transcripts. Then, A.M.B. and L.E.C. coded the same three transcripts used in the previous step, and κ was calculated for each transcript a second time (see **Table A3.2** for details). As predicted, the second κ for each transcript was higher, indicating that our discussions contributed to an *improvement* in our abilities, as coders, to apply the instrument to the data with fidelity. This process for codebook development, refinement, and assessment for reliability is aligned with multiple studies about data analysis of qualitative transcripts (e.g., MacPhail et al., 2016; O’Connor & Joffe, 2020).

The transcripts for Study 3 consist of graduate students' written reflections and the text generated from semi-structured interviews. The interview data supported and enhanced our understanding of the themes generated from analysis of the written reflections, providing us with the opportunity to use data triangulation to support trustworthiness (Patton, 1999; Stahl & King, 2020). For example, during interviews graduate students referred to one or more undergraduates they were working with (at the time of the interview), and research team members could look at the written reflections for a detailed description of an undergraduate’s role as part of the larger research team. Interviews provided unique insights and emotional reactions to aspects of graduate students’ working relationships with undergraduates, but the written reflections often provided more technical details about the research projects, methods, and individual tasks assigned to undergraduates. Contributing further to the trustworthiness of this work, I chose to engage in thorough discussions and refinement of the codes, to leverage the extensive expertise of researchers – about UREs, CUREs, STEM learning, educational theory, and teaching/mentoring in higher education – in the creation of this instrument (Yardley, 2017). I dedicated time to observing the graduate students (a larger group than those who consented to participate in this study) in group discussions about teaching and mentoring undergraduate researchers, and generated some field notes which provided me with useful context to assist in my interpretation of the data. Additionally, following the interviews and analysis of transcripts, research team members communicated with study participants to clarify statements they made about teaching and mentoring and ensure that our interpretations were aligned with their intended meaning (Kornbluh, 2015; Thomas, 2017; Yardley, 2017).

The Berkeley Undergraduate Research Evaluation Tools Teaching and Mentoring (BURET-TaM) *instrument*

From my summary and analysis of the aforementioned literature about UREs and CUREs in STEM, inquiry, teaching, and mentoring (e.g., Auchincloss et al., 2014; Duschl 2003; Fletcher & Mullen, 2012; Furtak et al., 2012; Helix et al., 2022; Kram, 1983; Krim et al., 2019; Walkington et al., 2020) and application of the codes to data collected from graduate students, my research team and I have produced the first iteration of the *BURET-TaM* instrument. This instrument contains a set of codes – categorized by their relevance to teaching or mentoring – that can be applied to qualitative data (e.g., text, interviews, open-ended survey responses). As shown in **Table A3.1**, there are codes to differentiate between a goal or practice; the teaching codes include the Conceptual Domain, Procedural Domain, Epistemic Domain, Social Domain, teacher-centered pedagogy, and student-centered pedagogy; and the mentoring codes include career development and psychosocial development.

I envision that this new instrument could be used in a variety of ways. First, instructors, mentors, or programs could apply the *BURET-TaM* instrument to data collected from undergraduate researchers, to determine what teaching and mentoring practices they believe were used by the graduate students, postdoctoral scholars, faculty, or professionals who guided them to contribute to a research project. Similar to my work in Study 3, this instrument could be applied to future data collected from graduate students, postdoctoral scholars, faculty, or professionals, to identify the goals they had and/or the practices they used with undergraduate researchers. Finally, this instrument could be used in the development or assessment of a URE or CURE, to consider how specific learning goals could be accomplished through the use of teaching and mentoring practices.

Results

The findings in this section were generated by applying the *BURET-TaM* instrument (a codebook) to data collected from graduate students' written reflections and interviews. Together these written reflections and interviews provided us with details about the research projects that undergraduate researchers contributed to; their learning goals for the undergraduates; their perceptions about undergraduate understanding of the research project; activities they planned for undergraduates; their teaching and mentoring approaches; and the nature of interactions between undergraduates and research team members. Most graduate students worked with undergraduate researchers in “faculty labs” at a university, and the other worked as part of research teams at the DOE national laboratory located nearby. Some of these undergraduates were supported through formal programs in the summer or academic school year, while others worked with research teams that had recruited them for these activities in other ways (e.g., expressing interest via email, inquiring about research opportunities by attending office hours with a graduate student instructor or faculty member).

Teaching is addressed in Section 1, and the findings associated with the following codes are included in this section: Conceptual Domain, Procedural Domain, Epistemic Domain, Social Domain, Teacher-Centered, and Student-Centered. Mentoring is addressed in Section 2, and includes findings about the career development and psychosocial development codes. There is a sub-section dedicated to each code (e.g., Conceptual Domain), which contains the following sections: a) an introduction to define and frame that code and distinguish it from the other codes in the same section; b) the practices identified as being part of that code from the data; c) the ways in which graduate students carried out the practices described in the previous section; and d) factors identified by graduate students as barriers to implementing the aforementioned practices. Throughout the text, there are examples and quotes from graduate students to provide readers with context, and to represent the voices of the study participants in Study 3.

Table 3.2

Individuals most commonly referred to in the data

Type	Description
graduate student	Enrolled as a Ph.D. student (in life sciences, physical sciences, and/or STEM education) at a U.S. university, these are the individuals from whom data was collected for Study 3. Their experiences, teaching and mentoring activities, and perspectives are represented as a result of submitting written reflections about working with undergraduate researchers *and* being interviewed by a research team member.
undergraduate researcher	Enrolled as an undergraduate student at a U.S. college or university, making progress toward a bachelor's degree. The majority of the undergraduate researchers referred to in this study are STEM majors, as described by graduate students.
primary investigator	The faculty member, scientist, engineer, or other STEM professional who leads the research group. In this study, the primary investigator is the graduate student's faculty advisor (or one of two faculty advisors) who oversees the graduate student's progress in their Ph.D. program, and provides teaching and/or mentoring to the graduate student. Graduate students most commonly referred to the primary investigator as their "PI" or "advisor."
colleague	An individual who is part of the graduate student's research team (which is led by the primary investigator). They may be faculty members, scientists, engineers, STEM professionals, postdoctoral researchers, or other graduate students. If needed to understand a quote or example in context, the role of the colleague will be specified.

Note: This is a list of the most common types of individuals referenced by graduate students in the written work (typed) and interviews collected for Study 3. For example, graduate students commonly referred to their supervisors or advisors when describing their rationale for making certain decisions about the teaching and mentoring practices used with undergraduate researchers. Beyond the individuals listed here, graduate students also occasionally made references to people who work outside the research group, department, or institution, but this was infrequent.

Section 1. Teaching themes

Conceptual Domain

Teaching practices associated with this domain engage undergraduates in learning about content knowledge, a collection of different types of information (e.g., theories, principles). I recognize that people working in different disciplines refer to this content knowledge in various ways, and may not describe content knowledge as "scientific" knowledge. For example, graduate students whose research relates to STEM education often referred to the "frameworks" and "theories" that guided their research questions and approaches to data analysis. Graduate students in biology described the "mechanisms" important to their field, the "factors" that impact a species or community of interest, and "the purpose, theory, concepts, [and] mechanism" related to the project. Graduate students in chemistry identified the "biochemistry and physical chemistry knowledge" needed for the project, the "general knowledge of organic chemistry … and cancer biology," and knowing "what is chemically happening" while carrying out a specific protocol. Across disciplines, graduate students often referred to relevant content knowledge as being "behind" the project (or a component of the project), "basic" information, or "background" information.

> *... the physics behind their project.*
>
> *... what's happening behind the scenes, the science.*
>
> *... the principle scientific questions behind their research.*
>
> *... understanding the theory behind the experiment.*
>
> *... what phages [are] and very basic things like that.*
>
> *... the basic theory for kinetic studies.*
>
> *... talk through the science of the protocol, maybe read a paper about where the protocol's from and some background, …*
>
> *... at least a general scientific background of what they are doing.*

Teaching goals

When describing their teaching goals for working with undergraduate researchers, 42 (91%) of graduate students referenced the Conceptual Domain. Nearly three-fourths of graduate students described their desire to teach undergraduates about content knowledge related to the overall topic of the project. More than half of graduate students identified goals related to teaching undergraduates about the content knowledge needed to understand the project details, experimental setup, and/or specific research techniques. This was most often described as a planned topic of conversation in response to a graduate student's perception that undergraduates would benefit from additional context to support their learning in other areas (e.g., research tasks, writing an abstract, analyzing data, presenting at a group meeting). One individual explained that they were making preparations to teach an undergraduate about a laboratory technique – western blotting – and believed that reading some "background papers" about the technique would be beneficial to the undergraduate.

> *[At the] end of first semester, [I want my student to] understand and independently implement the basic hands-on techniques … with some understanding of what the samples are (i.e. what are the materials, why do we care about them, why do we combine them in this way), [and have] basic knowledge of the physics that is interesting in these systems …*
>
> *[The student will learn] how the HPG axis works and why GnIH is important in different contexts and in relation to the HPG axis and animal physiology, behavior, ecology, and evolution … An understanding of avian seasonal reproduction is needed as well.*
>
> *The experiment is a measurement of the Hall effect at cryogenic temperatures and high magnetic fields … My student [should] know what the Hall effect measures in a piece of material, and what is expected of the Hall measurement as a function of temperature in typical metals, and how to model its behavior.*
>
> *[The] undergraduate [will] become well versed in the enzymology of NRPSs and PKSs as well as gaining a vast knowledge of the antimycin natural products … [they will learn about] the actinomycete producing strains as well as molecular biology, protein engineering and compound purification and characterization.*
>
> *I think they understand the biological aspect of the technique, but the microscope is a bit complicated, so I think I should send them a video going over the basics of confocal microscopy which should go well with their formal training this week.*
>
> *[The student needs to understand] organic chemistry and biochemistry. To be more specific, knowledge about proteins, especially metal-dependent enzymes, is needed for this project.*
>
> *I would like my undergraduate to have read enough example papers [about] parasitization to be able to design and execute an experiment while properly considering the above variables. She should know basic aspects of the biology/immunology of Drosophila larvae in response to wasp parasitism.*

Approximately one-fourth of graduate students described a goal related to undergraduates' understanding of the content knowledge needed to understand the data collection or analysis for the project. One individual planned to teach an undergraduate about the theory and equations they would need to understand prior to analyzing data, and planned to have the undergraduate "write up notes in their own words" to summarize the most important content knowledge from their discussions.

> *To probe their understanding of the conceptual basis of the analysis, I will ask: Why do we want to use statistical analyses to help interpret our data/results in light of our hypothesis? What are some common features about the distribution of count data? Why do we care about choosing an appropriate theoretical distribution for analyzing our count data?*
>
> *She has a good understanding of the concepts behind lab work, and I'm hoping to teach her how to apply these concepts to results and translate the skills she's gained from the classroom into a tangible research presentation … We meet weekly to discuss results, troubleshoot together, read relevant literature, and practice articulating results and planning next steps. Hopefully by the end of the summer she will have a dataset that she can present to our lab with an overall understanding of the mechanisms at work.*

> *I'm still working with him to learn how to interpret data independently … I think there's still a little bit more to learn in terms of fundamental organic chemistry and fundamental understanding of say, NMR spectroscopy or something like that.*
>
> *… my undergrad needs to understand how to describe the crystallography of hexagonal crystal structures which is not taught in normal curriculum … people are taught Miller indices for cubic crystals in their either inorganic chemistry class or materials science class … The goal is to take what they already know about indexing cubic systems and translate that to [a] hexagonal system.*

Teaching practices

When describing their teaching approach, 45 (98%) of graduate students reported using practices in the Conceptual Domain. Most graduate students described teaching undergraduates about content knowledge related to the overall topic or subject of the project. The following are examples of content knowledge that graduate students reporting teaching to undergraduates: protein purification, developmental stages of arthropod larvae, relative polarity of compounds, structure of wurtzite materials, phage-resistance in bacteria, how nanocrystal shapes affect their properties, positive feedback loops, principles of yeast transformations, common strategies for optical alignment, interfacial polymerization, antigen-antibody binding, characteristics of paramagnetic compounds, genetic variants in DNA, and geologic time scales.

> *[I usually] give them papers starting with the basic underlying science and then a couple of the papers from our lab … Then I would just ask them to read them and then we'd go through them and for the most part they got the big picture, but ... without going through it [together], it would have been pretty much useless for them to just read the paper.*
>
> *[I am] continually searching for new ways to rephrase and "translate" these concepts … I placed significant effort into providing relatable and tangible examples when developing an analogy. For instance, … I asked the student to think of a positive feedback loop as a series of microphones and attached amplifiers in tandem and speaking through the first one.*
>
> *I often work with two types of materials … So, when you abbreviate those, you say PTO, which is lead titanate and LTO, which is lithium tantalate … and I asked my [undergrad] and he called PTO "lead tantalate" … It was just funny, because that was one of the most basic things … I think he jumps so quickly into the experiment that he [loses] sight of even the most basic things.*

Approximately three-fourths of graduate students reported teaching undergraduates about the content knowledge that informed the experimental design and/or specific techniques, protocols, or methods used in the project. One individual explained their belief that undergraduates initially do not possess enough relevant knowledge to make a contribution to a research project. For this reason, they begin training undergraduates with readings and discussions about "conceptual and theoretical studies" related to the experimental design.

> *… he had no background knowledge of our lab or what we do, because he had never taken chemical biology before … I ended up explaining the chemical basis behind protein purification, which my undergrad found really interesting. He said he always feels like biology is a "black box," but when I explained it chemically, it really clicked for him.*
>
> *… my undergraduate is still developing an understanding of a compound's relative polarity, and how to connect a chemical structure to how it will move on silica [gel]. I think this understanding of*

> *relative polarity is developed over time (especially with respect to deciding a mobile phase to use), so I have been making a point of talking about a compound's polarity and the IMFs [intermolecular forces] it could partake in (especially with respect to silica) ... he came back … with some very useful questions and had circled words and phrases in the research description.*
>
> *I asked my undergraduate about the unexpected bands in his gel. His first answer didn't make much sense, and so I prompted him with questions such as, "What did you put in the sample? What is the molecular weight of the unknown band?" He was able to correctly identify the bands with this prompting.*

Aligned with findings from Thiry and colleagues (2012), more than one-third of graduate students described teaching undergraduates about the application of content knowledge to the collection and/or analysis of project data. In some cases, this was related to teaching undergraduates how to improve the quality of data collected by improving their proficiency in carrying out research tasks. One individual recalled how they discussed content knowledge to support an undergraduate learning to complete a specific RNA extraction protocol. During the training process, they discussed *why* the protocol requires "adding this buffer at this step" and "[making] sure that everything's RNase-free." In other cases, graduate students referred to the discipline-specific concepts "behind" the project to teach undergraduates how to correctly analyze data collected for the project and understand how those results help them to address project goals.

> *The UV-Vis spectrophotometer works according to the Beer-Lambert Law … [I provided them with] some background reading materials to give them a better understanding of the theory and mechanism they are working on … I think that is better than just simply asking students to operate the instrument and record data without understanding the theory … The students can get more understanding why the data is important and what the data means.*
>
> *[When discussing the project], my suggestions were to consider referencing some important frameworks … particularly as it relates to their own project … talk about how content from these frameworks is connected to their project so that there is more of a theoretical basis for their work … they can then get into the empirical nature of their work and how their results support the referenced frameworks.*
>
> *I explained some of the basic experimental conditions that need to be developed first in order for <u>Rhizobium leguminosarum</u> to grow. I am having her read papers on different ways people have set up these assays and asked questions that probe her understanding. In some cases she seems to think they are trick questions when in reality the answer is just, "This is one of many things that needs to be standardized in order to get meaningful results!"*

Approximately one quarter of graduate students supported undergraduates in making connections between the *current* project and the content knowledge undergraduates learned from their coursework and/or from working on a *previous* research project in the discipline.

> *… he's learned a lot over the summer and … It's kind of fun now … he'll come in and be like, "Oh, I learned about this today." and, "I knew that because we did this thing [in class]. I know about pKa!" That's pretty nice that we are connecting things to his class.*
>
> *I often ask questions about what my undergraduate researcher is doing and, more importantly, why they are doing something, to test their understanding of the techniques we use in lab …*

> *[they] were able to apply their previous experience with NMR [nuclear magnetic resonance] spectroscopy to the analysis of new compounds … they have become quite advanced in a topic/technique that they were familiar with when we started this project.*
>
> *My questioning went well. I was able to get a better idea of what coursework my undergraduate student has taken and, out of those courses, what she enjoyed learning about. Additionally, it made me realize how little exposure outside of the classroom she has had with genetics and made me alter the way I explained things to her.*

Implementation

Regarding their efforts to teach undergraduates about relevant content knowledge needed to understand and contribute to the project, graduate students explained the specific approaches they used. Nearly all graduate students described having real-time conversations with undergraduates about the ideas or concepts "behind the project," through in-person interactions or the use of virtual meeting platforms such as Zoom. Involving two or more people, these "working meetings" were often used to teach new content, assess undergraduate understanding, and connect ideas together in a productive way. As described by one individual, who spent time going through the calculations to solve example problems with two undergraduates, these conversations "really helped … when they made connections" between different concepts. Half of graduate students described teaching undergraduates through conversations about relevant content knowledge from previously published work on the subject. When these texts were named, they most commonly referred to peer-reviewed papers, literature reviews, or textbooks on the subject. One individual provided an undergraduate with introductory reading material about a specific time frame in "geologic history," and then they had a discussion about the types of research questions and hypotheses scientists can construct based on this type of information. More than one fifth of graduate students used visual aids (including drawings) or the generation of typed or written materials to teach about content knowledge related to the project.

> *At the beginning, he knew very, very little … when we started, we would mostly just work through [textbook] problems and derive things that were in the book, because I worked with him on theory stuff … He successfully validated the code as amply as he could for the simple practice problems in a textbook, and moved on to more complicated systems.*
>
> *… when we're doing a new protocol, [I have] them read the protocol, talk through the science of the protocol, maybe read a paper about where the protocol's from …*
>
> *In order to teach a technique or concept, I like to explain the concept while also using a visual aid that the student can later refer to. ... I will draw things and then give [them] to her so she can take it home and look [them] over …*
>
> *Some techniques I use to enhance learning for undergraduate researchers are repetition and visual examples. Much of biology is taught using cartoon images and by giving my undergraduates these resources it gives them something to look back on as well as fosters their understanding.*
>
> *… I think it is especially important to build connections with their prior knowledge through a variety of methods. To that end, it's important to understand what they know and help them bridge any gaps/misunderstandings rather than simply giving the correct answer. [I] use a combination of visual aids, text, and slowly walking through the information verbally. I have found drawing out*

> *how molecules want to move in a system is more clear than reading a journal article. While explaining, it is good to ask questions about what they think is happening and why.*
>
> *I would be there sitting and typing, and then I would leave a note for her and I'm like, "try to fill this in with some of the background that you know." And I would let her do that, and then I could clearly see ... where she was struggling to actually write something there. Something was missing, concept-wise. And then we'd work on it together …*

Barriers

The most common method used by graduate students to teach in the Conceptual Domain was to have real-time conversations about relevant content knowledge. Although these conversations were described as beneficial to undergraduate learning, some graduate students felt limited by time constraints, which has been described previously as a barrier to the implementation of inquiry-based teaching practices by K-12 classroom teachers (e.g., Meyer at al., 2013; Strat et al., 2023). Several individuals explained that after focusing primarily on technical or research tasks for several months, they learned that the undergraduates had forgotten most of the content knowledge they had learned previously.

> *Altogether, we talked about the theory for about 1-2 hours and I showed them an example of how it works along with the various output files*
>
> *I think the problem was: we did chemistry and then we spent a lot of time learning how to do the data analysis and then we forgot about that, actually doing the chemistry, for eight months or something, and then we're now trying to get back into that. It wasn't the best way to do ... it's better to move both aspects along simultaneously.*
>
> *I found that the stuff did not stick as well long term, so doing a follow up a few days later would have been good to help with long-term understanding.*
>
> *I had to explain to her how [these] polymer chains could impact the molar volume near the interface, and change the density of the overall system. We had discussed this previously, but I think having brought it up to her again, and struggling through it, it will hopefully "stick" for her.*

In some instances, graduate students felt challenged when undergraduates did not communicate about their lack of understanding (about specific concepts) until the undergraduates were tasked with preparing a presentation or performing their knowledge of the material in some other way. As described in a previous *BURET* study, presentations about a research project allow undergraduates to showcase "their insights to relevant discipline-specific content knowledge to form coherent arguments" (Helix et al., 2022). Additionally, graduate students in Study 3 explained that preparation for presentations were opportunities to review important scientific concepts and assess undergraduate knowledge.

> *… at least from my experience, undergraduates are hesitant to ask as many questions as they need to, simply because they don't want to look as if they don't know what they're doing because they're already in a position here.*
>
> *When recurring technical challenges occur that they are unable to solve, it is often because they don't fully understand the reasoning behind the procedure.*

> *It was very promising that he understood the details of the experimental setup, but I quickly realized we need to spend more time on the fundamental physics and motivation. One of the challenges that became clear was how hard it is to talk about the physics, given that he is still just starting upper division physics courses. But, our conversation was very instructive. In all, we talked for almost 45 minutes. Most of that time was just spent on my very first question, which was the most basic question.*

Procedural Domain

Teaching practices in the Procedural Domain create opportunities for undergraduate researchers to use the procedures, materials, techniques, and facilities of scientists in their discipline. Additionally, this domain includes activities in which undergraduates engage in critical thinking, clarifying conversations, and planning meetings about protocols and experimental design.

Teaching goals

All 46 (100%) of graduate students in the workshop described teaching goals related to the Procedural Domain. When articulating these, nearly all graduate students described their desire to improve undergraduate proficiency in: technical skills; working independently on research tasks; and/or reading and understanding field-specific literature. Graduate students often expressed goals in terms of what they envisioned might change for the undergraduate over the course of a summer or year, in terms of competency and level of independence. One individual explained that at the beginning of the summer they would expect the undergraduate to carry out PCR protocols under supervision, but “[by] the end of the summer, she will be comfortable enough with ddPCR to carry out the protocol on her own.” Others described their goals that undergraduates would begin to read, find, and discuss primary literature more often, increasing their initiative over time. One individual explained their goal of having “weekly (at least) discussions of the readings,” while another expressed their desire for the undergraduate to “feel comfortable reading scientific literature.”

> *I think that it is important for my undergrad to acquire basic [lab] skills that could be applied in different areas and that they feel comfortable reading scientific literature.*
>
> *In the beginning I just wanted her to be able to work independently … Now, I want her to understand [our] project related goals, … what drives molecular interactions … [and] to gain familiarity with this experimental technique which is what we're using for our system.*
>
> *In the next few weeks, my undergraduate will continue to perfect the technical/manual skills required to successfully purify compounds by column chromatography … they will be able to independently perform this … they will already know what mobile phase to use, how much silica to use, what the fractions/product should look like and when to collect them.*

Additionally, more than half of graduate students described teaching goals related to supporting undergraduates to: engage in troubleshooting related to their assigned research tasks; collect data for the research project; and/or feel comfortable completing research tasks.

> *In the next couple weeks, I want them to make their first full device -- I have helped them to choose the best [samples] for the device, but they will do the final transfer themselves. By the end*

> *of their time in our lab, I want them to be able to do the entire process independently and really understand [if] the decisions they make are good or bad.*
>
> *So my plan [is to first] let her watch me do experiments, then she performs experiments with [my help], then I will let her do experiments on her own but I will stand by to make sure nothing goes wrong. After all of [this], I will ask her if she is comfortable [doing] those kinds of experiments alone. If not, repeat what we did before. If yes, I will let her enjoy [doing] the experiments.*
>
> *She is currently retrying the assay to see if she can complete it successfully. Once she can, she will move on to using experimental samples and generating data that can be put [toward] the project goals … Hopefully by the end of the summer she will have results for a set of samples and we will be able to focus on data analysis and interpretation.*

Teaching practices

All 46 (100%) of graduate students in the workshop described teaching practices related to the Procedural Domain. Nearly all graduate students described the ways in which they supported undergraduate researchers to: develop proficiency in carrying out research techniques, procedures, protocols, or methods; work independently to carry out those techniques; and select the appropriate techniques or protocols to accomplish a particular goal related to the research project.

> *I have very little experience with this, but I have found that my undergraduate retains information best when I show her a technique once or twice, then guide her in exactly what to do a few times as she does it. I think it takes a lot of practice to retain information just by seeing something. So, having an undergraduate perform a technique as soon as possible is good.*
>
> *I demonstrated cell assembly in front of my undergrad and then watched them repeat the process. During the assembly I asked about certain components to see what they understand already.*
>
> *She’s a community college student … and she's also doing research here, with us after school … after doing this for a month, I [asked] her to walk me through the steps, of what she [thought] we were doing, and she knew all of it. And she could repeat it, verbatim. And I was like ... I lost my shit. I was super excited. She remembered all of it and she knew why we were doing everything … she knows it way better than I do.*
>
> *So, he has set hours that he comes in, [and] every time he comes in I'll be like, “these are the tissue samples that I need. Genotype this, from this strain.” … And he knows that for each strain of mouse, there's a specific genotype and protocol that he follows. Now it's reached a point where … anytime he comes in, I just give him the mouse tails and he just does the genotyping.*
>
> *We have gone through the steps of a genetic cross together … when I gave my student more independence to start preparing for the screen on her own, she had difficulties with the timing of making sure we had enough animals for the screen … To help with her timing of experiments … [we started using an app] to write specific things that need to be done and the relative timing of experiments and setting things up … [this] helped my student to become more independent and aware of the timing that goes into these experiments*
>
> *I brought some … crystalline samples to the X-ray facility and had my undergraduate student practice manipulating crystals (finding, moving, cutting, mounting, checking for ability to extinguish polarized light) under the microscope and choosing appropriate samples to run on the instrument. … I think he is ready for more sensitive samples that we need for our research.*

Approximately three-fourths of graduate students described teaching undergraduates to read and understand field-specific literature; or generate results for the research project through the collection of data. Half of graduate students shared about teaching undergraduates to: look up information about a topic to inform the selection of a particular technique or protocol (e.g., literature, special programs, repositories, websites); or troubleshoot and overcome challenges faced when engaged in the completion of research techniques. Some examples of teaching undergraduate researchers about troubleshooting and overcoming challenges include: deciding how to time experiments properly, selecting which materials to use (and when); choosing the best samples for the next step; and verifying that newly written lines of code are working properly.

> *Before we started working in lab, I sent him a bunch of stuff to read … basically the fundamentals and some review articles that were more general, to understand why we use the techniques that we use, and I thought that was helpful in terms of giving him a broad understanding.*
>
> *Most of the literature I've given her was aimed to help her understand my field of research … I like having a weekly meeting with my undergraduates where we discuss a paper, some aspect about the project, or data. This helps them learn the material in small chunks and keeps them engaged with the project.*
>
> *I'll send them papers … the same progression of papers that I read when I was joining the lab. It's hard to know that you should read this particular paper from 2001 first, because often times people will start just looking at recent stuff. So, that's how I guide them.*
>
> *My student was a bit confused, so I suggested he read a paper on protein expression and golden gate cloning. I also got him set up with Benchling [to get] familiar with the site and all it has to offer. [That was] a helpful activity itself, in understanding what we are actually doing with these primers and plasmids.*
>
> *… we've tried to look things up together … We've mostly been looking for technical information on the methods that we're using. So for that, I show them … where I find reagent guides, and [how to] read an MSDS or a product sheet, and things like that.*
>
> *In my experiment, there's a lot of parameters that you have to choose. And choosing those parameters is important because you'll break things, or you'll waste a lot of time ,or both. … So, in the beginning, if there was a problem I would go help him solve it. And now I'm getting to the point where he'll say like, "Hey, this is the problem." And then I'll be like, "okay, well what do you think we should do?" … he's definitely gotten a lot better. Like I can go, "if I went there over there right now and said I want to do this, what should we do?" He would feel confident, and he'd give a pretty good idea of the parameters that we'd want.*
>
> *I found that lots of technical challenges required a fair amount of repetition for them to realize that it is a recurring problem. For example, often they would start the gold sputtering machine, and because the o-ring seal wasn't seated properly, the system couldn't achieve vacuum. They would keep going with the standard procedure without checking this because they don't have a full understanding of how the system operates. … I asked [them], for example, why a vacuum is necessary in the gold sputtering stage, and this helped them realize that they should make sure an adequate vacuum is established before continuing along the process.*

Implementation

The most common topic related to teaching in the Procedural Domain involved graduate students' efforts to teach undergraduate researchers to observe, assist with, or independently complete project-related techniques, procedures, protocols, and research methods.

> *If it's a new experiment, usually the first time I show them how I do it. So, they watch me the first time. And then, the second time, they do it, and I watch them doing it. And then, the third time, they do it independently, but I will be around if they have questions to ask.*
>
> *"See one, do one, teach one" is one of my favorite teaching strategies; I like to show a student how to do an assay/experiment and talk through it with them, then next to have them do one on their own while I am still nearby (but not looking over their shoulder). This seems to work best if I give them a good detailed protocol to start with that they can add their own notes to.*
>
> *I have found it most effective when I lead by example for a technique or instrument and have the undergraduate take notes. Then, they will complete the task using their notes while I observe, and correct anything that needs to be changed, having them make appropriate changes or notes in their lab notebooks. Then, I will have them complete the task completely unaided, but with me in the lab working on something else. If they complete the task well and feel comfortable working alone, then from that point they are allowed to do that task by themselves.*

From previously published studies about teaching and professional training, I have identified two concepts that are similar in nature to the approaches described by graduate students in this study. The *see one, do one, teach one* model is one that involves the following: a) a student observes a technique being performed once, b) the student is now expected to perform that technique independently, and c) the student may be expected to teach that technique to another student (Kotsis & Chung, 2013; Speirs & Brazil, 2018). Many studies have referred to this "traditional" teaching method as insufficient to provide safe and effective training to physicians and other health professionals when they are learning a new skill (e.g., Rodriguez-Paz et al., 2009; Vozenilek et al., 2004; Speirs & Brazil, 2018). Some scholars have revised the original *see one, do one, teach one* model to align with new principles of teaching that have been found to result in better learning outcomes for learners in medical/healthcare settings, and safer conditions for patients. For example, the more current "learn, see, practice, prove, do, and maintain" framework and the "see many, learn from the outcome, do many with supervision and learn from the outcome, and finally teach many with supervision and learn from the outcome" approach make use of factors such as repetition, practice, refinement, and guidance from more experienced teachers (Rohrich, 2006). Another model, *Peyton's 4-step teaching approach*, has been referenced in many studies as useful in teaching procedural skills in a variety of medical education studies (e.g., Bosse et al., 2015; Giacomino et al., 2020). This teaching approach includes the following steps: 1) the teacher demonstrates the entire procedure for the student to observe; 2) the teacher repeats that demonstration while describing each step for the student; 3) the student describes each step of the procedure in order to guide the teacher as they perform the procedure; and 4) the student performs the procedure independently (Giacomino et al., 2020). As done with the *see one, do one, teach one* model, this 4-step approach has been studied and modified to improve learning outcomes in medical/healthcare settings. For example, adapting the original

4-step approach for learning in small groups highlighted the value of having more opportunities for observation and feedback from multiple people (Nikendei et al., 2014). Both of these teaching models illustrate the principle of “learning by doing” that is so prominently featured in inquiry-based teaching.

Some graduate students in Study 3 followed *Peyton’s 4-step teaching approach*, as shown below.

> *Yeah, so in the lab, to teach the actual assays and tasks, I'll have them watch me do one or two, depending on how complex the task is. And then, I'll have them watch one, talk them through one as I do it, and then have them do a few as I talk them through it, and then have them describe it back to me as they're doing it. And then eventually I'll have them take on that role, once they're very experienced, with other students, so that they have experience teaching others as well, to reinforce what they've learned.*

More commonly, graduate students used a modified version of *Peyton’s 4-step teaching approach*, in which they first “show” the undergraduate researcher how to set up, gather materials for, and perform a technique. Next, they implement some type of “side-by-side” work where a) the undergraduate researcher performs the technique while the graduate student observes, b) the undergraduate researcher performs the technique while the graduate student explains the steps, or c) the graduate student and undergraduate researcher complete the technique together. This teaching approach continues in stages, with the undergraduate progressively performing more of the technique over time, as they transition from novice to a more advanced researcher (e.g., Helix et al., 2022). As reported by graduate students in this study, the exact series of steps, particular level of independence that an individual undergraduate researcher reaches, and amount of time needed to advance through these stages varied between groups and projects.

> *So, normally what I'll do is I'll have them observe [me] doing that technique once and then the next time I'll have them do it with me supervising, like more hands-on, standing behind them being like, "Okay, and next do this," and walk them through it a little bit. And then the next time, I'll be in the area if they have questions. So, the third time they do it, I'll be around so that they can ask me questions or I can catch them if they're doing something horribly wrong, but they're mostly independent. And then, by the fourth time, my goal is usually to have them be able to do it without me or mostly without me. Obviously I'm usually still in the area, in case they have a question. So I'll usually try the see-one-do-one approach or something, I can't remember what it's called. But that's normally what I'll do if there were a new technique.*
>
> *I forget what it's called, but I think it's a fairly common technique. The way it goes is, I start by saying, 'this is the name of the technique' and, 'this is what we're going to try and measure,' and then I will do it in front of them. I'll do it for them and explain what I'm doing as I go, and the things I'm watching out for. So, that would be the first time and depending how long it takes, maybe [it takes] the first <u>and</u> second day … Specifically, the experiment the student is doing takes about four hours, so it's basically the entire time she's here. So, I go through the experiment. I go through setting up and running the measurement and cleaning up. And then the next day, I have them do it, and I supervise. So I'm watching over them, and I'm there mostly to answer questions. If they're like, “Is this the right button to push?” I'll say “Yeah, that's what you want to do.” So, I shadow them and I'm watching to answer any immediate questions, and then the third day they do it and I'm in the room. I might be fiddling with something else, but I'm pretty nearby if they need any help. And then, after that they can, if they feel comfortable, go ahead and do things while I'm at my desk or something, a little bit further away. So, that's the approach I have … with the experiment she was doing, I did it for her, I walked her through it as she did it herself, and*

> *then she ran it on her own with me in the room or me in the building. And now she runs it when I'm not even around, although she can always message me.*
>
> *I employ a three-step technique for teaching my undergraduate new skills. First, I allow the undergraduate to observe me perform an experiment while talking through what I do. Next, I have the undergraduate complete the experiment or task while I still talk him/her through it, while also asking them questions and allowing questions to be asked. Finally, I have the undergraduate perform the experiment/task without giving assistance before being requested. I have found this method to be very effective when teaching new skills, as by the end of the third step the student feels relatively independent while a comfortable dialogue has been developed between us about the experiment/task.*

Barriers

There were some instances in which project conditions and/or procedures impacted the ways in which a graduate student could teach in the Procedural Domain. For example, there were rules in some research groups prohibiting an undergraduate researcher from using certain equipment or working in designated locations without the direct supervision of a graduate student. In other cases, the materials used in an experiment were too expensive or sensitive to allow a graduate student to teach a new technique using “real” samples. One individual explained that the PI forbade them from teaching an undergraduate researcher techniques for a time-intensive project, which modified their initial plans.

> *I've struggled with it, whether it's actually the nature of our projects or the nature of our lab, but undergrads don't have ownership of a project that's independent at all. I'm in a chemistry lab … [our projects are] not more advanced than what anybody else is doing, but it does seem like it's very physically impossible to get anything done without sequential multiple days of work. Undergrads, by not being in there everyday, miss [some] of the experiment, so it's pretty hard for them to work independently unless they were to … come in every day after school from 6:00 to 10:00 pm, I think. … I don't really ask [that] of students, and because of that, I really struggle to [teach] them more than completing experiments. Only a couple of times I've been able to get them little experiments to do on the side ... I think in some labs you'll see these sub-projects that undergrads can complete and take ownership for, but I've never really been able to pull that off within my own projects, which I'm thinking about a lot. How do you do that?*

Epistemic Domain

Teaching practices in this domain engage students in learning about how scientific knowledge is generated and evaluated through active participation in this process. In the context of STEM research experiences, undergraduates can be guided to analyze data, develop explanations for an observed phenomenon, and revise their hypotheses associated with an ongoing research project. In many classroom settings, inquiry-based teaching in the Epistemic Domain pushes students to learn about the activities of professional scientists, and connect their classroom-based investigation to these activities whenever possible (e.g., Franco & Munford, 2020; Furtak et al., 2012). In contrast, undergraduates participating in research experiences can more easily work alongside scientists in ways that are nearly indistinguishable from the work of entry-level research assistant positions. Thus, teaching in this domain can integrate undergraduate researchers into the scientific community through the contribution of new ideas, data, and insights and, ideally, awareness of their participation.

Teaching goals

The teaching goals of 45 (98%) of graduate students included the Epistemic Domain. Graduate students most often described their goal to teach undergraduates about data analysis, although the undergraduates' level of involvement differed in the scenarios they envisioned. Approximately three-fourths of graduate students wanted undergraduates to conduct data analysis independently and/or have a deep understanding of the rationale for using a particular method of analysis. One individual explained that their goal was for the undergraduate to "be able to perform the technique without guidance, … collect the data off the computer, analyze her results, and generate plots of her findings," while another planned to support the undergraduate working with them to "think about new ways to analyze [the] data that may provide new insights." A few graduate students wanted undergraduates to take part in the development of a novel method of data analysis to be used by the research group.

> *By the end of the summer, she should be able to perform the technique without guidance, run her plates in the reader independently, collect the data off the computer, analyze her results, and generate plots of her findings.*
>
> *… I will assign him to read the most recent papers published by my lab that use this technique and the original paper that explains the use of the different control strains. Hopefully this will help him understand how to interpret the data he will obtain. I will also show him how to read the data, analyze it and graph it properly.*
>
> *I can encourage my undergraduate to take ownership of her project … Data analysis can also lead to a feeling of project ownership … I will challenge her to think about new ways to analyze her data that may provide new insights.*
>
> *The technique I will focus on with my undergrad for the next few weeks is the development of a qualitative coding scheme or rubric. The progression moves from "counting" and "vocab" based approaches to inductively identifying categories to characterizing responses and connecting these categories to existing theory.*

Two-thirds of graduate students described goals related to teaching undergraduates to influence the direction of the *current* research project through the generation of short- or long-term next steps informed by data, results, previous research, or some combination of these. Previous research has shown that undergraduates with research experience are better prepared to propose appropriate next steps for a research study than those with no prior experience (Heim et al., 2023; Helix et al., 2022).

> *In order to enhance my undergraduate's learning, I encourage him to understand the motivation behind his project … I hope that this facilitates him developing his own ideas and defining the direction of his project because he will understand the open questions in the field … and perform experiments to address those questions.*
>
> *To that end, I would like [the student] to optimize cell culture conditions … and assay senescence in "old" (high passage) cultures so that we can understand the most efficient, effective way to utilize the cells in additional experiments.*
>
> *I would like her to feel kind of comfortable asking scientific questions, beyond, "Oh, how does this work? How do I do this?" and go deeper into [questions like], "Okay, we've done this. What did we*

> *learn from it? What [would] be cool to do next?" ... I would like her to be able to think more broadly about the field that we're in, and where our project should go next.*

More than half of graduate students described goals to teach undergraduates to: construct hypotheses, explanations, or conclusions based on project results; understand how to select different experimental designs to achieve different project goals; and/or develop a *new* research project. Connecting this teaching goal with reading the literature, one individual explained their desire for the undergraduate to “generally understand these papers, what the [experimental] designs have in common, and where they differ …” Others described their goals for undergraduates to “generate” or “build out” new projects. These new projects were usually conceptualized as an extension or modification of the original project that undergraduates worked on when they first began working with the graduate student and/or larger research group. Some graduate students expressed the belief that these teaching goals would be more attainable if undergraduates chose to work with the research team for an extended period of time (e.g., one year or more) versus a single summer or semester.

> *They should be producing a lot of mass spec data at this point and should spend ample time assessing it and trying to draw conclusions and troubleshoot based on positive, negative or confusing results.*
>
> *Initially, I will ask my undergraduate to show me her raw data and explain how she came to her conclusions. Once she has shown that she can independently draw accurate conclusions from the data several times, I would trust her to do the same for similar experiments.*
>
> *By the end of the semester I would like the students to have read and generally understand these papers and what the designs have in common and where they differ (and why might this be the case).*
>
> *… the next step in his training will be to gain experience generating entirely new projects. … I plan to assign broad literature in a related area and ask my student to summarize some of the themes in an area, and ask questions like "what might the next step in this field be?" "what would be a useful contribution?" In this way, I hope my student will be able to begin formulating entirely new research questions.*
>
> *So, my goal is that by then, he's [working on] an experiment that doesn't exist yet. I want him to … build it out. [He will] get some results, even if they're not good results, … and then present [them at the] APS March Meeting.*

Approximately one-fourth of graduate students articulated goals related to teaching undergraduates to: think critically about and evaluate the quality of field-specific literature; determine how field-specific literature relates to or informs the current research project (and vice versa); and/or articulate how the current research project (and/or results) relate to projects larger in scope, the scientific field, or society.

> *[I want them] to consider more possibilities and really design experiments that would address the most possible outcomes, … get more comfortable with looking through the literature and [be] able to identify what is useful literature and maybe not so useful literature.*
>
> *To reach [our] goals, [the] undergrad will continue to practice measuring quantum yields and reading the literature. Discussions with other students in the lab will also help to understand how these measurements compliment other research projects in the lab.*

> *I expect that undergraduate researchers will understand the "big picture" of their research, even if the scope of their particular project may be small. As they become more experienced in the lab, I hope they will take on an intellectual leadership role (i.e. seeking out papers to read, coming up with ideas for follow-up experiments).*
>
> *… the student will likely be working on materials that I don't necessarily know [well enough to predict] how the data should turn out … In cases where test parameters had to be changed, we [will] discuss how this could have impacted the experiment and if it was valid. I would have them reading current papers and we would discuss our work in the context of the research of other groups.*

Teaching practices

In support of the aforementioned goals, all 46 (100%) of graduate students reported teaching in the Epistemic Domain. The most common teaching practices – used by more than three-fourths of graduate students – related to teaching undergraduates to analyze data for the project. Often, graduate students dedicated time to teaching undergraduates about why they were using a particular method to analyze project data. In some cases, they taught undergraduates to identify data and/or analysis methods from primary literature to inform their understanding of the methods used in their project. More than one quarter of graduate students reported teaching undergraduates to evaluate the quality of project data, in order to inform short-term next steps and/or modify the data collection methods in an attempt to produce “better” data.

> *This is harder, but when I am looking at data, I always have the student give me her interpretation of the data, make figures etc. before I give mine … she is beginning to get a feel for what to expect. [I ask], "What stands out to you about this data?" … "What types of things in the lab could have contaminated the data, and what would you expect to see if that is the case?"*
>
> *She noticed a few outliers in her data and figured out why those measurements gave a bad result. She was then better prepared to make the density measurements on more valuable materials where she only made three measurements per material. I think this strategy works very well when you have an expendable material that they can practice on. ... We then discussed why she should not have included that data in her plot if she had clear evidence that the data was not a true representation of the material's properties.*

Nearly three-fourths of graduate students taught undergraduates about how the current research project (and/or results) related to projects larger in scope, the scientific field, or society. More than half of graduate students taught undergraduates how to generate next steps for the project, based on analysis of data, results, and/or previously published work on the topic. In this way, undergraduates were making meaningful contributions to a project as collaborators. Comments about this active participation of undergraduates were often linked to a graduate student's perception that the undergraduate had developed ownership and/or motivation to support the project in further progressing.

> *They seemed to not really be able to project too far into the future, and really mirrored experiments that I had already told them were in the pipeline … I tried to overcome this by asking her how she might take the results of this experiment and translate them into a clinical setting depending on the results of the animal experiments, and that seemed to go a little better.*

> *As they progress beyond the basic techniques … they are asked to connect the daily experiments they do with the project's goals and explain how each experiment contributes to the final publication [and] asked to provide an alternate experiment that could be conducted and an example of it in similar literature ... The combination of technical training coupled with undergraduate reporting, and tying this in with the overall project contributes to the undergraduate's ownership within the project and their ability to make a conscious decision about their role within the research.*
>
> *My undergraduate mentee was pretty good at coming up with an idea for next steps that could be executed in a month or two, that was a little more related to some of their personal scientific interests (like impacts of environmental change on ecology), although they did not have many of their own ideas for how to test/implement it until I offered some suggestions myself … I think the exercise of discussing future projects gave them a little more encouragement to feel like they had some ownership in the current project.*

On its own, teaching undergraduates to read the literature is associated with the Procedural Domain. However, while teaching about reading the literature, graduate students often used teaching practices from other domains, and most often from the Epistemic Domain. For example, more than half of graduate students taught undergraduates to read and *evaluate* primary literature (Epistemic Domain) in order to accomplish a few different goals in support of the research project and overall understanding of the discipline. Through interactive discussions with one or more other researchers (Social Domain), graduate students taught undergraduates to consider different experimental designs described in the literature, and use this knowledge to consider the benefits or constraints of the experimental design (Epistemic Domain) used in their *own* research project. Graduate students also taught undergraduates to apply the findings from previous studies to: understand how their current project was informed by previous work; consider how their current project might contribute to new knowledge in the field; and inform their recommendations for specific next steps or experimental designs. For example, one individual taught the undergraduate they were working with how to verbally reference relevant frameworks from the science education literature, and connect these to the study design and results of their project. Often related to this critical evaluation of the literature, approximately one-fourth of graduate students reported teaching undergraduates to construct hypotheses, explanations, or conclusions for the project. These ideas were also informed by project data, but undergraduates learned more about how to articulate hypotheses, explanations, or conclusions after reading examples of these in previously published papers.

> *I've been going through papers with her to make sure that she understands how her project will fit into the current understanding of the field. ... We read a lot of papers together and that was separate from their lab work, but, as we went through more and more papers, I felt that they got better at interpreting what the figures meant and thinking about the big picture in the paper and then that's it. So I think that that was really helpful …*
>
> *I often tell him to sort of try to find the answer to something in the literature. And then he'll report to me back with the papers that he's found. And then usually it's the same line of questions [like], "Do you consider this paper trustworthy? Why or why not? What would you take from this, even if you don't consider it, overall, trustworthy?" And so we take it on a paper-by-paper basis … if, in that process, I feel like he hasn't identified key pieces of literature that I have [read], I will suggest those and try to identify why that didn't come up in his [search].*

> *For these paper discussions, he reads the paper, makes a PowerPoint presentation, and then presents the paper to me, and we have an in-depth discussion about the data in the paper and how that might help him understand his own project. I also give him the space to come up with ideas for his project based on a technique or concept from those papers. ...*

Nearly one-fifth of graduate students described teaching undergraduates about what is “normal” in their discipline and/or overall field, in terms of the typical approaches taken to address certain research questions, how certain methods commonly fail to generate high-quality data, and what experimental conditions are especially challenging to work under. Graduate students encouraged undergraduates to learn about how scientists make decisions despite these “typical” setbacks, complications, and limitations through interactions with other researchers, reading primary literature, and one-on-one conversations to bring all of these ideas together.

> *… we have already discussed many facets and potential complications of his research project before this conversation … I have frequent conversations with them to assess their understanding of the project and plans for future work. ... Sometimes reactions fail or research does not cooperate but these problems can then be addressed in the context of the larger plan. I believe it is much easier to keep trouble-shooting when you have a very clear sense of where the research is going and what you are ultimately trying to answer.*

> *So I'm an education researcher, so we don't have lab procedures or anything like that … I start with students just exploring the raw data … and then for some of our qualitative coding approaches, I'll typically describe it at a high level, and then [code] it together … I am using a lot of probing questions to push her to articulate her thinking and challenge some of the assumptions in her ideas … I'm also giving detailed feedback on her research plans and trying to make visible how I am thinking, and the questions I would ask myself when designing my own study.*

> *They became very proficient in the basic functioning of the lab equipment, and were confident up to the point of using and analyzing the data coming off of some of the instruments ... I [explained] that mistakes are made in experiments, and we can often get negative or confusing results.*

Implementation

For all of the teaching practices described as part of the Epistemic Domain, graduate students engaged in the aforementioned “working meetings.” Undergraduates can be exposed to new ideas from many sources, including STEM courses, specialized training opportunities, interactions with other scientists, and the media. Through working meetings, graduate students took opportunities to teach undergraduates how to sort through these ideas and learn about the process of producing new discipline-specific knowledge. This process of leveraging social interactions between undergraduates and “their mentors and research groups” to teach skills related to data analysis, problem-solving, troubleshooting experiments, and developing or modifying an experimental design was described by Thiry and colleagues (2012). This teaching approach is aligned with the Knowledge Integration framework to *elicit* student ideas, support their *discovery* of new ideas, guide them to *distinguish* between different ideas, and enable them to *reflect* on what they have learned about the topic overall (Helix et al., 2022; Linn & Eylon, 2011).

Many graduate students spent time teaching undergraduates to use literature to generate new ideas by going through individual papers together during working meetings, but expected that undergraduates would do this with increasing independence over time. One individual described this progression as the undergraduate “stay[ing] on top of the literature,” in order to design and propose new experiments to achieve project goals. In some cases, undergraduates were tasked with preparing slideshow presentations to organize one or more of the following, based on the papers they read: summaries, opinions, questions, connections to relevant content knowledge, support for analysis of project data, and ideas for next steps or future projects. In these examples, an undergraduate would use their slideshow to present to the graduate student during the working meeting, which provided the undergraduate with practice making sense of their ideas (Social Domain) and showcasing their understanding of the connections between the project and discipline-specific content knowledge, previous literature, previous results, etc.

> *One of the strategies I use for teaching the undergraduate student I work with is to assign him papers and then taking some time to discuss the paper. I let him explain the paper and I help him interpret figures that he doesn't get, and I also ask him questions about the importance/ relevance of the paper to our research. ... He now reads papers by himself and tries to come up with different experiments to test some of the hypotheses he has.*
>
> *I ask [them] to prepare slideshows to present to me, which include the data they have collected, as well as some sort of literature review. I also ask that they prepare any questions that they might have about their data or the literature. Setting aside a time explicitly meant for them to ask questions and update me on their work requires them to constantly think about how their research fits into the overall scope of the project.*
>
> *They are asked to prepare a presentation that outlines the planned and completed experiments and [discuss] how each one contributes to the overall project.*

Some graduate students set aside time during working meetings to collaboratively solve problems, analyze data, or generate new ideas with undergraduates. Others asked undergraduates to revisit earlier documentation (e.g., written work in a laboratory notebook) as a way to make new connections between the different stages of the project. One individual explained how they used this technique to help the undergraduate “refresh himself on the experiments and reactions [completed] over the summer” and connect these to different aspects of the project completed more recently. In this case, the graduate student felt that taking time to review individual components of the project was a necessary step in teaching the undergraduate how to generate findings from the study as a whole.

While carrying out research tasks and during working meetings, many graduate students described the strategic use of asking open-ended questions in order to identify undergraduates’ “knowledge gaps.” This teaching practice was also used to provide undergraduates with opportunities to contribute their own ideas to the conversation. Previous studies have referred to this formative assessment practice as “teacher questioning,” in which the questions themselves bring “instructional objects to the forefront of students’ attention” and engage students in mental exploration of the intended content (Amos, 2003; Erdogan & Campbell, 2008; Heritage & Heritage, 2013). Aligned with the practice of *eliciting* student ideas in the Knowledge Integration framework, teacher questioning is a feature of inquiry-based teaching in which teachers guide students “towards coherent explanations of the phenomena in context” through dialogue (Erdogan & Campbell, 2008; Linn & Eylon, 2011; Kawalkar & Vijapurkar, 2013;

van Zee et al., 2001). In Study 3, undergraduate responses during teacher questioning informed what topics and/or content graduate students chose to address next in the conversation. One individual described using teacher questioning to “challenge some of the assumptions” held by an undergraduate. In this case, the graduate student wanted the undergraduate to become more comfortable articulating their thinking, working independently, and designing new research studies.

> *… the technique [we use] is immunohistochemistry. It enables us to label and visualize specific neuropeptides in the brain. However, the same result can have different meanings in different contexts. … We meet weekly to discuss results, troubleshoot together, read relevant literature, and practice articulating results and planning next steps … To probe her understanding of the conceptual basis of the technique’s results, I encourage her to walk me through the meaning of particular results [and] use other evidence [to explain] what her specific results mean …*
>
> *I focused on filling in the gaps of my mentee's understanding of the techniques and analysis method because it felt more important than a more in-depth understanding of the technique …. First, I asked some questions about their understanding of the analysis code and explained some things graphically to fill in gaps … The following week, we reviewed the previous discussion, but with my mentee leading the explanation instead.*
>
> *So, usually they come to the lab maybe six to eight hours per week. And during that time, I will actually teach them some basic experimental skills or how to analyze that data. ... I will ask them questions. Yeah, I'll often ask them questions like, “why do you think we are going to do this experiment?”, or “what if we do some other things, what's your opinion?”*
>
> *… as I watched her progress, I developed additional expectations. I wanted [the undergraduates] to be able to explain their research, the motivation, and why the measurements/procedures were chosen … there was a day where she really demonstrated that she understood … there were two things we did that day. One was I had her explain the project to me, and then we literally went to the dry erase board and drew what was happening. I explained what we would expect for the different experiments [by] drawing it out and talking through it, and then having her drive the talking. I think having her frame the project in her own words really helped.*

Barriers

Graduate students found teaching in the Epistemic Domain to be valuable to undergraduate development as scientists, but time-consuming to implement. Based on the pace of their work, graduate students often estimated how much time would be needed to teach an undergraduate about all of the most important aspects of the research project. One individual was hopeful that the undergraduate would have enough results to begin learning data analysis and interpretation for their project after working together for a semester. Another individual explained that it would take approximately one year for the undergraduate to become involved in sample collection and processing, data analysis, and understanding how to navigate common challenges faced during the analysis stage.

> *An experienced undergraduate, [at the] end of year two, should be much more confident and self proficient in everyday tasks and will begin thinking about designing their own experiments and goals … They should be familiar with other research in the field from other labs and understand how the work they are doing fits into the bigger picture of the field.*

Many graduate students described needing “lots of time” each week to teach undergraduates about all aspects of the research project, and ensure that they understood enough to collaboratively influence its direction. Without sufficient time dedicated to working meetings and research tasks, graduate students felt that undergraduates were unable to fully participate in the investigative process. Instead, undergraduates understood those aspects of the project they had been taught in more depth (typically in the Procedural Domain), but struggled to connect this knowledge with experimental design, previously published work, project data, etc.

> *I wish we had more regular meetings over the course of that full year when she was working, because she got really proficient at lab skills, but when it came time to write her honor's thesis and present it, there were definitely some gaps where I was like, “Whoa, that is not why we did this experiment!” … [In the future] I would be much more demanding that they learn the theoretical aspect behind each technique and the “why” behind each experiment.*
>
> *I think my undergrad has a limited view about what the potential next steps could be, only focusing on [using] other materials, not any parameters we could change … I think their ownership of the project may be minimal [and] they don't think they can change anything else. I think this is, in part, due to them having limited time available to work on the project, so I generally tell them what I am working on and have them assist me … If they had more time to work in the lab, then they would be able to fully generate their own samples from start to finish, allowing them more freedom to change things.*
>
> *So, usually they come to the lab maybe six to eight hours per week. And during that time, I teach them some basic experimental skills, or how to analyze that data … the next week, they [came in] again and I asked them to look at what I taught them before, [but] they forgot what I taught, because they don't really have enough time to spend in a lab. You can imagine, if they come to the lab every day, so that they can practice every day, they will know how to do [these] things.*

A defining feature of this domain is the emphasis on teaching students how scientists produce new knowledge through research activities. Graduate students described the challenge of accomplishing this when undergraduates a) had a limited understanding of content knowledge relevant to the project (Conceptual Domain), or b) were not yet proficient in research tasks needed to advance the project (Procedural Domain). First, graduate students commonly felt that undergraduates would be better positioned to contribute to the project design, data analysis, next steps, or future work with a strong grasp of relevant literature. However, they felt that if undergraduates did not understand the discipline-specific concept “behind” this literature (Conceptual Domain), they spent an unnecessary amount of effort trying to make connections between concepts. One individual explained that, over the course of several months, an undergraduate was regularly confused about “why” they were engaged in particular research tasks, which was a barrier to understanding the overall project. The graduate student explained that it would not have been possible to quickly answer these questions while working on research tasks, and so they decided to “spend more time talking about different projects” and review previously discussed content knowledge.

> *Well from my understanding, if they don't know what the next step is, to do in their current experiments, I feel they actually don't know why they're doing the current step. Or, what they’re getting out of the current step. So, that might be a sign that they're not understanding the scientific concepts.*

> *… moving forward, I [am] primarily focused on his [ability] to interpret data independently. He's gotten quite a bit better throughout the program, [but] there's still a little bit more to learn in terms of fundamental organic chemistry and fundamental understanding of NMR spectroscopy.*
>
> *As a student progresses, the most important changes in their understanding, I would argue, would be their ability to design experiments, to understand the data they collect, and to generate new research ideas which follow up on their current project. This level of understanding can only be attained from understanding a large amount of related literature, [which] is not typical of an undergraduate researcher.*

Second, graduate students described challenges with teaching undergraduates to make intellectual contributions to the project when they were not yet comfortable with carrying out project procedures, techniques, or tasks (Procedural Domain). One individual working in science education observed that an undergraduate could not yet “use the coding scheme [to] accurately code data,” which made it challenging for the undergraduate to suggest appropriate next steps for the project. Another individual explained their desire for the undergraduate they were working with to become proficient in “processing” samples, in order to have enough work done to begin learning about how to analyze data and contribute their own findings to the project. Some graduate students felt that their teaching efforts in the Epistemic Domain would not be impactful until undergraduates had developed the ability to complete work efficiently and accurately.

> *They are having some difficulty with data analysis because it relies on coding skills, [but] learning more about their experience with MATLAB gave me more insight on where to start explaining …*
>
> *I observed … when they moved on to an independent project, and I realized how much they didn’t know, and that they had gaps in connecting all the individual procedures … This showed me a lot about what I had not taught them, and also what we needed to work on more.*

Social Domain

Teaching practices in the Social Domain provide undergraduates with opportunities to communicate with others in a way that clarifies, changes, or confirms their understanding of their research. In other words, this domain covers communication beyond the typical “daily” communication one would expect to engage in with people in their research group, and has been associated with the development of science identity (e.g., Vasquez-Salgado et al., 2023). While teaching a student to analyze data is associated with the Epistemic Domain, engaging in a brainstorming session with them about the implications of that data is associated with the Social Domain.

Teaching goals

When describing their goals for teaching undergraduates, 40 (87%) of graduate students referenced the Social Domain. Approximately half of graduate students expressed their desire to support undergraduates to effectively engage in communication with other researchers through: presentations at group meetings or conferences; written work (report, paper, or grant application) about the project; and/or “working meetings” that influence the direction of the project or student perspectives (through the receipt of critical feedback).

> *... when they do present at our group meetings, [I hope] that they're able to explain why they're doing what they're doing, rather than just [saying], "Oh, we did this." Start putting it in a bigger context, I guess.*
>
> *… I actually don't know how well my undergrad knows this information, so it seems like presenting [would be] really good. Especially presenting and getting feedback immediately, like, "you're not making the correct point at all" or, "I think you should put it this way and that way." … I'll just have them present to me, basically like what I have to do with my advisor, where you're like "this is what I'm working on, this is what the results have been," and put together a monthly report.*
>
> *[I want to] see how my student argues [during] disagreements because I myself might not have the right code. I want my student to feel that they can "override" my coding if supported by ample evidence.*

Approximately one-third of graduate students articulated their desire for undergraduates to accomplish one or more of the following during conversations with other researchers: convey a strong and logical argument about the importance of the project; provide critical feedback on others' projects; and/or make a clear connection between relevant literature and the current project, all of which relate to the Epistemic Domain. While explaining these goals, graduate students named several instances where they imagined undergraduates would engage in these conversations, including: "journal club" style discussions; "roundtable" discussions during research group meetings; and/or networking opportunities at conferences or departmental poster sessions.

> *We'll get back to having weekly journal clubs where we discuss relevant literature for her project. She will drive most of the discussion. We'll start with the papers she absolutely needs to know for the project and that I found out, by asking her about the project, that she doesn't completely understand yet.*
>
> *When teaching an organic chemistry lab, I found students were often unable to articulate the link between TLC and column chromatography and so this is something I will want to assess. ... I hope that they build a number of skills such as being able to effectively communicate their project and its importance …*
>
> *I believe I need to work with them more about how our lab work has implications farther than successful results in lab. ... My goal for them by the time they have finished working with me, as that they have achieved some level of independence within the project, which is best demonstrated through their confidence and ability to effectively communicate the results from their time in lab.*

Teaching practices

The teaching strategies of 44 (96%) graduate students included practices aligned with the Social Domain, and provided undergraduates with opportunities to communicate with other scientists to "work things out," make an argument, or reach a decision about the project. Nearly all of these graduate students described efforts to teach undergraduates how to give a presentation about the project to other researchers and/or to a "general audience." The settings for presentations to other researchers included small group meetings with the PI, research group meetings, departmental meetings, conferences, and poster sessions. In the context of presenting to other researchers, more than half of graduate students taught undergraduates to make a strong argument about the societal or scientific value of the project and/or the rationale behind the experimental design (Epistemic Domain), which may or may not include references to the literature. This result is aligned with a previous *BURET* study in which our research team found that undergraduates engaged in research experiences often need support to understand and communicate about a) how their research project might impact the scientific community, and b) the rationale for selecting a particular experimental design for the project (Helix et al., 2022). In Study 3, some graduate students took steps to teach undergraduates to prepare for and give presentations during which they addressed these aspects of the project. Some individuals explained that this preparation is critical to ensuring that the undergraduate would "represent" the group in a positive way.

> *[I] had her watch a TED talk where science similar to ours was communicated, to get a feel for sharing our work with a general audience. ... I suggested that some terms be changed to ones more accessible for a general audience and that some of the experimental specifics could be removed … I also suggested that she write out a few short bullet points [and] practice giving them verbally without looking … [this] helped me see where some gaps in her knowledge were.*
>
> *I focused most of our discussion on preparation for my student's final poster presentation at the end of the summer [and] how important it is to consider your audience, and I provided some suggestions for gauging the audience interest and knowledge of the topic (for example, asking if they want the short or long version of the poster presentation, and pausing at various points to ask if they are familiar with various aspects of the biology/methodology behind the project).*
>
> *So this summer, our undergrad did present a poster and short presentation … skipping general context seemed to be an issue. I think because we always discuss the detailed issues with the project, it's easy to skip over the overall purpose for the project. Even going all the way back to why batteries are important in the first place would be nice. He did a great job summarizing a couple main points while resisting the temptation to talk about all the things he's done so far.*
>
> *So, ... subgroups are very informal. They're just in our PI's office. Very comfortable. … he used to show me all the slides beforehand, and I'd go through them, one at a time, with him and talk about … anything from formatting to actual content. Mostly how you are presenting information, and what you're going to say about that. And at a certain point, he picked up on that well enough that I didn't need to babysit that sort of thing. So these days, I'll talk about his slides and his information after [his talk], but I don't really need to look at it beforehand.*
>
> *The main guidance I gave was about making the pitch persuasive. Oftentimes, the general audience for the work being done needs to be "convinced" that things need to change from the status quo. The research that the undergrads are doing lends support to this, [and is] convincing … I thought it was important to craft a pitch that was as persuasive as possible. A call to change.*
>
> *… the student who has been working with us for a long time, she attends as much as she can, and people talk to her, and sometimes she presents and asks questions and stuff. She doesn't talk as much as others, but she does a good job. ... [students] will add more details and talk more about those things that they know more about, and will try to avoid talking about those things that they feel less confident about.*

When teaching undergraduates about preparing an effective presentation, two-thirds of graduate students emphasized the importance of including content related to an undergraduate's own progression as a scientist. Specifically, graduate students asked them to share details about what they learned from working on the project; give examples of the successes and challenges they faced over the course of the project; and/or clearly state their unique contributions to a particular project.

> *Some of the suggestions I gave them focused on trying to help them see/gain their ownership over the project, and that a lot of pitches are just about them telling their own scientific story, that there are multiple strategies that can be taken/ways that results can be interpreted and that they should try to find a pitch that they are excited about …*
>
> *The guidance I gave her was that [the talk] should be short and to the point. I told her the beginning should contain the big picture first, then build up to what she did specifically, then she could explain how our work ties into the field of robotics. ... This was helpful for me because it can tell me how much the undergraduates understand … [and] what parts of the project need to be explained better to them. It was helpful for my undergraduate, because she wanted to be able to better explain what she was working on.*
>
> *I asked each undergraduate mentee to prepare an elevator pitch for a short sub-group meeting including three undergraduates and myself to give each other a basic idea about what the project he/she is doing, what knowledge or technique they have learned, what the progress they have made the past one month, what difficulties they have met and how to solve them, and how they expect the projects to be done.*

Approximately half of graduate students reported teaching undergraduates how to write about the project as part of an abstract, report, paper, or grant application; translate content from others' papers or presentations into their own words; and engage in conversations with other researchers about the project they are working on or others' projects (with a focus on providing or asking for feedback). Within both the Social and Conceptual Domains, nearly one-third of graduate students engaged undergraduates in discussions and/or writing about content knowledge relevant to the research project.

> *I commonly encourage students to teach one another (and myself) the topics that they are learning [and] making sure they know that I am always open to improving the projects, so if they have new ideas, they have the freedom to test them out themselves or present their ideas …*
>
> *The hypothesis and next steps for the project may be too advanced for her so I plan to add that part when she gains more experience. I sent her a few papers closely related to the project and asked her to read these materials before writing … I helped her sort out ideas in each paper I sent to her, making her grab the most important part of each paper. Then I let her talk about the significance of this project and the methods used in these papers in her words.*
>
> *I tried to give helpful ideas when explaining the physics behind their project. ... So, in our regular meetings I tend to try to actually go through all of the arguments of a paper that we're currently writing and explain to them which parts they were directly involved in, which parts were the results of their work, and I think that helps.*

Implementation

Teaching practices in this domain require undergraduates to engage in productive conversations with others, in-person or virtually. Aligned with their efforts to teach the components of giving effective presentations as scientists, graduate students commonly organized scenarios in which undergraduates could have discussions with other researchers about the project. Most described the use of “working meetings,” during which the undergraduate was actively involved in a conversation that helped them learn more about the project in a way that influenced their behaviors and/or tasks on the project. Some organized “journal club” discussions during which undergraduates would familiarize themselves with published concepts, methods, and research approaches through conversations with other researchers. Through undergraduates’ active engagement, these conversations were helpful in clarifying their thinking about content knowledge and making decisions with others about appropriate “next steps.” Some graduate students reflected on the fact that these working meetings provided opportunities for graduate students to engage in self-assessment about their teaching efficacy in the Social Domain.

Barriers

Many graduate students described challenges they faced, with respect to their teaching efforts in this domain. In some cases, graduate students felt as though they had to prioritize teaching undergraduates about practices associated with the Procedural Domain (e.g., data collection), and thus did not have “enough time” to teach undergraduates about engaging in conversations and presentations about the project. Others described the ways in which an undergraduate’s academic schedule (i.e., coursework, studying) prevented them from attending meetings and/or spending time with colleagues for intellectual conversations, journal clubs, and other opportunities to engage in dialogue, brainstorming, and project planning.

> *I don't think we get much time to reflect on these types of questions during the actual research process. It kind of just ends up being a mad rush to do the actual research and writing …*
>
> *I've tried to do things where we'll both read a paper and we'll sit down and talk about it, but it's hard to keep that regular. That's the hard part. Just in general, they're like, "I'm busy, I have this and this and this," you can't be like, "Oh, you need to read this and do it by Monday." They're like, "I have a midterm on Monday," so I always tell them, "Your classes are the most important thing right now. That stuff should be before."*

Some graduate students explained that it was challenging to prioritize teaching about technical writing when the department did not require undergraduates to submit any written deliverables associated with the research experience. Those graduate students who requested that undergraduates produce written work had a difficult time “enforcing” this request when there was no formal requirement to do so. One individual explained that, for the undergraduates they work with, “... most of them don't get much [practice] because it's not required of them.” Another individual is required to “give them a letter grade … on what they did [that] semester” but would feel more comfortable doing so if the department provided clear expectations for undergraduate performance.

Often associated with disappointment and frustration, some graduate students described how the workplace culture of their department and/or research group prevented some learning opportunities for undergraduates. This theme aligns with the “abuse of power” and “lack of psychosocial support” themes from Limeri and colleagues (2019), described as ways in which mentors “act[ed] in ways that were inappropriate given the differences in rank” and “fail[ed] to provide encouragement” to mentees, respectively. Most examples described events that occurred during research group meetings, which are opportunities for undergraduates to learn about how scientists communicate with each other, share information, and argue in favor of project ideas. Graduate students explained that if these meetings were stressful or unwelcoming to undergraduates, teaching undergraduates how to present to other scientists was challenging or altogether impossible. One individual recalled how the undergraduate they were working with was an active participant in one-on-one meetings about the project. However, this same undergraduate was “pretty much silent” in larger group meetings, due to the “lab’s dynamics.” Several individuals described how the typical behavior of PIs (i.e., their own doctoral advisors) were distressing, intimidating, or exclusionary to undergraduates and/or other colleagues. In some cases, this realization inspired graduate students to have conversations with PIs and/or colleagues about creating a more welcoming environment for undergraduates (and others) in their research group.

> *Um, so in those like meetings with the PI, she's usually, um, like very good at sharing her progress. Uh, but kind of in the bigger meetings, we have joint lab meetings. So it's two labs. Uh, she hasn't been able to go this semester, but usually in the past she doesn't participate as much. It's still very intimidating for her to ask questions because it’s a very big group. Yeah.*
>
> *My advisor's really cruel at these meetings … he writes a letter for everyone, [and] this is his <u>one</u> chance to determine if they're good, which is brutal. And so he interrupts them every five seconds to ask questions. It's rough. We try to prepare them well for that. So it's not just practicing your presentation, but it's also testing [out] answers a lot.*
>
> *Basically, my advisor doesn't want undergrads in those meetings … which I don't really agree with, but that's the way it is in our lab. So, [the undergraduate is] not really involved at all, which I think is unfortunate.*
>
> *I always try to sit down with them, "Here's what you did well, here's what you can work on," it's always stressful for them to present to your advisor, and I've also been trying to work with [the primary investigator] on how he should interact different with undergrads presenting and with grad students, because there have been some times where he goes [from] zero to 60, and is asking ... in my view, ridiculous questions that he [expects] an undergrad to know.*

Some graduate students described how their efforts to teach about effective presentations through practice “stressed out” undergraduates, which aligns with previous studies about the anxiety and stress caused by undergraduate engagement in public speaking (e.g., Gallego et al., 2022; Grieve et al., 2021). Some individuals attempted to relieve stress by teaching about and assessing their students on “smaller amounts” of material or through written work, while others were not able to come up with a way to address this.

> *I do think that having students know they will be quizzed, even if it isn’t graded, makes them more invested in the process and knowing the material. However, recently I’ve realized that I need to temper my questioning, and if there are a string of answers that the undergraduate seems to be having difficulty with I should a) stop questioning or b) ask them a question they should almost certainly get right so as to end things on a positive note.*

> *… in the bigger meetings, we have joint lab meetings … she hasn't been able to go this semester, but usually in the past she doesn't participate as much. It's still very intimidating for her to ask questions, because it's a very big group.*

> *… so that was the hardest thing with one of my undergrads, specifically. I think they're a little bit uncomfortable in speaking [even though] they know a lot about the project! … I'm still trying to get them to offer their own insight and that's the one that I just started more blatantly asking, like "what next steps could we be doing? What's interesting?" But I think that just came down to their own comfort level.*

> *… directly asking questions like 'why do you think this matters?', 'what do the results mean?', 'what would you do next?', … made students a little nervous … most likely because they think there is one right answer and they aren't sure of it.*

Teacher- and student-centered teaching

In the context of STEM research experiences as a learning environment, both teacher- and student-centered approaches are used. Similar to classroom-based teaching, even when a hands-on activity (i.e., student-centered) is planned for the day, a teacher might begin with teacher-centered approaches to introduce the topic (e.g., demonstrating, lecturing).

Teaching goals

When describing the teaching goals they had for working with undergraduate researchers, 43 (93%) graduate students identified both teacher- and student-centered pedagogical strategies. Teaching goals most often included the following teacher-centered strategies: performing a research technique for an undergraduate to observe; telling an undergraduate information about the project or a technique; assigning research papers to an undergraduate to read; and asking an undergraduate to answer specific questions about the project. These planned activities were designed to introduce new material, assign specific tasks, provide explanations, and clarify concepts that graduate students anticipated undergraduate researchers to struggle with understanding. Most often, graduate students described the ways in which they planned to teach undergraduate researchers new technical or research skills, to allow the undergraduates to make tangible contributions to the research project. They planned to do this by having undergraduates "shadow" or "watch" the graduate student perform tasks using these skills, encouraging students to "discuss" or "ask questions" while observing these tasks being performed, and to have undergraduates perform some of these tasks at the *same* time as the graduate student and/or other undergraduates (often referred to as "working side-by-side"). Another common example of teacher-centered goals related to direct instruction. One individual explained his goal of providing one-on-one instruction to the undergraduate about "the necessary knowledge he needs to understand the material which would be beyond the scope of his coursework."

> *I expect to be teaching him the necessary knowledge he needs to understand the material which would be beyond the scope of his coursework. I expect to communicate my expectations verbally, through writing, or by showing him the correct way to do things in and around the lab.*

> *… I would like my student to gain a more fundamental understanding of all of the equipment and how it works together … these goals will be met by shadowing me, asking questions and then running the experiment while I watch. Additional reading I plan to assign will be based on the materials we are studying.*
>
> *My undergraduate will shadow me and will gain practice working with the less sensitive samples that I bring to the facility. He will use the instruments under my close guidance … [while] running these experiments, we will discuss each step in detail. We will also talk about the next aspects of these experiments that he will be learning how to do.*
>
> *In the early summer, I will have more discussion and explanation of the projects to my undergrads. I will list all the techniques that they will use in the projects … I will ask them to describe what we will do [that day] in the lab … we will do the real practices in the lab. During these procedures, we will have lots of discussion. So they will have an enhanced understanding about what we are doing.*
>
> *I will first go over all the basics behind the technique with her and make sure she knows why we use this technique and how [we are] going to use this technique. Then I will give a demonstration and explain every step in detail to her. I would like to make her feel comfortable to interrupt me and ask questions any time she has confusion.*
>
> *Daily working sessions where I sit down with my undergraduate researcher and show them how to take the chunks of code in this file and copy them into their own Rscript and run it. Also where I describe (fairly verbatim of the written explanation in the file) while we are together so they can ask questions and receive answers immediately.*
>
> *While the student is working learning the technique, I will assign him to read the most recent papers published by my lab that use this technique and the original paper that explains the use of the different control strains.*

The following student-centered strategies were most often described when graduate students articulated their teaching goals: supporting an undergraduate to perform a research technique independently (or with minimal assistance); engaging the undergraduate in research activities involving data collection, data analysis, drawing conclusions from project data, writing literature reviews, and/or writing reports; having discussions with the undergraduate about relevant papers they have identified, and/or the undergraduate's opinions, questions, conclusions, etc. generated by reading the literature; and positioning the undergraduate as a research collaborator by supporting them to make recommendations about the direction of the project, designing new experiments, and/or presenting project progress to the research team.

> *I expect her to be an independent researcher who is able to do basic experiments without my help and critically think about the research projects.*
>
> *… I want them to feel confident in their abilities to do the assays without me supervising them. Currently, I'm planning on having them observe me do each assay, and I gave them each their own mini-project where they will need to utilize each assay.*
>
> *… as my undergraduate strengthens their understanding of the technique, I would like them to be able to use this technique to purify an unfamiliar reaction. For example, they should be able to run a TLC and choose a mobile phase based on their [judgment] of the polarity of a molecule and adjust [it] accordingly.*

> *My undergraduate will be able to do basic data analysis using the programs we use for X-ray crystallography … My undergraduate will be capable of using these programs for his own research and will be able to produce publishable quality results.*
>
> *… next semester, I would like to have her write a practice [grant] proposal on future directions to help her think about what she would do next in the project.*
>
> *I would like to encourage her to find papers that are relevant or interesting and have started asking her to propose experiments working toward solving our research problem.*

Teaching practices

When describing the teaching practices they used with undergraduate researchers, all 46 (100%) graduate students described the use of *both* teacher- and student-centered approaches. When describing their teaching practices, nearly all graduate students described using the following **teacher-centered** practices: asking an undergraduate to answer specific questions about the project; and performing a research technique for them to observe. More than half of graduate students described telling an undergraduate information about the project or a technique and assigning research papers to read. There were also examples of graduate students engaging undergraduates in conversations during which the graduate student would "walk them through" the different components a/an of a) scientific concept, b) effective research presentation, c) research abstract or paper (as an author), or d) previously published research paper (as a reader).

> *… the first thing I'll always do is have maybe like a five to 10 minute conversation about what the actual technique is, what it's for, and then I will discuss it, the step by step process, and then I would have them shadow me.*
>
> *I found note taking to be a huge help. When he didn't understand something, I explained it and then asked him to write down the answer. This reduced duplicate questions significantly.*
>
> *In addition to gaining understanding of the data analysis, I have also aimed to improve my [student's] understanding of the literature. I assigned several articles for my student to read several weeks ago …*
>
> *My guidance to the mentees I am working with focused on the basics of an elevator pitch - we went through the general outline of what should be discussed in an elevator pitch. We then talked about how one should have 2-3 slightly different pitches depending on the audience. Lastly, we discussed some easy strategies to make pitches more effective (e.g. make it more of a story).*
>
> *I explained to him what goes into every section, like your introduction, methodology, and results, and conclusions. And I gave him my poster as an example of how things should look. And I went over my poster with him, so that he knows what kind of things to do, and what things I don't include in the poster, what things can be like, you know, too much information or too little.*

Nearly all graduate students described using the following **student-centered** teaching practices: supporting an undergraduate to perform a research technique independently (or with minimal assistance). Approximately half of graduate students positioned the undergraduate as a research collaborator by supporting them to make recommendations about the direction of the project, design new experiments, and/or present project progress to the research team.

> *I encourage him to explain his project to others in the lab in order for him to solidify his understanding of the motivation behind his project and practice articulating his findings.*
>
> *I believe that a meaningful undergraduate research experience includes aspects of research above and beyond benchwork. I have trained my mentees on additional skills such as critically reading papers, seeking out funding opportunities, analyzing data, and presenting their results in oral, poster, and written forms.*
>
> *… the project was … about interactions between particles in a solution. The undergraduate successfully developed a model and tested the hypothesis. Unfortunately, the model showed that our hypothesis was incorrect.*
>
> *[I have been] working really hard to put the students in the right direction on a project, then giving them the freedom to explore and develop the project on their own … the goal should always be to have the student driving the direction and understanding why to take [certain] the next steps.*

Approximately one-fourth of graduate students reported engaging in one of the following practices, in support of undergraduate researchers' learning: giving undergraduates work or a unique project aligned with the student's goals, interests, or personal strengths; having discussions with them about relevant papers they have identified; and engaging them in research activities involving data collection, data analysis, and writing reports. Several graduate students described the benefits of using written work, presentations, and other activities that require undergraduates to "synthesize" what they have learned as both assessment tools and opportunities for their professional development.

> *The skills and knowledge they have gained is necessary to their role as a researcher, but at this point they should be informed enough to decide if they wish to complete experiments as a part of the project (i.e., receive and complete tasks), or if they wish to operate independently.*
>
> *… we first went through her drafts until we came to two good final [elevator] pitches together. Then, after practicing on her own and timing herself, she practiced the pitches in front of me, mostly to make sure the timing was okay and that it didn't sound [too] wordy.*
>
> *We read a lot of papers together and that was separate from their lab work, but, as we went through more and more papers, I felt that they got better at interpreting what the figures meant and thinking about the big picture in the paper … I think that that was really helpful for them.*
>
> *I've tried to make each meeting involve active learning, minimizing the time I'm speaking and allowing them to talk as much as possible.*

Implementation

Based on the experiences shared by graduate students, they employed both teacher- and student-centered teaching approaches from the beginning of their collaborations with undergraduate researchers. In general, the proportion of time spent using student-centered practices (as compared to teacher-centered practices) increased over time, as undergraduates developed more autonomy and independence. Many graduate students associate the use of student-centered pedagogy with their mentoring goals to support undergraduates in becoming “independent researchers.” As compared to the aforementioned teacher-centered practices, some of the student-centered practices graduate students used often involved some initial direct instruction from graduate students followed by tasks completed by undergraduates with little or no supervision.

> *… my undergraduate researcher [has] his own project … Through initial shadowing, followed by guided, hands-on experience under my supervision, [he] became quite independent in his work while at the same time making significant progress on a project that will lead to a publication. His clear comprehension of his work shows during … meetings [when he] presents his own work.*

Barriers

Many of the teacher-centered practices used by graduate students (e.g., meetings to “walk through” the components of a concept or paper) involved direct communication between graduate students and undergraduates, and were described as being “time consuming” or requiring considerable effort to accomplish. Additionally, some graduate students commented on the labor and time commitment required to use many teacher-centered approaches, and thus preferred to move toward the use of more student-centered approaches over time.

> *My approach to teaching these students involves continually searching for new ways to rephrase and “translate” these concepts. Crucially, I placed significant effort into providing relatable and tangible examples when developing an analogy. For instance, when a student of mine struggled to understand the concept of a positive feedback loop, … I asked [them] to think of a positive feedback loop as a series of microphones and attached amplifiers in tandem, and speaking through the first one.*

Section 2. Mentoring themes

Career development mentoring

Although the actions taken by a graduate student in support of an undergraduate’s professional goals might result in outcomes associated with both of the mentoring themes in this study, they are distinct categories. The first theme associated with mentoring describes **career development** approaches, in support of undergraduate researchers’ academic or career goals, professional development, and steps toward integration into the scientific community. In the literature about STEM research experiences, these are strong motivators for participating in a research experience, and provide long-term benefits to undergraduates (e.g., Coté et al., 2023; Gin et al., 2021; Linn et al., 2015; Romero et al., 2023). As defined for this study, a graduate student taking steps to support an undergraduate in achieving defined goals (e.g., success in coursework, degree completion, obtaining grant funding, publishing a paper, working independently as a researcher, entering the workforce, or being accepted into a graduate program) would be practicing a career development approach to mentoring.

Mentoring goals

In total, 43 (93%) of graduate students described their mentoring goals in support of undergraduates' career development. Nearly two-thirds of these graduate students expressed hope that the time spent working as a researcher with their team would ultimately support undergraduates in achieving their academic and/or career goals. Although they were aware that undergraduates have a variety of professional interests, most graduate students had goals associated with familiarizing undergraduates with the responsibilities and experiences of doctoral students. For example, graduate students wanted to support undergraduates in "successfully applying to grad schools," and completing the type of tasks that doctoral students are assigned. Some graduate students did not mention graduate school, but instead mentioned their goals to prepare undergraduates for a research-based career, or to acquire the skills, knowledge, recommendation letters, or "improved" resume needed to be eligible for future jobs and/or degree programs.

> *My goal is definitely not for them to be a perfect applicant for graduate school, but I also think that it's such a unique opportunity to gain knowledge so far beyond what their classmates have if they do research.*
>
> *I think that's really important for them to become excited in science, rather than just doing what they're told … They're doing it because they want to put it on their resume …*
>
> *… she's one of those rare pre-med people who is actually very interested in learning new skills beyond what will help her to get into med school. But there's still a little hope in the back of my mind that she'll be like, "Wow, this is actually way cooler than going to med school."*
>
> *I also want them to be able to get to where they want to go. Like, if they want to go to graduate school, they can get the letters they need …*
>
> *I expect undergraduate researchers to gain skills that will help them succeed in graduate school, specifically scientific integrity, proficiency in recording, writing, and presenting data, [and] development of laboratory skills in their area of research …*

More than half of graduate students wanted undergraduates to become skilled in staying organized as a researcher, which has two components: assessing what needs to be done, and then taking the initiative to complete those tasks. Examples include keeping track of what tasks to work on and in what order and then making a plan to do so; determining what supplies are needed and then placing the order (or informing others that new supplies are needed); and determining what type of information is needed to make progress on the project and then looking the information up.

> *… one of the goals I [have is] to get them to think independently as a researcher, … Rather than telling them, "This is what you should do today, this is what you should do tomorrow," I wanna help them learn how to do that themselves.*
>
> *my goals for her are to really get her working on her own project independently and have her think of solutions to questions that we have, and work on her own problem solving within that scope … [have] a consistent starting time and days throughout the regular semester … actively ask questions about anything that is unclear … even if [she has] already been told how to do it … keep an organized list of samples ...*

> *[I want them to be] organized, detail-oriented, willing to ask questions. The most important [thing] is that they should know what they are doing and why they are doing that.*
>
> *By the end of summer, I am hoping they can have a kind of self-study ability that they can use to keep learning new things from different areas, and put them together to complete the research tasks ... to encourage them to think carefully, practice immediately, and conclude reasonably.*

Aligned with previous studies, many undergraduates participate in STEM research experiences, to learn technical/research skills, gain discipline-specific work experience, or prepare for graduate school (e.g., Coté et al., 2023; Hess et al., 2023; Vasquez-Salgado et al., 2023). Half of graduate students described their goals to show undergraduates "what it's like" to work and/or attend graduate school in a particular field or discipline. Graduate students often expressed their desire for undergraduates to have a clear understanding about how a research team functions, including group culture, workplace dynamics, norms of communication, and how the team distributes shared tasks. For example, teams who work in a laboratory setting may have a rotating schedule for cleaning often-used areas (e.g., benches, refrigerators, sinks) and disposing of hazardous materials. Two-fifths of graduate students wanted undergraduates to show their commitment to working as part of the research team by being a "reliable" colleague, and expressed mentoring goals aligned with this theme. For example, some graduate students in Study 3 expected undergraduates to dedicate a certain number of hours each week toward achieving project goals without needing to be reminded. One individual wanted undergraduates to effectively communicate with team members when they are scheduled to support an experiment but are too sick to report to work. These two concepts – about showing undergraduates "what it's like" to be a graduate student and being a "reliable" colleague – are similar to the concept of "self-regulation" developed by Faber and colleagues (2020) from interviews with undergraduates about who researchers are. In that study, self-regulation includes "having a desire/motivation to learn, being meticulous, being studious, having resilience and persistence, and working independently" (Faber et al., 2020).

> *… we're hoping that some of them will … see what the project is like … from the animal work, to the wet lab work, to actually analyzing the data … especially for those who have expressed interest in graduate school, [to] have a good idea of what different types of projects are like, day to day.*
>
> *I expect roughly 7 hours of time spent in lab per day, with most of that time spent working on or thinking about research-related topics. I do not expect you to come to lab on weekends, but if your experiments run later than usual on weekdays, you need to stay to follow up on them as necessary … You should keep a detailed lab notebook such that someone could repeat the experiments you carry out, just from reading your notebook. You should plan to present your research in subgroup every month, and you will also present on your work during group meeting at the end of the summer.*
>
> *[My goal is for them to] be able to communicate well, show up on time, not break anything, follow directions, practicing safe lab protocol, and be engaged in the science.*

One-third of graduate students wanted to support undergraduates in doing one of the following: presenting or publishing about the research project with other scientists; independently taking active steps toward learning more about the project; and producing high-quality work associated with the project. In this study, supporting undergraduates to give scientific presentations or contribute to technical writing for a publication can involve teaching in the Social Domain (if the activities provide students with an opportunity to engage in decision-making or argumentation and learning about how scientific knowledge is constructed) and professional development mentoring (if these activities support their academic or career goals). Examples of "high-quality" work include the collection of "usable" or "publishable" data, properly documenting findings through technical writing of sufficient quality that it would not need to be re-written by others. In some cases, these comments were associated with graduate students' desire for undergraduates to work "at the level" of a graduate student.

> *I just want him to be able to finish putting that together in the form of a manuscript to submit to a peer-reviewed journal [because] one of the things that I didn't learn particularly well as an undergrad, or that I struggled with, was how to realize that I was done with a body of work that could be packaged as an individual story, and then to realize I was done, and then figure out what to pick out … to make it a complete story …*
>
> *… publications are important, because one of the undergraduates, I think it's her fourth year now, and she's looking into graduate school, and so if she could get a publication with me, I would be very happy for her, and she can apply for the schools she wants and also a fellowship.*

For one-fifth of graduate students, it was important for undergraduates to develop the skill of knowing when to ask for help. Related to the second mentoring theme (psychosocial development), some graduate students explained that they expect undergraduates to ask for help in the beginning of the research experience, but to develop confidence in working independently, which would allow them to be an independent researcher. They perceived this as important to their overall mentoring strategy, because it would allow undergraduates to be in a better position to achieve their professional goals.

> *When she encounters a problem, [I will] ask her to try to solve it first before talking to me. Explain why I am doing this, offer to discuss the problem at a concrete future time, and clarify that I will always be there to help if she gets stuck. If I actually don't know something, say I don't know it and encourage her to try to figure it out (while being there to help and support if needed).*
>
> *My primary expectations for an undergraduate researcher are that they follow lab safety rules, that they are careful to follow protocols accurately and use instruments properly, and that they ask me questions when they are confused or need help.*

Mentoring practices

All 46 (100%) of the graduate students in this study described the use of mentoring practices that they believed would support undergraduates in achieving their academic and/or career goals. As described by Vasquez-Salgado and colleagues (2023), participating in the activities of scientists, such as giving presentations, can support science identity development in undergraduates. In Study 3, three-fourths of graduate students supported undergraduates to give scientific presentations or publish about the research project with other scientists.

> *My student presented her results at a poster session as part of her summer research program, but if she were not doing that, I would have had her present her results in a formal way at one of our lab meetings.*
>
> *… our goal was to present the work at a conference and so that was something I'm trying to foster as much as possible within the students to think like, "okay, what would be impactful work that's novel that's interesting that's worth spreading to other folks?*
>
> *My undergrad would like to have a publication out before applying to grad school … To help us get on track, I have asked him to start writing NSF-style research proposals that we can work on together over the summer.*

Two-thirds of graduate students engaged in mentoring practices that they believed would directly support undergraduates in achieving their academic and/or career goals. This will be described in more detail in the Implementation section, but many graduate students dedicated time to communicating about the academic and career plans, goals, and interests of undergraduates, and then used this information to take specific actions. For example, many undergraduates expressed interest in graduate school, and so graduate students provided assistance in acquiring knowledge or developing skills to make these undergraduates more competitive applicants.

> *… one of my undergraduates wanted to get an [internship] this summer, so … I wrote a recommendation letter for her to apply for that internship program.*
>
> *Their goal over the summer is just to get experience. They're newer to research [and] open to different career paths. I've encouraged them to voice aspects of the project they like [or] dislike, to better shape the project [and] their experience.*
>
> *Both students are going to be doing honors theses in their senior year, so we've been setting up plans for that, and how their projects will help them gain the skills they want before they graduate.*

Nearly two-thirds of graduate students mentored undergraduates to become committed and reliable members of the research team. Examples of the expectations graduate students had for undergraduates include: following a regular weekly schedule; accurately documenting methods, data, and/or results; completing project tasks without reminders; and communicating with others about mistakes, unexpected challenges, or safety hazards. In support of undergraduates' professional development, these efforts were to enable undergraduates to a) be perceived by others as valuable team members, *and* b) believe that they themselves were productive team members. In this way, undergraduates are receiving training to assist them in being successful as an employee or graduate student in the future. One individual described their efforts to support an undergraduate to work "independently and on [their] own schedule." In this case, their goal was for the undergraduate, who had been taught to use immunostaining techniques (aligned with the Procedural Domain), to complete the staining process on tissues from "12 animals by the end of the summer." Aside from the laboratory skills needed to achieve this goal, this would require the undergraduate to manage their time, keep clear records in a laboratory notebook, and update the research team with their progress during weekly meetings.

> *I make my schedule for the week on Mondays and will share this with my undergraduate student so that she knows the plan going into each week … I'm flexible and only expect [her] to adhere to*

> *my schedule when she is learning experimental techniques … It is important to find the right time to start letting your mentee do everything on their own when it comes to the protocol they're supposed to be using, without feeling like they are abandoned and making sure you're still available to them for critical questions. This is also important training for future relationships that mentees will have in graduate school.*
>
> *I think that she's really gotten comfortable in the lab. In the beginning I just wanted her to be able to work independently and feel comfortable doing that and she's definitely reached that. … Now, I want her to understand more [about] project related goals ... We meet regularly and I mostly have her tell me what she's done this past week, or what she's done recently, … what's happening [and] why they think it's happening. [She keeps a]Lab Notebook, a log of daily activity, and share[s] raw and processed data over Google Drive.*

More than half of graduate students described the mentoring practices they used to support undergraduates in staying organized as a researcher, and understanding "what it's like" to work and/or attend graduate school in a particular field or discipline. Most often, graduate students included undergraduates in the activities that they (the graduate students) were required to complete, such as "chore rotations," research group meetings, and communication with the PI about project results. One individual shared their memory of the "PI ask[ing] both of us for slides, for him to give a presentation," and reflecting on how the culture of their group supported their efforts to include the undergraduate as part of the team.

> *… so she spends about, I'd say, 10 hours a week in the lab, working on research and project-related tasks. She also joins in our lab meetings and other lab functions … we are continually looking for things, beyond the research project, that we'[ll be] working on together.*
>
> *I demonstrate how to be a respectful colleague, how to maintain work-life balance in a competitive environment, how to be an honest, organized, and responsible scientist, and how to advocate for yourself in a scientific community. By emphasizing these skills, which are often not easy to develop, I hope that students will learn to build a rich and supportive environment for their own scientific growth.*

One-third of graduate students provided mentoring that they believed would support undergraduates in becoming proficient in knowing when to ask for help from others, and taking steps to learning more about the project. In both cases, graduate students were focused on the development of undergraduate independence as researchers.

> *It is extremely helpful for them to have their own independent project, not just something they work on together with another student or a mentor. "Independent" does not mean that they do not receive help or guidance, but it means that the project does not advance if they do not actively put work into it. … I just [work with] one undergraduate right now [and] at a certain point he picked up on that well enough that I didn't need to babysit.*
>
> *In the lab, I emphasize that one of the most important parts of science is asking questions - and then slowing down to think about potential answers. My expectations [include] showing up when they have said they will show up, and asking questions when they aren't clear on something. For research and technical questions, I'd like them to try to answer their own questions before coming to me. I don't expect a major hours-long effort, rather this would look like spending 5 minutes "looking" for something [or] looking up how to do something before asking. If this doesn't yield answers, that's fine. But I would expect them to try to understand first before asking.*

> *I do expect my students to be more independent now than I did at the start of the summer … I expect them to ask questions when they need clarification, but I also expect that they will be able to make experimental decisions on their own, and set their own schedules based on how long experiments will take them.*

One-fifth of graduate students employed mentoring practices that they believed would support undergraduates to produce high-quality work associated with the project, most often in the form of “usable” data or written text. These practices were connected with the perceived benefits to supporting undergraduates’ academic/career goals through the documentation of their contributions. For example, the overall experience of working with a research team would be less valuable to all parties if the undergraduate “produced” data that could not be used in future presentations, publications, or reports. One individual stated their belief that, “mentoring isn't about teaching someone how you do science, it's giving them the tools to develop into their own independent scientist.” They further explain that when *any* research team member generates results, it is common practice to discuss this with a colleague to ensure that the data is correctly interpreted. Similarly, they engage in this practice with the undergraduate working with them, to ensure that the undergraduate has a clear understanding of the quality of the data they generated, and how it should be interpreted.

> *… they want to learn about chemistry, [and] how to do the synthesis … we meet every day. When they finish their classes, they drop by the lab, and we start doing something in lab … The reports they handed in were good enough to convert [into] sections of the manuscript … They will continue working in the lab in the fall semesters but not on [a] daily basis. I expect they can continue working nicely, to wrap up another project and get publications.*
>
> *I find that usually for the first year or so, you never hear much out of the undergrad. But then, as they get more comfortable, they'll start asking questions … I knew, going into it, that she was a very strong undergrad, so I gave her a start out project, that is going to end up going into a comprehensive study … she'll be third or fourth author [on] … once we wrap this up, I want to start discussing with her, get her ideas of what she wants to do with her last semester, and hopefully she can formulate her own ... second project, with my help.*

Implementation

Most of the goals and practices within this theme involve two major phases. In the first phase, a graduate student “sets up” an undergraduate researcher with the resources they need to be successful. This might include discussing the topic, the graduate student modeling an activity for the undergraduate to observe, and/or engaging in activities together. In the second phase, the graduate student observes the undergraduate engaging in those same activities, but with more independence and autonomy. For example, a graduate student may discuss “best practices” when writing an essay for a multi-year fellowship application with an undergraduate researcher (first phase) and then later observe the undergraduate making progress on their essay, asking for feedback, and/or submitting the essay as a part of their application package (second phase). Many graduate students described specific actions they took to support undergraduates in achieving their stated academic or career goals, such as writing recommendation letters, editing application essays, introducing undergraduates to other professionals in the field, and identifying conferences or programs to apply to. In some cases, graduate students helped undergraduates in clarifying their goals. For example, one individual recalled that an undergraduate stated that they were “interested in everything.” In this case, the graduate student engaged the undergraduate in follow-up discussions about the project and specific tasks completed in recent weeks. Over time, the undergraduate learned more about their own preferences, and the graduate student helped them to articulate these in preparation for job or graduate school applications.

> *I meet with them individually at least once a week and then, all together, we meet informally once a week … One of my students plans on applying to grad school in the fall, so I’ve been working with him on his applications ... I have written one of my undergrads a recommendation letter, and I was also her reference for job applications. [The] newer undergrad was applying to summer research fellowships, so I edited her applications for those [programs].*
>
> *I've encouraged them to voice aspects of the project they like or dislike to better shape the project [and] their experience ... it depends on what the student wants, right? The student from the summer wants to go into industry, so when I heard about internship openings through other people in my group, I would pass her name along, so hopefully she can get an internship.*
>
> *… it's really important for [us] to know what we're striving for, in regards to both the specific project goals (i.e., "doing" the experiment) and the more general learning or professional development goals (i.e., 21st Century skills). A specific strategy that has helped [is having] a running Google Doc with our learning goals, that we come back at key points during the project to collaboratively update and edit as things are happening.*

Nearly all graduate students described the ways in which they communicated about expectations for the mentor-mentee relationship. Graduate students utilized formal “working meetings” and informal “check-ins” to accomplish this goal. The most common topics discussed were: work schedule (e.g., hourly commitment each week, days/times available), meetings schedule, compensation (e.g., stipend, hourly rate of pay, course credit), specific goals (e.g., present a poster at a conference, obtain a strong recommendation letter for graduate school applications), learning goals (e.g., technical skills, graduate school preparation), topics and/or sub-disciplines of interest, which help to guide which projects and tasks the undergraduate will spend time working on; and ways of working together (e.g., amount of oversight, when/how to ask for assistance, which tasks the undergraduate is responsible for). A key aspect of these conversations involved learning more about the undergraduate’s background, preparation, previous knowledge, interests, and preferences. Each of these details could support the graduate student in making weekly decisions about the way in which a particular undergraduate spends their time, in support of their academic or career goals.

For many, it was important to discuss expectations at the beginning of the semester/term, and then revisit these over time, in order to a) modify behaviors to meet expectations, or b) revise expectations to support the success of both graduate students and undergraduates. Many graduate students made decisions about project topic, scope, or activities based on their conversations about undergraduate expectations and goals for engaging in research with their group. Some described their use of written documentation of these expectations, especially in circumstances when communication between graduate students and undergraduates was not clear.

> *His ideas for short-term (one month) follow-up experiments are reasonable and rather in line with my own expectations. This is likely because we talk about the one-month timeline frequently. … If*

> *ever I feel like there is a misalignment in our expectations, I bring it up at the earliest opportunity in an informal discussion between the two of us so that we can get back on the same page … we eventually [determined] that he really likes electron microscopy and looking at nanostructures. And so we decided to just say, "Okay, so you're interested in this, [so] you can just focus on this."*
>
> *For students who are interested in grad school, I try to give them a little bit more advice about what that actually entails and what running a project is like … after having discussions with [the undergraduate], I have noticed that she isn't as interested in the basic science as the translation applications. Given this, I have tried to increase her understanding of the basic science approaches that lead to translation breakthroughs, by having her work backwards through the process instead of bottom up. I have also tried to work on her professionalism and communication as a priority …*
>
> *So, I originally started with [letting the student be] very independent. [I said,], "hey, I'm not gonna dictate your time in the lab. I like checking in with you, but just know that every time I ask, it's not a hard set deadline ... I'm setting these goals for us, and then we can come back to them." And that didn't actually work very well ... Creating a list of research and personal goals in the form of a development plan has helped ground the research experience for both parties.*

Barriers

Some graduate students were surprised by the amount of effort required to support an undergraduate's development as a reliable team member and/or lack of progress in this area. For example, one individual described how an undergraduate working with their team had been trained on the "housekeeping" tasks that all research team members were responsible for, but were not consistent in completing these. Another individual recalled how an undergraduate worked fewer hours on the project than what was agreed upon. In some cases, graduate students reflected on their own practices, and realized that their expectations for working collaboratively with an undergraduate would not be clear unless explicitly stated. Others believed that undergraduates were not motivated to follow expectations despite having clearly communicated about these.

> *During the summer, some students were more active "lab citizens" than others, even though we had a lab chore rotation … I was trying to give them as much of the full range of research experiences [as] I could, not just the pipetting.*
>
> *I think it would be best if I started the semester with a discussion of my expectations, not just hours worked, etc;. I do sort of come in just expecting that students will participate fully and be invested, but that has not always been the case.*

Psychosocial development mentoring

The second mentoring theme describes **psychosocial development** approaches, to support undergraduate researchers' emotions and feelings associated with discipline-specific learning and career development. Although technical/research skills are valuable to an undergraduate in pursuit of a STEM career, feelings of belonging, confidence, self-efficacy, motivation, and interest can support them to persist in STEM, despite encountering setbacks (Bottia et al., 2021; Estrada et al., 2018a, 2018b; Syed et al., 2019). Previous studies have shown that emotions and social connections are critical to learning and applying knowledge to real-world situations (e.g., Immordino-Yang & Damasio, 2007; Zull, 2006). For example, feelings of project ownership and enjoyment have been connected to critical thinking, academic achievement, and STEM career aspirations (e.g., Ahmed & Mudrey, 2019; Corwin et al., 2018; Hanauer et al., 2012; Hinton et al., 2008; Zull, 2006). In this study, a graduate student engaged in mentoring practices to cultivate positive feelings in and a good rapport with an undergraduate would be taking a psychosocial development approach to mentoring.

Mentoring goals

Of the graduate students in this study, 34 (74%) articulated mentoring goals that were associated with the positive emotions or feelings they hoped and/or anticipated undergraduates would experience. Three-fourths of these graduate students expressed their desire for undergraduates to develop feelings of **project ownership**. In alignment with previous studies about STEM research experiences, I define project ownership as student perception that they are in control of some portion of the project, possess some personal responsibility for the project's success, and feel excited to contribute to the overall effort (e.g., Hanauer & Dolan, 2014; Hatfull, 2010; Hernandez et al., 2018a). To generate feelings of project ownership, graduate students usually described ways in which they might support undergraduates in taking responsibility for part or all of a research project.

> *After gaining confidence in their technique, I hope they will be able to do the microscopy and data analysis on their own ... To create these opportunities for undergrads to feel ownership, I can encourage them to talk about their observations.*
>
> *My goal for them by the time they have finished working with me, is that they have achieved some level of independence within the project, which is best demonstrated through their confidence and ability to effectively communicate the results from their time in lab [and] assume some accountability for the work that was completed …*
>
> *I think the main things I could do to encourage my undergraduate to feel a sense of ownership are to give her independence and ask her opinions about data interpretation and next steps for the project. ... I am increasingly interested in making science something that everyone feels like they can access, and do, and learn about.*
>
> *They should eventually take ownership over a project or part of a project, taking direct responsibility for troubleshooting obstacles and moving it forward.*

Nearly half of these graduate students wanted to provide mentoring that led to increased feelings of **confidence** for undergraduates. Graduate students often made general statements about their desire for undergraduates to be "confident scientists" or to be confident when completing specific technical tasks. Approximately one-third of graduate students expressed mentoring goals associated with undergraduates' **sense of belonging** or **motivation**. Many previous scholars have examined the importance of feeling a sense of belonging in STEM as a student (e.g., Estrada et al., 2018a; Morton, 2021; Rainey et al., 2019), though the "level" of belonging differs between studies (e.g., group, department, institution, STEM discipline, scientific community). In this study we define a sense of belonging in an undergraduate researcher as feelings of happiness and comfort associated with a positive rapport between the undergraduate and other members of the research group. Lastly, approximately one-fifth of graduate students shared mentoring goals aligned with their desire to foster **curiosity** for the research topic of study or **enjoyment** working in STEM and/or as part of a research team.

> *… once she's able to complete an assay independently and successfully, I think she will quickly become more confident and feel like she belongs in the lab as a contributing scientist.*
>
> *Ideally they should be comfortable asking anyone in the lab for help with something. ... I believe she will quickly develop confidence and independence.*
>
> *I want them to be curious and suggest ideas they might have for independent projects once they have gained a few semesters of experience in lab.*
>
> *The number one thing that I expect from my undergrad is to show up and find something to be excited about with science. I think the most important thing is to be happy with the work that you are doing, and this is achieved by finding a project that you are interested in.*
>
> *… my focus is mostly on her enjoying her time [and] learning about science and scientists*

Mentoring practices

Graduate students (40; 87%) reported the mentoring practices they engaged in that they believed contributed to undergraduates' positive emotions or feelings. Of these, approximately half of graduate students provided mentoring that they believed would lead to gains in undergraduates' **confidence**. These practices were most often related to empowering undergraduates to work independently on their technical/research tasks associated with the project, seek help from others, share ideas about the project, and make decisions to advance the project.

> *I often see undergraduates asking questions such as "is this right?" and "does this look ok?" which, understandably, comes from a lack of confidence. I try [to] guide the conversation until they reach the answer themselves … often they already know the answer.*

More than one-third of graduate students engaged in mentoring practices in support of undergraduate feelings of **project ownership** or **motivation**. To promote project ownership, graduate students supported undergraduates to work toward a goal of completing the following technical or research tasks without needing regular reminders: completing technical or research tasks, "looking up" information or resources, determining short-term next steps, engaging in troubleshooting, addressing challenges, and reporting recent project results. In support of their motivation, graduate students tried to prevent undergraduates from feeling discouraged by challenges with research projects or emotionally detached from their research topics. One individual explained that some of the undergraduates they have worked with can "lose interest" in the project when they encounter failures. So, they addressed the fact that failure is a normal part of doing "real" research (Epistemic Domain), and that, "it's not the end of the world!"

> *… him having ownership of something is very motivating. So I think he definitely looks up more stuff on his own, compared to when I was just training him on stuff I had already worked out.*

Nearly one-third of graduate students described their desire for undergraduate researchers to feel **enjoyment** or a **sense of belonging**. Sometimes explained as a reaction to the stress that undergraduates can experience in a research environment, graduate students supported undergraduates to enjoy the experience overall by creating a “fun” or “low stress” work environment. To cultivate feelings of belonging, graduate students most often described their strategies to make undergraduates feel “welcome” and accommodated in the research team. For example, one individual strived to create an inclusive work environment by being flexible on the types of assessments they administered and deadlines for written work or research tasks, for religious, cultural, or other personal reasons. Again, approximately one-fifth of graduate students hoped to promote **curiosity** in undergraduates by learning about their interests, and connecting these to the project.

> *Initially, I ensure that they are placed on projects with clearly defined goals to help them get started in research, and not become frustrated by a very challenging project … [they] have honest discussions with me about what areas of research they are enjoying and which they don’t enjoy as much.*
>
> *I also try to strike a balance between having fun in the lab, while also performing high-quality research. For me, this has included playing funny music soundtracks … my main goal as a mentor to an undergrad is to create a space for them to work and advance their knowledge and career, without making it feel like work and instead have it be a passion.*
>
> *I try to be very open with them that there is lab work that needs to be done and it needs to be done efficiently and correctly. Beyond that their involvement and commitment level is up to them and … remind them that they are supported to do, whatever they decide to do next.*

Implementation

Nearly two-thirds of graduate students provided encouragement or praise to undergraduates, because they believed that these mentoring practices would provide them with motivation, confidence, and the comfort needed to seek support. One individual explained that they deliberately provided information about expectations with positive encouragement, to “make it really clear that it is okay if something goes wrong.” They go on to explain that it’s important for the undergraduates to feel comfortable asking questions and be honest if/when a problem arises. Others chose to provide encouragement when they observed undergraduates getting “unmotivated or too distracted” or experiencing “mental roadblocks.”

> *I've tried to encourage asking questions and sharing their own ideas by giving positive feedback (e.g. "that's a really good question", "what do you think would be good?")*
>
> *My career has been greatly aided by others who have respected and encouraged me, and I seek to play the same supportive role for my students as they discover biology … I want my undergrads to feel comfortable coming to me with questions or concerns …*
>
> *I use positive affirmations and language. I always want my undergraduate to feel encouraged and excited about science. I want to reassure them that mistakes are made in experiments … I've noticed that if I do not put pressure on my undergraduates to get it perfect the first time and allow them to make mistakes, that they learn to improve upon them in the future.*
>
> *We're [trying to note] positive progress and really talking like, "You did this, that was great!"*
>
> *… if a student is enjoying what they are doing in lab, learning and the eventual feeling of project ownership follows … I first try to emphasize that it is okay to fail and that, while it may be an*

> *annoying part of the research, we can still come out better for our failures, whether that means gaining more practice with a technique, or learning if an enzyme in a kit has gone bad.*

Within this group of graduate students who provided encouragement to undergraduates, some also took steps to make undergraduate ideas and contributions visible to others by explicitly naming the contributions made by undergraduates during formal presentations. This relates to the "partnership" mentoring practice, in which an undergraduate is treated "as an equal or valued partner," which is thought to connect to science identity development (Ann Mabrouk & Gapud Remijan, 2023). Other strategies used by the graduate students in Study 3 to "give credit" to undergraduates included listing them as co-authors on publications, adding their name to slideshows or other visuals used during presentations, and encouraging them to give presentations to highlight their contributions.

> *I am going to have my undergrad present his summer work at our next sub group and have him do this more often as a way to give him more ownership and visibility on the project.*
>
> *I've been trying to be really encouraging, … giving them credit, on slides, and talking about what they've specifically done in lab. So, if I'm presenting [in] group meeting, I'll be like, "so [student name] has been working on this synthesis, and this is what's been working and what hasn't …"*

During "working meetings" with undergraduates, one-third of graduate students discussed ways to incorporate the undergraduate's perspectives and interests into the project. Connected with teaching practices from the Knowledge Integration framework, graduate students often supported undergraduates to become more aware of their existing knowledge and efficacy during these meetings (Linn & Eylon, 2011). Some encouraged undergraduates to be more confident in sharing their ideas by asking them for their opinions, discussing norms in the research group, and explaining how the undergraduate is *already* prepared to make meaningful contributions. One individual explained how, during these meetings, "treating them more like a colleague than a student" supported undergraduate motivation and project ownership over time.

> *In order to foster a similar sense of ownership in my student, I have left a large part of the experimental planning to [him]. Instead of giving specific directions, I can give a vague goal "optimize this reaction" and discuss options ... we try to tailor his projects [to line] up, not only with his interest, but also so that he's actually learning things, because research can get repetitive.*
>
> *I usually ask my students what they liked and disliked about different experiments [and] pick a project for my mentee that is based on what they liked the most, and is also important for the overall success of my own project. This way, both of us feel invested in the work and hopefully my mentee feels like their project [is] useful for their own research goals and is something they can tackle with increasing independence.*

Nearly one-third of graduate students worked to foster positive working relationships between undergraduates and other team members, to increase the chances that undergraduates could easily receive assistance and/or career advice from these individuals.. For some, the culture and/or working environment of their research team was conducive to open communication, while others had to put effort into creating this environment. Some graduate students counseled other team members to check in with undergraduates, while others encouraged undergraduates to approach team members with questions, training, or support.

> *To combat feelings of being overwhelmed with new information, I [try] to gradually build their confidence … it is important for undergraduates to feel welcome in their new work space, so I … introduce them to other members of the lab [and] encourage these interactions, so there are multiple people they can turn to for help in the lab space.*
>
> *I also pair undergraduate students with others at similar levels, and I actively make them aware of the support system that is around them. For example, I introduce undergraduates to young graduate students in the lab who are also learning new techniques, but perhaps have greater experience with troubleshooting experimental challenges …*
>
> *I try to keep a very open line of communication with them, so that they're not afraid to ask me questions if they don't understand something. And then, I think our lab's culture in general is very open which is really nice, so I think they're comfortable asking other undergrads, or other grad students, or postdocs for help if they need it, and especially if they need help understanding a concept.*

More than a quarter of graduate students described giving undergraduates “space” to figure out how to solve a problem related to the project, or accomplish certain tasks on their own. This was described as part of the process of working together after undergraduates had received most of their training, and could work safely and efficiently on their own. Some graduate students associated this approach with reducing the stress or “pressure” undergraduates may feel when they are new to working in a research environment and/or have recently learned content knowledge that requires some reflection to fully understand.

> *I find that students learn best, and, importantly, produce the best results when they are truly invested in their own projects. To foster this engagement, I attempt to give them projects with a depth of levels of complexity. Initially, it may be a mundane task, but I choose it such that it can morph into something meaningful, and along the way I try to probe and push the project to a more meaningful one. This approach is successful because it allows the student to choose their own path for the project, face challenges (and hopefully overcome them), and slowly build complexity at their own pace.*

Reported in multiple studies, undergraduates view their mentors as less effective – and find the research experience less impactful overall – when they are unavailable to provide guidance (e.g., Ann Mabrouk & Gapud Remijan, 2023; Coté et al., 2023; Limeri et al., 2019). In this study, some graduate students communicated clearly with undergraduates that they were available and willing to answer questions about the project, content knowledge, or academic/career pathways. Related to the theme of “being available,” one-fourth of graduate students engaged in regular “check-ins” (as opposed to more formal “working meetings”) to learn more about an undergraduates’ overall emotional state during the STEM research experience.

> *The act of explaining [or] teaching a concept to [the students] seems to both motivate them to learn the material well [and] generally leading to a good discussion about the research project.*
>
> *I talk to the student whenever I see him get unmotivated or too distracted [and] have tried to mentor my undergrad in a way that would make him take ownership of his project, by making him feel more confident about his work. For example, I have encouraged him to speak to the other undergrads and grad students in the lab about his project. I also started having paper discussions*

> *two times a week. I started selecting the papers but after two weeks, I gave him the opportunity to select the papers (related to his project) that he thinks are going to help him understand his project better.*

Finally, one-fifth of graduate students engaged in reflection about their own personal perspectives in order to implement or improve their mentoring practices in this area. For example, one individual observed the impact of their teaching and mentoring practices on the emotions/feelings of an undergraduate researcher, and decided to modify their overall strategy. In this case, they felt that their initial emphasis on teaching the undergraduate to generate usable data for the project was not sufficient to support their development. As a result, they observed which activities the undergraduate enjoyed most, and increased the time spent on these activities *in addition* to those activities that would result in the generation of project data. Others shared about their efforts to recall what it was like to be an undergraduate researcher themselves, and used this information to inform their future mentoring practices.

> *… a useful strategy is to focus on the fact that everything is new to them, and that things that seem mundane to me were exciting when I was an undergraduate researcher myself.*

> *I had just outlined that I wanted them to 'stay engaged' … without really defining what that expectation would look like in practice. Part way through the experience, I was a little disappointed in my view of their engagement, but we had a discussion about how we both view engagement and switched up our strategy … I was much more pleased with [their] engagement moving forward.*

> *To support students who have been historically excluded from research spaces, I make sure to [create] space for their ideas [and consider] my perception of their confidence, while we're meeting with each other.*

> *Do good researchers make mistakes? Do they understand their projects immediately? ... I have to put myself back in their frame of mind …*

Barriers

Previous studies show that undergraduate researchers can feel emotionally challenged in scenarios such as learning a new skill, collecting data from a complex apparatus, problem solving, being responsible for part of a project over time, troubleshooting, or preparing for a research talk (Coté et al., 2023; Limeri et al., 2019). While learning new content knowledge, skills, or ways of “being” part of a research team, some undergraduates seemed – to the graduate students in this study – to experience discomfort, fear, or stress. Although graduate students did not express surprise, some explained how these stress-related emotions added to the amount of time and effort required to mentor undergraduates. Several graduate students felt that, although they had established good communication habits with each other, undergraduates were hesitant to reveal that they did not understand instructions, terminology, norms, or other information needed to make progress on the research project. This aligns with results from a study by Limeri and colleagues (2019), in which undergraduate researchers recalled situations in which the training or teaching they received was beyond their knowledge or skill level. Once they realized (or were told) that undergraduates did not understand a topic, graduate students in this study felt that they needed to check in more often, and/or find a new way to assess undergraduate understanding.

> *… it really helped to be in the positions of 'devils advocate' [or] naive observer to ask questions I normally wouldn't, to get a sense of her understanding. I hope it was helpful to her, but it's hard to gauge because I've increasingly noticed she isn't comfortable admitting when she doesn't understand something, so it's hard to get a reading.*
>
> *One thing I have learned is to check in on them … they will not always seek you out for help or clarification.*

One individual believed that they needed to spend additional time to support undergraduates in “divorcing any critical feedback about improvement [as a researcher] from their personal and professional self-worth,” a skill they would need as part of any research team. Another individual observed that an undergraduate felt “down” when experiencing research-related failures, although they had focused on teaching them about how the normal occurrence of failure in research (Epistemic Domain). This is another example of a situation in which both teaching and mentoring practices can be intertwined when working with undergraduate researchers.

> *I have found [it] effective [to administer] multiple different types of assessments, so students are not always in high-stress or high-stakes environments when they are being evaluated.*

Section 3. Frequency of codes

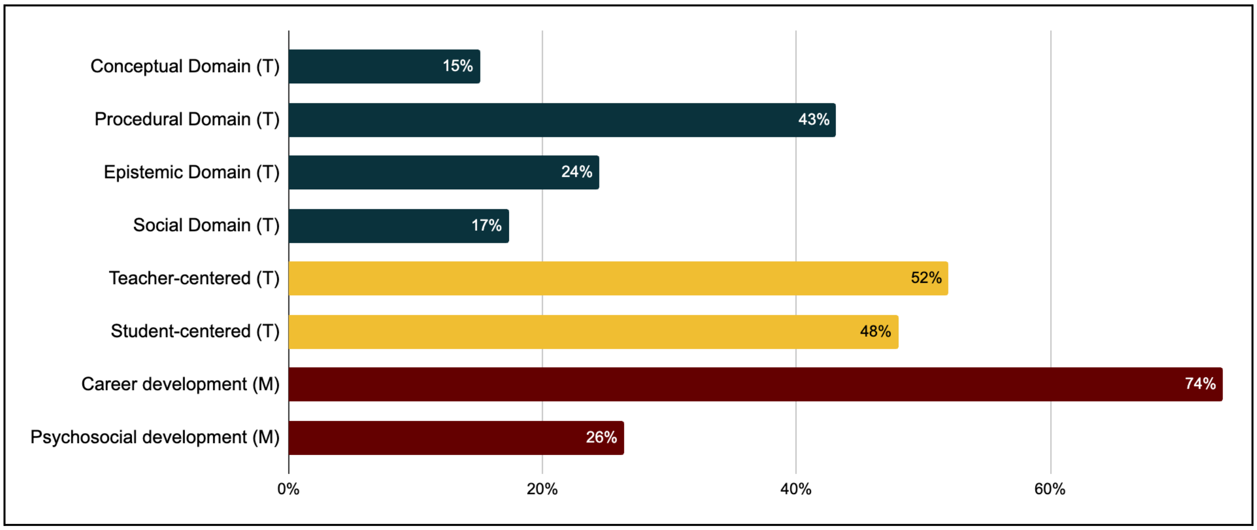
An analysis of all of the transcripts revealed that the Procedural Domain is mentioned *most* often: an average of 19.07 times per transcript, with graduate students using 334.04 characters per mention. The following codes are in the mid-range: on average, teacher-centered pedagogy was mentioned 12.46 times per transcript (335.03 characters); student-centered pedagogy was mentioned 11.50 times per transcript (295.75 characters); career development mentoring was mentioned 11.13 times per transcript (339.28 characters); and the Epistemic Domain was mentioned 10.80 times per transcript (238.50 characters). The *least* often mentioned codes were as follows: on average, the Social Domain was mentioned 7.63 times per transcript (296.34 characters); the Conceptual Domain was mentioned 6.65 times per transcript (193.84 characters); and psychosocial development mentoring was mentioned 4.28 times per transcript (239.88 characters).

As shown in **Figure 3.1**, I determined how often each of the individual codes were mentioned by graduate students, in relation to other codes most closely related. Regarding the four Domains of Scientific Knowledge, the Procedural Domain was mentioned most often (43%), followed by the Epistemic (24%), Social (17%), and Conceptual (15%) Domains. When comparing teacher- and student-centered teaching approaches, teacher-centered was mentioned most often (52%), followed by student-centered (48%). When describing mentoring themes, career development was mentioned most often (74%), followed by psychosocial development (26%).

Finally, I determined how often each of the individual codes were mentioned by graduate students, framed as their “goals” or “practices” used in the past. **Figure 3.2** shows how often each code was mentioned, compared to the total number of codes. When discussing their teaching approaches, graduate students most often mentioned Procedural Domain practices (12.5%), teacher-centered practices (10.8%), student-centered practices (8.6%), and Procedural Domain goals (8.3%). When discussing their mentoring approaches, graduate students most often mentioned Career Development practices (13.7%). Notably, all codes were discussed more often as practices than goals.

Figure 3.1

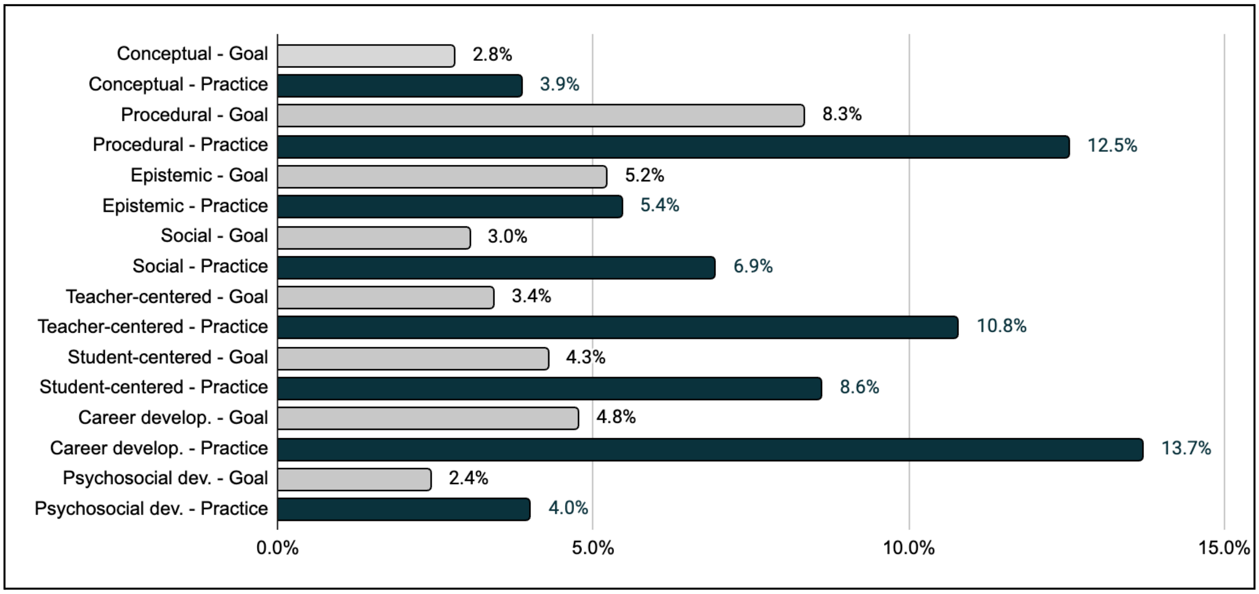
Occurrences of teaching and mentoring codes across all transcripts



Note: For each of the three code groups (separated by color), the graph shows what proportion of the time a particular code was mentioned across the set of 46 transcripts. Codes marked with (T) are teaching codes, and those marked with (M) are mentoring codes.

Figure 3.2

Comparing occurrences of each code, framed as goals or practices



Note: For each of the codes in the *BURET-TaM* instrument, the graph shows the occurrences of goals versus practices, collected as data in written form (typed) or verbal responses to interview questions. To be coded as a “goal,” the graduate student referred to the practice as something they envisioned doing in the future. To be coded as a “practice,” the graduate student referred to the practice in a way that indicated to researchers that they had engaged in the activity previously, when working with undergraduates on a research project.

Table 3.4

List of BURET-TaM *instrument codes and definitions, with representative quotes and practices generated for Study 3*

Code	Definition	Representative quotes	Practices
Teacher-centered pedagogy	Practices that involve showing, telling, explaining, or "lecturing" to students; and asking students to answer a question or provide an explanation.	*One strategy that I have found useful … is to ask them questions as they are learning and performing new techniques, in order to gauge their understanding and identify [knowledge] gaps. … I did ask her if she was familiar with traditional PCR (in which you can't reliably quantify concentration) and explained that this method allows for absolute quantification of your samples.*	Assessing undergraduate knowledge by asking them to answer questions about the project (while teaching skills, during a working meeting, etc.) Teaching undergraduate about the project by explaining and/or providing information about concept knowledge, methods, experimental design, results, progress, etc. Explaining different components of a/an a) scientific concept, b) effective research presentation, c) research abstract or paper (as an author), or d) previously published research paper (as a reader) to undergraduate
Student-centered pedagogy	Practices that involve active learning, such as positioning a student to "do" the task themselves, with the level of support that the teacher believes is needed; engaging a student in critical thinking about the scientific knowledge or processes needed to participate in research; and allowing the student to make contributions.	*I challenged him to explain design decisions more often rather than telling him what to do. One example was on device size – he asked how large of capacitors to use, I asked him to justify why he wanted to use one over the other, and eventually he came to the same conclusion I would have told him from the start.*	Teaching undergraduate to perform a research technique independently (or with minimal assistance) Teaching undergraduate about project through their participation in data collection, data analysis, writing reports, etc. Assigning undergraduate tasks or responsibilities on a project that are aligned with their goals, interests, or personal strengths
Teaching practices in the Conceptual Domain	Practices that engage students with science as a body of knowledge. This content knowledge includes scientific facts, theories, and principles.	*I have given my undergraduate researcher his own project that is conceptually related to my own research … I often ask questions about what [he] is doing and, more importantly, why he is doing something, to test his understanding of the techniques we use in lab ... For example, if we want to make a new molecule, I will have him look through the chemical literature himself and come up with a proposed way to make*	Teaching undergraduate content knowledge that informed the experimental design, data collection, data analysis, techniques, protocols, or methods used in the project Engaging undergraduate in conversations about the scientific ideas or concepts considered to be "background" information for the project Teaching undergraduate relevant content knowledge through the use

		the molecule, even if I already know a way [or] have an idea in mind.	of visual aids (e.g., drawings, diagrams, graphs, flowcharts)
Teaching practices in the Procedural Domain	Practices that utilize the methods of discovery, such as protocols or techniques, data collection, discipline-specific literature.	*… I have found a progression from shadowing to side-by-side benchwork to independent research to be an effective strategy. Because different skills and protocols take each person different amounts of time to become proficient at, I check in with my undergraduate each time to see if she feels like she can do something herself or if she would like me to demonstrate it again or perform it in parallel.*	Teaching undergraduate to carry out research methods, techniques, procedures, or protocols with proficiency, which may involve the undergraduate observing or assisting the teacher with this work Teaching undergraduate to read and understand field-specific literature Teaching undergraduate to look up information about a topic (e.g., literature, special programs, repositories, websites) to inform the selection of a particular method, technique, procedure, or protocol
Teaching practices in the Epistemic Domain	Practices that engage students in learning about how scientific knowledge is generated, through their direct involvement with scientific investigation.	*I gave them "news and views" articles from journals like nature and science. These usually do a good job of tailoring the points to a general audience while still maintaining precision and staying true to the physics. ... I think it was helpful to my mentee, because it got them engaged in the broader picture, which can make the more mundane or tedious components of what they are doing exciting. It also gives [them a] fresh perspective on research, and emphasizes that what they are doing is truly novel, and that failure is to be expected.*	Teaching undergraduate to analyze project data Based on analysis of current project data, results, and/or previous work, teaching undergraduate to a) construct hypotheses, explanations, or conclusions for the current project, b) generate or suggest their own short- or long-term next steps for the current project, or c) develop a new research project Teaching undergraduate to think critically about and/or evaluate the quality of field-specific literature (e.g., is this study relevant to our work? can we trust this source?)
Teaching practices in the Social Domain	Practices that engage students in discussions with group members about the project, research, or work, in a way that allows the student to “work things out,” make an argument, or reach a decision.	*From my own experiences with research, having coworkers to troubleshoot, discuss, and practice with leads to a huge growth in understanding and in preparation for future work environments. Towards this goal, I ask students to attend our sub-group and group meetings, which allows them to observe and participate in the nitty-gritty discussions of unfinished data and the broad conversations about a whole research project.*	Teaching undergraduate to communicate effectively with other researchers through written work (e.g., abstracts, papers, proposals) about the project Teaching undergraduate to give and receive critical feedback to other researchers about research projects (usually done through “working meetings” that influence the direction of the project) Teaching undergraduate to make a strong argument about the societal or scientific value of the project during presentations or conversations with other researchers

Career development mentoring practices	Practices related to academic/career goals, professional development, (physically doing things related to) entering the scientific community. Mentors take active steps to help students achieve their goals.	*I think that initial part of the meeting is always good to have, that check-in of academic goals, professional goals, things that they're looking forward to, and having that space is critical to establishing a strong rapport in which you're not just a "boss," … the students are individuals you care about, and you want them to grow into professionals and to graduate students, into whatever they might want to do … I've invited them to larger group meetings ... Talking less, allowing the undergrads to speak up as much as possible. Hearing from them, asking them questions I myself have about the research …*	Communicating with undergraduate about expectations for the mentor-mentee relationship, such as work schedule, meetings schedule; compensation, professional development goals, learning goals, topics and/or sub-disciplines of interest Making decisions about project topic, scope, or activities based on communication with undergraduate about their expectations, interests, and academic/career goals Taking action to support undergraduate in achieving their academic/career goals (e.g., writing recommendation letters, introducing them to others in the field, reviewing application essays)
Psychosocial development mentoring practices	Practices related to psychosocial support, community-building, inclusion, getting to know the mentee better. Mentors engage in activities to impact how a student feels (e.g., happiness, satisfaction, confidence, self-efficacy, belonging, curiosity, ownership).	*Two strategies I have found effective are connecting topics back to students' lives, or to topics they've learned about in the past, and administering different types of assessments so students are not always in high-stress or high-stakes environments when they are being evaluated ... I also make my assignments flexible, so if students need extensions for religious, cultural, or personal reasons, they feel comfortable coming to me and asking for them ... I value making the environment comfortable and open so students feel welcome to ask questions and make mistakes without judgment.*	Engaging in regular "check-ins" with undergraduate to learn more about their emotional state over time (versus only checking up on the status of project tasks) Supporting undergraduate to feel motivated by creating an emotional connection with the project, and addressing the fact that challenges are a "normal" part of research Supporting undergraduate to feel curious (about the project) by learning about their interests and connecting these to the project Fostering positive working relationships between undergraduate and other team members

Note. This table includes the major codes from the *BURET-TaM* instrument, high-level definitions, and representative quotes from graduate students. Additionally, this table shows some of the practices generated for Study 3, by applying the *BURET-TaM* instrument to the set of 46 transcripts. The complete definitions of codes can be found in **Table A3.1**.

Table 3.5

Practices used when teaching undergraduate researchers

Theme	Practice
Conceptual Domain	Teaching undergraduate content knowledge related to the overall topic or subject of the project (e.g., theory, previous studies)
	Teaching undergraduate content knowledge that informed the experimental design, data collection, data analysis, techniques, protocols, or methods used in the project
	Teaching undergraduate to make connections between the *current* project and the content knowledge undergraduate learned (or are currently learning) from their coursework
	Teaching undergraduate to make connections between the *current* project and the content knowledge undergraduate learned from working on a *previous* research project in the discipline
	Engaging undergraduate in conversations about the scientific ideas or concepts considered to be “background” information for the project
	Engaging undergraduate in conversations about relevant content knowledge from previously published work on the subject (e.g., peer-reviewed papers, literature reviews, textbooks)
	Teaching undergraduate relevant content knowledge through the use of visual aids (e.g., drawings, diagrams, graphs, flowcharts)
	Teaching undergraduate relevant content knowledge through the generation of typed or written materials
Procedural Domain	Showing undergraduate how to prepare for, set up, and perform a method, technique, procedure, or protocol
	Teaching undergraduate to carry out research methods, techniques, procedures, or protocols with proficiency, which may involve the undergraduate observing or assisting the teacher with this work
	Teaching undergraduate to independently carry out research methods, techniques, procedures, or protocols
	Teaching undergraduate to select the appropriate methods, techniques, procedures, or protocols to accomplish a particular project goal
	Teaching undergraduate to troubleshoot and overcome challenges faced when engaged in the completion of research methods, techniques, procedures, or protocols
	Teaching undergraduate to read and understand field-specific literature
	Teaching undergraduate to generate results for the project through the collection of data
	Teaching undergraduate to look up information about a topic (e.g., literature, special programs, repositories, websites) to inform the selection of a particular method, technique, procedure, or protocol

	Teaching undergraduate to independently search for field-specific literature relevant to the project
Epistemic Domain	Engaging undergraduate in conversations about how to sort through scientific ideas (from any source) to produce new scientific knowledge
	Asking undergraduate to answer questions about the project's goals, experimental design, results, etc., to identify "knowledge gaps"
	Teaching undergraduate to understand how current project's goals and results relate to the larger projects of the research group, the scientific field, or societal goals
	Teaching undergraduate to understand how different experimental designs can support the achievement of a particular project goal
	Teaching undergraduate to select an appropriate experimental design or method for data analysis for the project
	Teaching undergraduate to analyze project data
	Teaching undergraduate to understand why a particular experimental design or analysis method has been selected for use in the current project
	Based on analysis of current project data, results, and/or previous work, teaching undergraduate to a) construct hypotheses, explanations, or conclusions for the current project, b) generate or suggest their own short- or long-term next steps for the current project, or c) develop a new research project
	Teaching undergraduate to think critically about and/or evaluate the quality of field-specific literature (e.g., is this study relevant to our work? can we trust this source?)
	Teaching undergraduate to evaluate the quality of project data, to modify the data collection methods (to produce higher quality data in the future)
	Tasking undergraduate to summarize ideas from field-specific literature and connect these to their own ideas about the project, through a presentation or written work
	Teaching undergraduate to understand how field-specific literature relates to and/or informs the current project
	Teaching undergraduate to examine the results from previous studies (in published field-specific literature) to understand how the current project might contribute to new knowledge in the scientific field
Social Domain	Teaching undergraduate to deliver an effective presentation to other researchers and/or to a "general audience," at conferences, meetings, poster sessions, etc.
	Teaching undergraduate to communicate effectively with other researchers through written work (e.g., abstracts, papers, proposals) about the project
	Teaching undergraduate to give and receive critical feedback to other researchers about research projects (usually done through "working meetings" that influence the direction of the project)
	Teaching undergraduate to make a strong argument about the societal or scientific value of the project during presentations or conversations with other researchers

	Teaching undergraduate to make a strong argument about the rationale behind the project’s experimental design during presentations or conversations with other researchers
	Teaching undergraduate to include relevant details about the undergraduate’s own progression as a scientist during presentations
	Teaching undergraduate to make a clear connection between relevant literature and the current project during conversations with other researchers
	Teaching undergraduate to engage in technical writing about content knowledge relevant to the project
	Teaching undergraduate to translate or summarize content from others’ papers or presentations into their own words
Teacher-centered pedagogy	Assessing undergraduate knowledge by asking them to answer questions about the project (while teaching skills, during a working meeting, etc.)
	Teaching undergraduate about a research technique by performing tasks for them to observe
	Teaching undergraduate about the project by explaining and/or providing information about concept knowledge, methods, experimental design, results, progress, etc.
	Assigning research papers, reports, technical documents, or protocols to undergraduate to read
	Explaining different components of a/an a) scientific concept, b) effective research presentation, c) research abstract or paper (as an author), or d) previously published research paper (as a reader) to undergraduate
Student-centered pedagogy	Teaching undergraduate to perform a research technique independently (or with minimal assistance)
	Teaching undergraduate about project through their participation in data collection, data analysis, writing reports, etc.
	Teaching undergraduate to make recommendations about the direction of the project, which can include short- or long-term next steps
	Assigning undergraduate tasks or responsibilities on a project that are aligned with their goals, interests, or personal strengths
	Teaching undergraduate to design new experiments
	Teaching undergraduate to present project progress to other researchers
	Engaging undergraduate in discussions about relevant literature they have identified or selected to read

Note. In the context of research experiences as learning environments (in UREs or CUREs), these are teaching practices that can be used when collaborating with undergraduate researchers on a research project.

Table 3.6

Practices used when mentoring undergraduate researchers

Theme	Practice
Career development	Communicating with undergraduate about their academic/career preparation, experiences, interests, goals, etc.
	Supporting undergraduate to clarify their academic/career goals
	Communicating with undergraduate about expectations for the mentor-mentee relationship, such as work schedule, meetings schedule; compensation, professional development goals, learning goals, topics and/or sub-disciplines of interest
	Making decisions about ways of working together with undergraduate (e.g., amount of oversight, when/how to ask for assistance), based on their expectations, interests, and academic/career goals
	Making decisions about which tasks and responsibilities will be assigned to undergraduate, based on their expectations, interests, and academic/career goals
	Making decisions about project topic, scope, or activities based on communication with undergraduate about their expectations, interests, and academic/career goals
	Taking action to support undergraduate in achieving their academic/career goals (e.g., writing recommendation letters, introducing them to others in the field, reviewing application essays)
	Supporting undergraduate to become proficient in staying organized as a researcher, which includes assessing what tasks should be completed next, and taking the initiative to complete those tasks (with increasing independence over time)
	Supporting undergraduate to understand “what it’s like” to work and/or complete a graduate program in a particular field or discipline
	Supporting undergraduate development as a committed, reliable, and valuable member of the research team
	Supporting undergraduate to communicate with others when they need help, and accurately assessing when this is needed
	Supporting undergraduate to give accurate and high-quality presentations to other scientists about the research project
	Supporting undergraduate to publish research findings, to enable this new knowledge to be shared scientists in the field
Psychosocial development	Engaging in regular “check-ins” with undergraduate to learn more about their emotional state over time (versus only checking up on the status of project tasks)
	Supporting undergraduate to feel confident by empowering them to work independently on technical/research tasks, seek help from others, make decisions to advance the project, etc.
	Providing undergraduate with “space” to engage in problem-solving and/or accomplish tasks independently (with less pressure to perform tasks quickly)

Supporting undergraduate to feel project ownership by completing the following without needing regular reminders: completing technical or research tasks, “looking up” information or resources, determining short-term next steps, engaging in troubleshooting, addressing challenges, and reporting recent project results

Supporting undergraduate to feel motivated by creating an emotional connection with the project, and addressing the fact that challenges are a “normal” part of research

Supporting undergraduate to feel enjoyment by creating a “fun” or “low stress” working environment

Supporting undergraduate to feel a sense of belonging by making them feel welcome, providing accommodations when needed, etc.

Supporting undergraduate to feel curious (about the project) by learning about their interests and connecting these to the project

Providing undergraduate with positive encouragement or praise

Communicating to undergraduate about availability to answer questions about the project or academic/career goals

Fostering positive working relationships between undergraduate and other team members

Encouraging undergraduate to share their their ideas by asking for their opinion, discussing research group dynamics/norms, and explaining to the undergraduate how they are already prepared to make meaningful contributions

Making the contributions of undergraduate visible to others by listing them as co-authors, explicitly naming the contributions made by undergraduates during meetings or formal presentations, and encouraging the undergraduate to give presentations to others

Note. In the context of research experiences as learning environments (in UREs or CUREs), these are mentoring practices that can be used when collaborating with undergraduate researchers on a research project.

Discussion

Teaching and mentoring practices are intertwined in STEM UREs

My review of the literature revealed many instances in which the concepts of teaching and mentoring co-exist in some way, to describe the nuanced activities of professionals and students who interact with each other during STEM research experiences. For example, a 2020 study by Ceyhan and Tillotson identified three domains of support received from mentors during research experiences based on interviews with STEM majors. Intellectual support involved teaching students the content knowledge, research skills, and technical skills needed to carry out research projects; professional support involved academic and career advice, teaching students about the “big picture” of the project, and supporting their development as independent researchers; and socioemotional support involved “being accessible, helpful, patient, understanding, and respectful” (Ceyhan & Tillotson, 2020). Their intellectual support category is similar to the definition of teaching listed in **Table 3.1**. Additionally, their professional and socioemotional support categories are similar to the career development and psychosocial components of mentoring listed in **Table 3.1**. The concept of instrumental mentoring which provides undergraduates “with the skills and resources to engage in specific research-related tasks successfully,” from a 2023 study by Ann Mabrouk and Gapud Remijan, overlaps with the definitions of teaching and mentoring (the career development component) in Study 3. Multiple studies provide examples of instrumental mentoring practices, including scenarios in which mentors model and teach students the technical or research skills needed to work on a particular project (e.g., Chemers et al., 2011; Curtin et al., 2016; Haeger & Fresquez, 2016; Jayabalan et al., 2021; Robnett et al., 2018; Syed et al., 2019).

I do *not* argue that there is no overlap between teaching and mentoring. Instead, I believe that much of the recently published literature about STEM research experiences has neglected to acknowledge the amount (and value) of teaching that takes place within “mentoring” relationships in these specialized learning environments. In practice, it would be rare for a faculty, professional, postdoctoral scholar, or graduate student “mentor” to oversee the daily work of an undergraduate researcher and *not* engage in teaching associated with technical skills, research methods, or scientific content knowledge. The findings in Study 3 suggest that there are many possible scenarios in which a research team member might be engaged in *both* teaching and mentoring an undergraduate researcher. However, my decision to separate these two themes addresses many calls to distinguish between these concepts, in support of communication with undergraduates during UREs or CUREs, expectations of participants, and assessments of these experiences (e.g., Dolan, 2016; Steneck, 2006; Titus & Ballou, 2013).

There are many common activities during which an undergraduate researcher would be learning a new technical skill (e.g., DNA extraction) while also learning how to work as an independent scientist (e.g., gathering supplies from the laboratory, setting up a station, keeping accurate notes). Applying my definitions of these practices in this example, a postdoctoral scholar working with the undergraduate could be engaged in *teaching* some content knowledge about DNA, *teaching* about what is known about the types of samples they have obtained for the research project, teaching how to record data in a lab notebook, *mentoring* about how to stay organized as a scientist, and *mentoring* about how to communicate with the research team when they need assistance. In many cases, examination of the scenarios in which undergraduate researchers “learn” to work as a productive member of a research team in their scientific discipline will often reveal the presence of teaching, mentoring, or both used simultaneously. Still, the development of the new instrument tool as part of Study 3, to investigate the teaching and mentoring practices used during STEM research experiences, benefitted from clearly defining and separating practices into each category.

Procedural Domain, teacher-centered, and career development practices were most common

In the STEM community many working professionals have had apprenticeship-style training, professional development experience, or access to mentors during their undergraduate or graduate studies. However, it is common for STEM graduate students and professionals to “fall back” on the teaching and mentoring practices that they have been exposed to, even after receiving formal training in the use of evidence-based practices (e.g., Austin, 2002; Amundsen & McAlpine, 2009; Duffy & Cooper, 2020; Ebert-May et al., 2011; Hund et al., 2018; Mutambuki & Schwartz, 2018). This suggests that the process of obtaining a STEM education may not be sufficient to become skilled in teaching or mentoring others.

Graduate students most often reported their use of Procedural Domain and teacher-centered approaches when teaching, and career development approaches when mentoring. Our collective experiences participating in research experiences as undergraduates, working with undergraduates, graduate students, faculty, and other professionals in URE and CURE settings, and conducting research about teaching and mentoring in STEM disciplines have allowed us to observe that a large proportion of time at the beginning of a semester is dedicated to “training” undergraduates in research methods and techniques needed to work on a research project. This observation is supported by most studies about UREs and CUREs, which report undergraduates learning, practicing, and/or independently carrying out protocols and techniques as part of a research project (e.g., Bixby & Miliauskas, 2022; Borlee et al., 2023; Camacho et al., 2021; Freeman et al., 2023; Trott et al., 2020; Vasquez-Salgado et al., 2023). Thus, I would expect to see graduate students spending much of their time teaching in the Procedural Domain and using teacher-centered practices.

Similarly, previous literature coupled with our own experiences suggest that many graduate students in STEM disciplines who work with undergraduate researchers are motivated to do so, in part, to support their own professional development, undergraduate retention in STEM, and the future STEM workforce (Hayward et al., 2017; Limeri et al., 2019). Thus, it was thus not surprising to find that graduate students most often utilized career development mentoring with the undergraduates they collaborated with. Future studies might investigate the relationship between a graduate students’ professional development and the mentoring practices they employ with undergraduate researchers. Additionally, it is now well understood that there are many possible socioemotional impacts of UREs on undergraduate attitudes toward STEM, so it would be beneficial to learn more about the influence of psychosocial development mentoring practices on undergraduate attitudes.

UREs provide unique opportunities for teaching in the Social Domain

Although there is consensus in science education that communication and argumentation are important to inquiry-based teaching and learning, the Social Domain is rarely mentioned in studies about inquiry (Agustian et al., 2022; Jegstad, 2023; Strat et al., 2023). Recent scholarship has explored the role of project-based argumentation, writing, and other forms of communication in STEM engagement, identity, motivation, and understanding in students (e.g., Çetin & Eymur, 2017; Gao, 2024; Sewry & Paphitis, 2018; Suárez, 2020; Vasquez-Salgado et al., 2023). I was pleased to find that most graduate students in Study 3 were using teaching practices associated with the Social Domain, though it was one of the two domains least often discussed by graduate students. Aligned closely with their career development mentoring goals, graduate students felt that skills associated with argumentation, technical writing, and giving effective research talks would be valuable to those undergraduates interested in entering STEM careers. Some graduate students were challenged to teach in this domain when the program or department hosting the undergraduate did not have any formal requirement for a final deliverable (e.g., paper, poster, talk) and/or guidance regarding their expectations for undergraduate performance in this domain.

UREs provide undergraduates with varied opportunities to learn and develop their communication and argumentation skills through participation in small group discussions, research team and/or departmental meetings, technical writing of research papers, and conference presentations. In the undergraduate classroom, the development of argumentative writing skills – which involves both the Social and Epistemic Domains – supports conceptual knowledge and motivation (Chen et al., 2020, 2023). These findings suggest that teaching practices in the Social Domain that engage undergraduate researchers in discussions, presentations, and writing with other scientists support teaching (Conceptual and Epistemic Domains) in UREs and CUREs. These activities also have the potential to support career and psychosocial development mentoring goals in UREs and CUREs, especially when undergraduates are provided with opportunities to engage with the professional community beyond their immediate “daily supervisor.” If an undergraduate is supported to prepare a research talk for a regional or national conference, for example, this activity can support the expansion of their network (professional development), access to new programs and jobs (professional development), and feelings of confidence, interest, and self-efficacy (psychosocial development) from the experience (e.g., Little, 2020; O’Connor et al., 2024). Although relatively few studies have leveraged the Social Domain to support undergraduate STEM learning, I hope that future studies about UREs and CUREs will document how teaching in the Social Domain is used, and the impact of these practices on student learning and development.

Conceptual and Procedural Domains support teaching in the Epistemic Domain

Scholars believe that epistemic cognition – which includes epistemic knowledge, beliefs, and practices – may be critical to solving “ill-structured problems,” which is a key feature of working professionally as a researcher (Kitchener, 1983; Lindfors et al., 2020; Schraw et al., 1995). Additionally, studies and meta-analyses about inquiry have shown that teacher-led practices in the Epistemic Domain (or a combination of multiple domains that *include* the Epistemic Domain) lead to the largest student learning gains overall (Furtak et al., 2012; Lazonder & Harmsen, 2016; Minner et al., 2010). Graduate students in Study 3 indicated that most of the undergraduate researchers they worked with were interested in research-based careers, or hoped to clarify this goal through the URE. Thus, I argue that teaching in the Epistemic Domain is especially valuable when teaching undergraduates who are exploring or wish to enter research careers in STEM fields.

While it is common to teach scientific concepts (Conceptual Domain) in science classrooms and processes (Procedural Domain) in laboratory-based courses, neither of these practices is sufficient to engage students in learning aligned with the Epistemic Domain (Furtak et al., 2012; Stroupe, 2015; Ko & Krist, 2019). When tasked with answering questions about science that would require the use of epistemic constructs – such as selecting the "best" information, testing hypotheses, troubleshooting, and experimental design – students often apply conceptual and procedural content instead (Zetterqvist & Bach, 2023). Additionally, students are more likely to gain epistemic knowledge when goals associated with teaching in the Epistemic Domain are clearly communicated to them (Sandoval & Reiser, 2004; Zetterqvist & Bach, 2023). This suggests that students require more explicit instruction about epistemic knowledge and practices, in order to effectively apply these to problems they are faced with.

However, even when teachers believe that it is important for their students to learn epistemic knowledge, they spend more time teaching in the Conceptual and Procedural Domains than the Epistemic Domain (Jegstad, 2023; Strippel & Sommer, 2015; Zetterqvist & Bach, 2023). In Study 3, I found that graduate students more often discussed their use of teaching practices in the Procedural and Epistemic domains than the Conceptual Domain. Strippel and Sommer (2015) found that Ph.D.-holding chemistry teachers focused more on the role of research questions in experimental design than their peers without Ph.D.'s, though they were challenged to incorporate this into their classroom activities. The findings from Study 3 indicate that graduate students were challenged to accomplish their goals when teaching in the Epistemic Domain when undergraduates lacked a strong foundation in discipline-specific conceptual and procedural knowledge. This is supported by previous findings that students are better able to systematically investigate a topic when they possess a strong foundation of conceptual knowledge (Lindfors et al., 2020; Schauble et al., 1991, 1995).

Although future investigation would be needed to further our understanding of the relationship between these concepts, I can make some initial recommendations to support epistemic learning for undergraduate researchers. First, in the context of UREs, teaching in the Conceptual and Procedural Domains should be prioritized when collaborating with an undergraduate researcher who is new to the discipline, project, or research team. It is most common for more experienced researchers to "begin" with teaching in the Procedural Domain, and so I suggest that some Conceptual Domain practices be integrated, as well. This will provide a strong foundation in procedural and conceptual knowledge that students will be able to leverage when experienced researchers employ teaching practices in the Epistemic Domain. Second, in alignment with *many* studies in higher education about academic achievement, students are more likely to achieve desired learning goals when these are clearly communicated with them. To support learning epistemic knowledge in UREs, experienced researchers should share their teaching goals with students, including some goals associated with the Epistemic Domain. This list of goals – which should be revisited and discussed over time – can serve as a powerful tool to support the achievement of epistemic learning goals.

Time as a perceived barrier to teaching

A connection between the findings from Study 3 and previous studies is the identification of "time" as a perceived barrier to implementation of inquiry-based teaching practices. Time was the most common "extrinsic barrier" mentioned in previous studies about K-12 teachers integrating inquiry-based teaching into their classroom practices (e.g., Meyer et al., 2013; Strippel & Sommer, 2015). In Study 3, graduate students referenced the time commitment required to achieve their teaching goals for all four domains, but this was identified as a *barrier* to implementation for the Conceptual, Epistemic, and Social Domains only. Future work is needed to confirm this perspective, but I suspect that time was not identified as a barrier to implementing teaching practices in the Procedural Domain, because it is expected – and communicated directly from some PIs – that graduate students will dedicate significant amounts of time to teach undergraduates the procedures and techniques required to support the progress of research projects. Based on the data in Study 3, activities associated with the other three domains might be viewed as "extra" by some research groups and/or PIs, leading graduate students to feel that time spent teaching in these areas is time "taken away" from tasks associated with the Procedural Domain. This is likely one of the reasons why the Procedural Domain was the domain most often discussed by graduate students. Regardless of the expectations that PIs have for graduate students, this topic further supports my belief that the individuals training and "mentoring" undergraduate researchers should receive credit for the amount of *teaching* they are doing, as well.

Research environments impact student learning, well-being, and success

The findings from Study 3 revealed that some graduate students found the working environment in their department and/or research team to be exclusionary, inflexible, or intimidating to undergraduate researchers. In a few cases, a team's expectations about what activities an undergraduate was permitted to participate in prevented a graduate student from teaching about certain aspects of the project. More commonly, graduate students were challenged to teach undergraduates about giving an effective presentation while simultaneously preparing them to navigate interruptions and arduous questioning from senior researchers. These environments were not conducive to graduate students' teaching efforts (especially in the Social Domain), and may have also created obstacles to the graduate students' own learning and professional development.

Scholars investigating the impact of STEM culture on undergraduate education call for the elimination of competition, elitism, isolation, and individualism in learning environments, which are harmful, especially to Alaska Native, Black, Hispanic, Latinx, Native American, Native Hawaiian, and Pacific Islander students (Greenall, 2023; Morton et al., 2023; Rodriguez et al., 2022). It is not acceptable for an institution, department, or research team to announce their commitment to diversity, equity, and inclusion in STEM, while contributing to cultural practices that exclude and further marginalize people who *already* have less STEM access, resources, role models, and support (Morton, 2022). In one study, Asian, Black, Latinx, and multiracial graduate students were discouraged from engaging in non-research activities, which decreased their mental health and ability to form connections with others (Rodriguez et al., 2022). Instead, learning and work environments that foster community, friendship, openness to diverse forms of knowledge, racial solidarity, teamwork, and well-being will support all students to be successful in STEM (Albuquerque et al., 2021; Zidny et al., 2020; Santana & Singh, 2022). Although research team culture was not the intended focus of Study 3, documenting *only* the positive aspects of UREs or CUREs would result in an incomplete understanding of student experiences (Limeri et al., 2023).

Many graduate students in Study 3 reported the mentoring practices they used to support undergraduates to feel confidence, enjoyment, motivation, project ownership, and a sense of belonging. Graduate students also recognized the importance of being available for meetings and check-ins, offering positive feedback, and fostering working relationships between undergraduates and other team members. Previous studies have shown that mentoring in the form of career assistance, goal alignment, emotional support, and personal development is associated with persistence in STEM, especially for students from groups historically excluded from STEM fields (Eby et al., 2013; Estrada et al., 2018a; Hernandez et al., 2023). The majority of scholarship about mentoring practices in STEM that led to positive outcomes for undergraduate mentees has relied on self-report data from mentees, though there is concern that mentors and mentees may not agree about the practices used during UREs (Hernandez, 2019). Applying the *BURET-TaM* instrument to the data collected for Study 3 allowed for the generation of mentoring practices, as described by mentors themselves.

***The BURET* instruments can support UREs and CUREs**

In Study 3, I introduced two items: a novel instrument to identify teaching and mentoring practices used in UREs or CUREs, and a set of teaching and mentoring practices that were used by graduate students in UREs. To date, this is the third instrument developed as part of the *BURET* initiative, and all three *BURET* instruments contribute to scholarship about the UREs and CUREs as learning environments for undergraduate STEM majors. Both the *BURET Poster Presentation instrument* (*BURET-P*) and the reflective prompts (*BURET-R*) make use of data collected from undergraduate researchers, to assess their understanding of scientific practices through writing or presenting about their own research project (Helix et al., 2022). The *BURET-TaM* instrument is a codebook to identify and/or classify teaching and mentoring practices used with undergraduate researchers, and could be coupled with other data types to determine which practices are associated with particular outcomes from UREs or CUREs.

All three of these instruments can be applied to data collected from URE and CURE participants, including undergraduates, graduate students, postdoctoral scholars, instructors, faculty, professionals, and staff. Additionally, the research-based courses, projects, and activities analyzed using these instruments can be from any STEM discipline (e.g., biology, physics, STEM education) or work environment (e.g., laboratory, field, office), or work mode (e.g., in-person, virtual). Institutions that host

UREs or CUREs could make use of the *BURET-TaM* instrument or the list of teaching/mentoring practices when creating assessments to determine the efficacy of research experiences in achieving stated goals. On a smaller scale, departments or research teams could use the instrument to implement training sessions or materials to support scientists and professionals in learning how to teach/mentor undergraduate researchers, or to improve their skills in these areas. For example, if a research team discussed one or more of the practices listed in **Tables 3.5 or 3.6** as a group, the team would learn more about the practices currently being used, and the scenarios in which team members could benefit from oversight or guidance. This information could be used to "match" incoming undergraduate researchers with appropriate supervision, support performance evaluations, and make recommendations for improvement.

Limitations

This was an exploratory study to document different teaching and mentoring practices in graduate students across STEM disciplines, but not to compare the practices used between groups. Our research team did not collect demographic data from study participants, so future work would be required to identify the differences in practices based on gender, race, ethnicity, or other characteristics. Beyond this, it would be useful to collect demographic data from both graduate students and undergraduate researchers, to build on previous work reporting how graduate students with similar backgrounds to undergraduates were viewed as "role models" (Mireles-Rios & Garcia, 2019).

Although members of the research team collected extensive data about graduate students' perceptions of their teaching and mentoring goals and practices, we cannot verify that undergraduate researchers would agree with this self-report data. In an attempt to represent undergraduates' experiences, we asked graduate students to recall conversations and interactions they had with undergraduates. For example, some graduate students shared details about questions that undergraduates asked them, scenarios in which undergraduates expressed feeling comfortable with or challenged by research tasks, and observations in which graduate students interpreted the undergraduates' emotional state. However, it would be powerful to directly ask undergraduates about the practices that were used by graduate students and other research team members and their emotional state throughout the UREs. The list of practices in **Tables 3.5 and 3.6** could be used to develop a survey or interview protocol to collect this information in the future, from undergraduates in UREs or CUREs.

Both institutions represented in this study are research-intensive, so the results may not be generalizable to other institutions with lower levels of research activities. At an institution with different priorities for teaching and professional development of undergraduates and graduate students, the themes related to implementation and barriers might be more or less common. Related to this, faculty involvement with mentoring undergraduate researchers is supported differently based on their racial/ethnic background and institution type (Davis et al., 2020). Although I did not collect data from PIs directly for Study 3, it is possible that institutional support of PIs and research teams to include undergraduates in research activities impacted the implementation or barriers reported by graduate students.

Conclusions and future work

As part of a larger body of work designed to study and improve STEM research experiences, I synthesized relevant literature and collected data from graduate students who work with undergraduates on research projects in a variety of STEM disciplinary areas. In Study 3, I have described the development of definitions and an instrument, both of which were used to identify the collection of teaching and mentoring practices used by these graduate students. Future work could extend and/or improve this list of practices, study the practices being used in UREs and CUREs, and identify differences between practices used in specific disciplines, settings, or programs.

Additionally, I investigated the perspectives of these graduate students about how they implemented these teaching and mentoring practices, the barriers they encountered, and their goals for undergraduate researchers. Many graduate students understand the value of providing undergraduates with a “well-rounded” experience, in which they will learn discipline-specific knowledge, become proficient in new technical skills, make meaningful contributions to the work of the larger research group, socialize with other scientists, and participate in the activities of scientists. Through these experiences, graduate students hope that undergraduates’ perspectives are shifted, to view themselves as effective and valuable members of the research group and scientific community. Study 3 contributes to the growing body of work dedicated to characterizing the ways in which a research team can provide support or barriers to undergraduate researchers’ learning and professional development.

Self-report data have the potential to uncover “problematic” behavior that research team members may be unaware of or unwilling to report (Limeri et al., 2023). Thus, a major strength of Study 3 is the inclusion of commentary from graduate students about some negative practices employed by their doctoral advisors, PIs, research teams, or departments, and the impacts of their workplace culture. Study 3 thus highlights some factors that support or hinder their ability to achieve learning goals of undergraduates during UREs. Although research teams might recognize the benefits of UREs in supporting undergraduate learning and development, some teams may not be aware of how departmental or group norms impact graduate students’ teaching and mentoring efforts. Graduate students themselves might support learning by considering the order of activities, such as ensuring that conceptual knowledge is taught alongside procedural knowledge near the beginning of the collaboration with an undergraduate researcher, to support epistemic learning throughout the URE. Taken together, the findings from Study 3 and the literature about inquiry-based teaching suggests that teaching in the Epistemic Domain has the greatest potential to support undergraduate learning, STEM interest, graduation rates, and retention in STEM. To enhance understanding about epistemic cognition in UREs and CUREs, future studies could observe students’ epistemic practices and connect these with the teaching practices in the Epistemic Domain used to teach those students.

Aligned with the work of many previous studies about STEM research experiences, undergraduate STEM education, and mentoring in STEM fields, clear definitions of teaching and mentoring during UREs and CUREs will benefit these learning experiences for all parties involved (Titus & Ballou, 2013). Organizations that host UREs or CUREs at their institutions can use the *BURET-TaM* instrument to implement training sessions or materials to support staff and graduate students in learning how to teach or mentor undergraduate researchers. Additionally, departments may provide the instrument or lists of practices to support individual assessments. For example, departments could ask each person to identify which practices they currently use, and which practices they are struggling to implement. This reflective work can support departmental goals to broaden participation in STEM through the promotion of equity and accountability in research settings. Having a set of clear practices to guide teaching and mentoring can make it easier to determine if resources and support are being equitably distributed, especially if undergraduates have access to this information when they first join a research team. In summary, all research team members can use the definitions and lists of practices from Study 3 to set clear expectations, and prioritize those practices aligned with their shared goals. This is an important step toward setting standards for UREs, supporting teams' success and productivity, and increasing the likelihood that undergraduates will achieve their academic/career goals through the development of confidence, self-efficacy, STEM identity, proficiency in technical skills, and positive attitudes toward STEM.

Chapter contributions

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Conclusions

Collectively, the three studies included in this dissertation address a) ways in which undergraduates are supported to learn about STEM content knowledge, projects, and career pathways through engagement in technical and research experiences, b) long-term impacts of these learning experiences on their academic and career activities, c) the role of DOE national laboratories in technical and research experiences, d) strategies and perspectives of graduate students who teach and mentor undergraduate researchers, and e) perceived barriers to teaching and mentoring as described by these graduate students. The findings from these studies have motivated the development of additional studies that will be published in the near future.

Many of the most impactful intellectual and technological innovations in society have been made possible due to advances in STEM fields, and the STEM education community – which includes scholars and practitioners – is dedicated to improving the ways in which learners can access, use, and create STEM knowledge. In the U.S., many people do not have a basic understanding of STEM concepts when they enter the workforce, and many groups receive fewer resources to support their entrance and/or success in STEM degree programs and careers, including people who are first in their family to attend college or pursue an academic degree in STEM; Black, Hispanic, Latinx, Native American people; women and other gender minorities; disabled people; and people from low socioeconomic backgrounds (Honey et al., 2020; NASEM, 2023). In support of the development of a diverse workforce in science, technology, engineering, mathematics and medicine (STEMM) in the U.S., the White House Office of Science and Technology Policy (OSTP), the American Association for the Advancement of Science (AAAS), and the Doris Duke Foundation have recently released the *STEMM Equity and Excellence 2050: A National Strategy for Progress and Prosperity* (STEMM Opportunity Alliance, 2024). As a community, if we want to inspire people to learn and stay engaged in STEM disciplines over the course of their lives and careers, it is not sufficient to focus solely on high-quality instruction in the undergraduate classroom. Instead we can support **learning and retention in STEM** by providing a) early exposure to a variety of topics (e.g., climate change, renewable energy), b) encouragement to families, educators, and community members to “talk science” with children, c) opportunities for students and adults to engage in projects that connect STEM content knowledge and research questions to their cultures, communities, and identities, d) equitable access to STEM professional development opportunities, e) academic and professional environments that celebrate diversity and well-being, and f) protection against toxic, exclusionary, and harmful behaviors (Chaudhary & Berhe, 2020; Cian et al., 2022; Coté, 2023; Dou et al., 2019; Esteban-Guitart & Moll, 2014; Halford et al., 2023; Hazari et al., 2022; Marin-Spiotta et al., 2023; Schinske et al., 2016; Shellock et al., 2022; Yoon et al., 2023; Perez et al., 2023).

While this topic only addresses part of the national effort to support STEM learning and retention, **undergraduate research experiences (UREs)** are an important piece of the puzzle. There are a variety of ways that STEM research experiences can contribute to the STEM community in positive ways. The findings from Studies 1 and 2 suggest that undergraduates who participate in research experiences can learn STEM content knowledge and discipline-specific skills, become more competitive as applicants to graduate programs and jobs, develop new attitudes toward STEM, make connections between projects and their own lives, and increase the chances that they will achieve their academic and career goals. Study 3 is a first step toward defining and characterizing the teaching and mentoring practices of graduate students who work with undergraduate researchers. The findings from Study 3 suggest that, as a result of working with undergraduates, these graduate students gained experience relevant to future careers as academics, educators, industry professionals, and managers. Finally, all three of the studies in this dissertation indicate that the undergraduates participating in STEM research experiences across the U.S. each year contribute significantly to a wide variety of projects, and thus have the potential to support scientific and technological advancements in every sector.

Based on the work from Studies 1 and 2, another longitudinal study has been designed to study the experiences and academic/career activities of internship alumni from a larger set of programs hosted at LBNL. That future study (Study F1) will include information about alumni perspectives and academic/career activities in the years following their completion of a technical or research internship at LBNL, including: a) transfer from a community college to a baccalaureate granting institution, b) bachelor's, master's, doctoral, or health degrees earned, c) and entrance into STEM, health, or non-STEM workforces, d) experiences working at LBNL or other DOE national laboratories following their internship at LBNL, and e) their interest in working at any DOE national laboratory or facility in the future. Additionally, I will examine alumni motivations for applying to the programs at LBNL (when they were undergraduates), and their beliefs about how their experiences in these programs influenced their career plans and/or changed their perspectives about what it is like to work in research and/or STEM fields. Study F1 will include information about a larger group of individuals who completed a technical or research internship at a DOE national laboratory, and will track their academic and career activities between 8 and 15 years after their participation in these programs. Beyond Study F1, it would be useful for scholars to study the impacts of internships at other DOE national laboratories, in order to better characterize these learning environments. For example, it is possible that the DOE complex offers unique learning opportunities that differ from those at baccalaureate granting institutions, which are the environments most often featured in studies about STEM internships and UREs. Additionally, future studies could reveal similarities and differences between individual DOE national laboratories, and provide insights into the impacts of these internship sites and the ways in which programs across the DOE complex could be improved.

In collaboration with my colleagues in the *BURET* initiative, I have contributed to the design and implementation of a workshop series that was first offered to participants in 2018. Hosted on campus at UC Berkeley, the primary goal for this workshop series was to train participants – graduate students in STEM disciplines at UC Berkeley and LBNL – in **teaching and mentoring practices when working with an undergraduate on a research project**. Additionally, we wanted to a) expose graduate student participants to important themes related to the undergraduate experience, science education, diversity, equity, inclusion, and belonging (DEIB) in STEM, b) contribute to graduate students' professional development, c) increase undergraduate researchers' academic and career success, interest in STEM fields, happiness, and well-being, and d) contribute to a “teaching and mentoring community” at UC Berkeley and LBNL after the workshop series was complete. Although graduate students are well-positioned to serve as teachers and mentors, many will be relatively unskilled and inexperienced in these practices when they are asked to supervise the work of an undergraduate. Using Study 3 as a foundation for this work, a future study (Study F2) will be conducted to determine if the workshop impacted participants’ teaching and mentoring practices, and in what ways. Additionally, Study F2 will investigate which aspects of the training workshop participants find most useful, and how we might improve the existing workshop curriculum. Beyond the efforts of the *BURET* team to study our training workshop, other scholars could use the instrument developed in Study 3 to identify the teaching and mentoring practices used in other UREs, including course-based undergraduate research experiences (CUREs), field work experiences, etc. Applying the *BURET-TaM* instrument to other research experiences could reveal the use of additional practices that have not yet been documented and/or identify the absence of practices detailed in Study 3, in **Tables 3.5 and 3.6**. In Study 3, graduate students were asked to identify the teaching and mentoring practices they used when working with undergraduates, but a future study could do the opposite, and ask undergraduates which teaching and mentoring practices *they* believe were employed during their URE. The ways in which graduate students and undergraduates agree or disagree might allow scholars to determine where the major “gaps” in expectations are, and how to address this through training or reflective activities.

In summary, this dissertation makes several novel contributions to the field of STEM education through the investigation of topics that have little representation in the academic literature, but are deeply connected to the large number of studies published each year about research experiences for undergraduates majoring in STEM (or considering it). Studies 1 and 2 are the first of their kind to investigate the academic and career activities of individuals who completed internships at a DOE national laboratory. The DOE complex makes a large contribution to STEM education through programs and outreach activities each year, but they are extremely underrepresented in the scholarship about undergraduate education. Additionally, Studies 1 and 2 add to knowledge about the perspectives and career pathways of community college STEM majors, a population that is studied far less often than undergraduates attending baccalaureate granting institutions. Although nearly half of individuals with STEM bachelor’s or master’s degrees made use of the community college system, only a small fraction of studies about STEM research experiences and internships focus on community colleges. Finally, Study 3 provides a summary of the theory and literature about teaching and mentoring in STEM research experiences, new definitions and practices for scholars and practitioners to use, and a suite of recommendations about how to improve UREs and CUREs across STEM disciplines.

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Appendices

Figure A1.1

Community College Internship (CCI) Alumni Survey, *developed for use with CCI alumni*

Questions

First Name

Last Name

If applicable, please provide your previous name(s) used at Berkeley Lab (during your participation in the CCI program).

Contact email address(es)

Please select the term in which you first participated in the CCI program at Berkeley Lab:

If you completed a second CCI term at Berkeley Lab, please select the term:

If you participated in another internship program at Berkeley Lab (e.g., 1st term of SULI), please select the term:

If you participated in additional terms of another internship program at Berkeley Lab (e.g., 2nd term of SULI), please select the term:

Please explain why you initially decided to apply to the CCI program at Berkeley Lab.

If you completed more than one term in any of our internship programs, how did you feel that participating in an additional term would benefit you?

Did you graduate from community college? (Select all that apply)
- ☐ Yes, I obtained an A.A. or A.S. degree (STEM field).
- ☐ No, I'm currently attending community college (majoring in a STEM field).
- ☐ Yes, I obtained an A.A. or A.S. degree (non-STEM field).
- ☐ No, I'm currently attending community college (majoring in a non-STEM field).
- ☐ No, I transferred to a 4-year university without obtaining an A.A. or A.S. degree.
- ☐ No.
- ☐ I decline to state.

Did you attend a 4-year university? (Select all that apply)
- ☐ Yes, I obtained a B.A. or B.S. degree (STEM field).
- ☐ Yes, I attended a 4-year university (majoring in a STEM field), but did not graduate.
- ☐ Yes, I'm currently attending a 4-year university (majoring in a STEM field).

- ☐ Yes, I obtained a B.A. or B.S. degree (non-STEM field).
- ☐ Yes, I attended a 4-year university (majoring in a non-STEM field), but did not graduate.
- ☐ Yes, I'm currently attending a 4-year university (majoring in a non-STEM field).
- ☐ No, I'm currently attending community college.
- ☐ No.
- ☐ I decline to state.

Did you attend graduate school? (Select all that apply)

- ☐ Yes, I obtained an M.A. or M.S. degree (STEM field).
- ☐ Yes, I obtained a Ph.D. degree (STEM field).
- ☐ Yes, I attended graduate school (STEM field), but did not graduate.
- ☐ Yes, I'm currently attending graduate school (STEM field), with the goal of obtaining an M.A. or M.S. degree.
- ☐ Yes, I'm currently attending graduate school (STEM field), with the goal of obtaining a Ph.D. degree.
- ☐ Yes, I obtained an M.A. or M.S. degree (non-STEM field).
- ☐ Yes, I obtained a Ph.D. degree (non-STEM field).
- ☐ Yes, I attended graduate school (non-STEM field), but did not graduate.
- ☐ Yes, I'm currently attending graduate school (non-STEM field), with the goal of obtaining an M.A. or M.S. degree.
- ☐ Yes, I'm currently attending graduate school (non-STEM field), with the goal of obtaining a Ph.D. degree.
- ☐ Yes, I am currently attending graduate school or a professional school not represented by the choices given (e.g., medical school, law school, business school).
- ☐ Yes, I completed graduate-level studies or a professional school not represented by the choices given (e.g., medical school, law school, business school).
- ☐ No, I'm currently attending community college or a 4-year university.
- ☐ No.
- ☐ I decline to state.

Briefly describe your recent educational, professional, extracurricular, and/or personal activities.

Do you feel that your needs as a student were addressed and/or met by participating in the CCI program at Berkeley Lab? Why, or why not?

Briefly describe your recent educational, professional, extracurricular, and/or personal activities.

Briefly describe your "dream job", and why you would like to engage in that type of work.

Please specify in which of the following fields you have been employed, or have professional experience.

In the future, in which of the following fields are you interested in working? (Select all that apply)

- ☐ Academia
- ☐ Industry
- ☐ Government
- ☐ Research

- ☐ STEM policy
- ☐ STEM field, which requires use and/or knowledge of technical skills
- ☐ STEM field, which does not require use and/or knowledge of technical skills
- ☐ U.S. Department of Energy national laboratory
- ☐ U.S. Department of Energy facility (not a national laboratory)
- ☐ STEM education and/or outreach
- ☐ Science media and/or communication
- ☐ Non-STEM field, which requires use and/or knowledge or technical skills
- ☐ Non-STEM field
- ☐ None of these

Since participating in the CCI program, in what capacity have you worked at Berkeley Lab? (Select all that apply)

- ☐ Intern in another program
- ☐ Undergraduate researcher
- ☐ Post-baccalaureate researcher
- ☐ Research associate or research assistant
- ☐ Graduate student researcher
- ☐ Post-doctoral researcher
- ☐ Employee
- ☐ Technical staff
- ☐ None of these

In the future, in which ways are you interested in working at Berkeley Lab? (Select all that apply)

- ☐ Intern in another program
- ☐ Undergraduate researcher
- ☐ Post-baccalaureate researcher
- ☐ Research associate or research assistant
- ☐ Graduate student researcher
- ☐ Post-doctoral researcher
- ☐ Employee
- ☐ Technical staff
- ☐ None of these

Since participating in the CCI program, in what capacity have you worked at any U.S. Department of Energy national laboratory or facility? (Select all that apply)

- ☐ Intern in another program
- ☐ Undergraduate researcher
- ☐ Post-baccalaureate researcher
- ☐ Research associate or research assistant
- ☐ Graduate student researcher
- ☐ Post-doctoral researcher
- ☐ Employee
- ☐ Technical staff
- ☐ None of these

What factors do you believe are important for having a successful research experience at Berkeley Lab?

In your opinion, what makes the undergraduate research experiences at Berkeley Lab different or unique from other internships?

Are you still in touch with any of the members of your Mentor Group? If so, in what capacity?

As a result of your work during the CCI program at Berkeley Lab, please list any related project outcomes, such as publications, presentations, additional collaborations, employment opportunities, etc.

How did your experiences at Berkeley Lab influence your academic or career plans?

> *If possible, please elaborate on how these experiences did or did not change your perspectives about what it is like to work in research and/or science.*

Which activities or experiences from the CCI program made the biggest impact on your career, and why?

Please describe (or give examples) of ways in which you feel that engaging in undergraduate research experiences at Berkeley Lab prepared you to solve problems on other projects, or at other organizations.

What were the most valuable aspects of your experience in the CCI program, and why?

What are ways that the program could be improved to better support community college students?

Please share any memorable stories from your experiences in the CCI program.

> *These may be experiences which influenced your career goals, had a personal impact on you, changed your perspectives about working in a research-based environment, left you feeling empowered or frustrated, or challenged you in some way. Anything that comes to mind is fair game, and you are encouraged to share as much or as little as you feel comfortable with. Please note that any personally identifiable information about you or others (including names of individuals and group names) will be made anonymous.*

Please share any times when you, as an undergraduate, felt like a scientist.
(Or, researcher, biologist, chemist, physicist, mathematician, computer scientist, engineer, etc.)

Please share any other comments you might have about your experiences in the CCI program or working at Berkeley Lab.

What do you think would be an effective way to encourage community college students to apply to the CCI program at Berkeley Lab, or any undergraduate research experience?

Figure A1.2

Semi-structured interview protocol, developed for use with Community College Internship (CCI) alumni

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Questions

Section A.
Tell me a bit about you. What is your name, where are you from, and where do you work or go to school?

Why did you attend college?

What did you major in?

How did you become interested in this topic?

Can you describe what it felt like to be an undergraduate student, just beginning to study science or engineering? (use their field of study)

- How confident were you in your general research or technical skills?
- How confident were you in your ability to succeed in graduate school?
- How confident were you in your ability to succeed in the STEM workforce?

What words would you use to describe your identity?

How does <your field of study> fit in there?

Before becoming involved in research as an undergrad, did you ever feel like a scientist or engineer? (use term they chose)

What are you good at, that makes you well-suited for <their field of study>?

In <their field of study>, who are the people you identify with?

Section B.
Let's talk about the CCI program at Berkeley Lab now.

What happened that made you want to apply to the program in the first place?

Can you briefly describe the type of research you worked on?

What was the benefit of working on-site at Berkeley Lab, instead of collaborating with your team remotely?

Can you share any stories with me about times when you felt successful, as an intern?

What about times when you might have felt unsuccessful?

During the program, how much autonomy did you have as an intern?

How much did you collaborate with others on your CCI project?

When you were an intern, what kinds of conversations would you typically have with your mentors?

In what ways do you feel that participation in this program impacted you personally?

Were there times during the program when you really felt like a scientist or engineer? (use term they chose)

After you completed the CCI program:

- How confident were you in your general research or technical skills?
- How confident were you in your ability to succeed in graduate school?
- How confident were you in your ability to succeed in the STEM workforce?

Section C.
We're almost done! During the next few questions, we will discuss your future.

What are your future academic or career goals?

Thinking now about everything we've discussed, what aspects of your college experience really impacted how you might go about achieving those goals?

Let's pretend for a moment that you have a sibling who is 5-6 years younger than you. Inspired by your career path, your sibling enrolls in the same community college you attended, and declares the same exact major. What advice would you give them, or what strategies would you recommend to them, to support their success in this field?

Can you share any other experiences that you felt were important, that we haven't already discussed?

Table A1.1

Self-reported characteristics of the CCI alumni (n=12) interviewed for this study

Characteristic	interview subjects	
	n	%
STEM field of study		
Civil and/or mechanical engineering	4	33
Physics and/or mathematics	3	25
Chemistry	2	17
Biology	2	17
Environmental Science	1	8
School location		
Attended a California community college	10	83
Attended a community college outside of California	2	17
Academic achievement		
Has a B.A./B.S. in STEM	11	92
Has an M.A./M.S. in STEM	5	42
Has a Ph.D. in STEM	2	17
Studied STEM after obtaining a non-STEM B.A./B.S.[a]	2	17
Has an advanced degree in health (Ph.D., M.D., D.D.S.)	1	8
Current academic or professional activity		
Studying/working in a STEM field	11	92
Working at a DOE national lab	3	25
Attending graduate school for a STEM Ph.D.	3	25
Studying/working in a health field	1	8
Additional self-identified characteristics		
From a low-income family	5	42
Non-traditional age (during undergraduate studies)	4	33
First-generation to college	4	33
Working-class	3	25
From a rural community	2	17
Parent	3	17
Immigrant	1	8
Child of immigrants	1	8

STEM perspectives		
First in family to study science	8	67
Impacted by background, culture, and/or identity	6	50
Passionate about STEM education and outreach	6	50
“Always” liked science	5	42
Believes STEM is a pathway to upward mobility	4	33
Interested in how philosophy and science intersect	3	25
Became interested in STEM in high school	2	17

Note. The characteristics of each individual are described by more than one category.
[a] These individuals obtained a degree in a non-STEM subject and entered the non-STEM workforce before re-entering school to take STEM coursework at a community college.

Table A1.2

Interview data about CCI alumni confidence in being successful in the STEM workforce

Before CCI, how confident were you in your ability to succeed in the STEM workforce?	After CCI, how confident were you in your ability to succeed in the STEM workforce?
... in terms of getting into a science career, I felt a low sense of confidence before CCI.	*I felt that was much more of a possibility than ever before.*
I wasn’t thinking about it, it was more like, ‘I’m going to college and then I’m getting a job.’ I didn’t think about what.	*I think so, because now I had an idea of something I wanted to do in the future. Since I had a crack at it, it was … something I [could] see myself doing and feel confident doing.*
Pretty low. Yeah, I didn't have much confidence. I thought I’d just do physics as a hobby.	*Again, I wouldn’t say extremely confident, but from low to mildly confident.*
Yeah, yeah, I think I was. That’s why I wanted to have an engineering degree. I feel like it was very straight-forward. I know how to do this skill, and there’s a job I could fulfill that requires that skill.	*... it wasn’t like I hadn’t had experience in the job workforce before. Talking to well-educated academics, people of that different kind of caliber, … I think that was more of an experience for me.*
Not particularly.	*More confident. It [showed] me a different aspect of the workforce where, I think, I felt I excelled more.*

Note. During interviews, I asked the following two questions: As an undergraduate (before CCI), how confident were you in your general research or technical skills? After you completed the CCI program, how confident were you in your general research skills? These are a selection of the responses received from CCI alumni, which are representative of the individuals interviewed (n=12). Each row contains two quotes, and these are both from the same individual.

Table A1.3

Interview data about CCI alumni confidence in general research or technical skills

Before CCI, how confident were you in your general research or technical skills?	After CCI, how confident were you in your general research or technical skills?
Not very. When I first started community college the thought of doing research was ... I didn't even understand that research was something you do in an academic setting.	*I felt stronger ... I don't know if I considered myself like a great researcher, but I remember at the Lab we did, there was this whole component with CCI where we were doing … some sort of report ... and I came up with this whole research thesis ..."*
No. I was just like, 'books, study, books, study, books, study.'	*After I got done I was like, 'Oh, yeah, I can definitely do something else research-wise,' and now I can actually probably start my data collection and my analysis with whatever tools I needed. Yeah, I definitely have some understanding of how I would set up to study something.*
I couldn't grasp what scientists do. I could understand that chemists wear lab coats and do titrations. So, basically, I had no understanding.	*I felt you know, I could do research. Again, I don't remember one moment of clarity, like, 'I know this!' But, it was a gradual process. It was high, I'd say.*
I had no experience with general research.	*[The] reality was, that I wasn't that confident in my lab skills, but I really felt like I'd come a long way in putting together that research paper. I think just the process of writing a paper and doing a poster presentation and going from researching this background of this field and connecting that with my own research, ... it felt like I had gained a lot. For sure.*
At the time, I didn't know what research was.	*Very confident. Now I knew more of what that entails ... when it comes to doing research in biology and that kind of field, when it comes to wet lab stuff, way more confident.*

Note. During interviews, I asked the following two questions: As an undergraduate (before CCI), how confident were you in your general research or technical skills? After you completed the CCI program, how confident were you in your general research or technical skills? These are a selection of the responses received from CCI alumni, which are representative of the individuals interviewed (n=12). Each row contains two quotes that are from the same individual.

Table A1.4

Interview data about CCI alumni confidence in being successful in graduate school

Before CCI, how confident were you in your ability to succeed in grad school?	After CCI, how confident were you in your ability to succeed in grad school?
I didn't put thought into that. It was, I knew college was a thing I should do, but I didn't think past that.	*At that point, I was actually thinking about that more. I was confident enough that was what I wanted to do. I could do it.*
... it was on my radar, but I didn't really. I needed to know exactly what I was going to end up focusing on in civil [engineering]. … I don't think I had thought of research as something I wanted to focus on.	*Well yeah, [CCI] was like grad school 101. That was like, 'okay, this is a little tiny version of what you have to do in grad school.' So, yeah, for sure, that was … I don't know how much closer you can get in an internship with how he worked with us, you know.*
Oh yeah, no. I didn't think I could handle community college! Like, grad school was something other people did. No.	*Definitely was thinking about it. I felt pretty confident that I could get to grad school. I had a better understanding of what that entailed, and what that looked like. Like I said before, we were joking about how we were all going to get our PhDs. Now that was an option.*
I might've had an inflated sense of confidence because I had no idea what it would be like. I was so out of touch, I didn't really know what a PhD was.	*I felt excited and optimistic about my ability to [succeed] in grad school afterwards.*
No, I thought that would be a dead end. Yeah, so I, in the back of my mind, I thought I'd do engineering, so at least I could get a job ... That sounded the most financially viable path for me at the time.	*After research, after [the] CCI program, I said, 'absolutely I will go for graduate school.' I think the feeling that I could do research, because there was always a lack of confidence. I thought I was average, and how could I contribute to research? But, going in and doing research, I felt I could make a contribution. That all fell nicely in front [of] me.*

Note. During interviews, I asked the following two questions: As an undergraduate (before CCI), how confident were you in your ability to succeed in graduate school? After you completed the CCI program, how confident were you in your ability to succeed in graduate school? These are a selection of the responses received from CCI alumni, which are representative of the individuals interviewed (n=12). Each row contains two quotes that are from the same individual.

Table A1.5

Survey data about CCI alumni “dream jobs”

Briefly describe your "dream job", and why you would like to engage in that type of work.
I want to be a technical manager. I would have to do both technical and managerial work. Also, it would be at a company that cares about having a good workplace culture and investing in its employees.
I would ideally like to be a research scientist at a DOE National Lab … studying nuclear reactions as they pertain to nuclear astrophysics. I am interested in understanding the origins of the elements in our universe, which many government and university labs are working towards.
I want to be a research scientist working in a collaboration on a large experiment. I enjoy working with diverse groups of people and I would enjoy … choosing what direction I want my research to go in.
I would like to do the mechanical work that can best maximize efficiency [for] major utilities … figuring out what would be the best equipment to transport water from treatment plants, or designing the best route for electricity to travel with the least amount of power loss.
I would like to work as a pharmaceutical liaison acting as a medical and scientific expert engaged in driving key initiatives in research, publications, medical education and field intelligence ... collaborating with researchers and physicians to develop new life saving drugs and treatments.
My dream job was to be a renewable energy scientist at [DOE national lab] or similar … because I am deeply passionate about the intellectual challenges and excitement of working with cutting edge people.
My dream job would be to be a design engineer or process engineer for companies such as [for-profit company] or [for-profit company] … because the work of an engineer is directly related to the advances we see in this world today. It is always exciting to say that ‘I have been a part of this great invention.’
I'd like to work in computational research focusing on the ocean and atmosphere. Computer programming keeps me excited to solve problems every day, and applying it to natural science keeps me interested and passionate about my work on longer time scales.

Note. In the survey CCI alumni were asked to respond to the prompt shown above. These responses are a representative selection of the responses received.

Table A1.6

Coding categories, codes, and sub-codes applied to survey and interview data

Category from SCCT model	**Coding category**	**Generated codes**	**Generated sub-codes**
Personal inputs	Personal inputs	Gender	
		Race/ethnicity	
		First-generation to college	
Background contextual influences	Background contextual influences	Pre-program social supports and barriers	Attitudes toward community college
			Support from family and friends (of STEM academic/career goals)
Proximal contextual influences	Proximal contextual influences	Pre-program social supports and barriers	Support from people associated with the community college
			Learning experiences available to community college students
		Social supports and barriers	Support from people associated with the learning experience
			Established network associated with the learning experience
			Kindness from people associated with the learning experience
			Mentoring received during the learning experience
Learning experiences	Learning experiences	Pre-program learning experiences (Courses, clubs, other opportunities to learn about STEM)	
		Learning experience (Community College Internship at LBNL)	
	Skill development	Pre-program STEM skills	
		STEM skills	

	Knowledge about STEM careers	Knowledge about STEM careers	
Self-efficacy	Self-efficacy, confidence, STEM identity	Self-efficacy	
		Confidence	
		Feeling like a scientist or engineer (STEM identity)	
Outcome expectations	Outcome expectations	Pre-program STEM outcome expectations	Expectations of admittance into the learning experience (CCI)
			Expectations of success in a STEM career
			Expectations about working in research
			Expectations of graduating from a baccalaureate granting institution
			Expectations of attending graduate school
		STEM outcome expectations	Expectations of success in a STEM career
			Expectations about working in research
			Expectations of graduating from a baccalaureate granting institution
			Expectations of attending graduate school
Interests	Academic and career interests	Pre-program STEM interests	
		STEM interests	Interest in a specific research or STEM field/topic
Choice Goals	Academic and career goals	Academic and career goals	
Choice Actions	Actions	Academic and career actions	
Persistence	Persistence	Persistence in STEM	

Table A2.1

Primary academic major of study participants

Primary academic major	CCI alumni		SULI alumni		CCI/SULI alumni combined	
	n	%	*n*	%	*n*	%
Total	86	100	90	100	176	100
Biology	11	13	17	19	28	16
Chemistry	11	13	12	13	23	13
Physics	8	9	13	14	21	12
Chemical engineering	9	10	11	12	20	11
Mechanical engineering	16	19	3	3	19	11
Electrical engineering	5	6	8	9	13	7
Computer science	3	3	8	9	11	6
Environmental science	7	8	4	4	11	6
Engineering	6	7	1	1	7	4
Materials science/engineering	1	1	6	7	7	4
Civil engineering	6	7	0	0	6	3
Mathematics	1	1	4	4	5	3
Bioengineering	1	1	1	1	2	1
Non-STEM	1	1	1	1	2	1
Nuclear engineering	0	0	1	1	1	0.5

Table A2.2

Current jobs held by study participants

Current job	CCI alumni		SULI alumni		CCI/SULI alumni combined	
	n	*%*	*n*	*%*	*n*	*%*
Total	86	100	90	100	176	100
Research or laboratory assistant [a]	8	9	16	18	24	14
Chemical engineer	9	10	10	11	19	11
Civil or mechanical engineer	17	20	1	1	18	10
Software engineer	6	7	8	9	14	8
Physicist	3	3	8	9	11	6
Chemist	3	3	6	7	9	5
Postdoctoral scholar	1	1	8	9	9	5
Engineer	6	7	1	1	7	4
Biologist	3	3	3	3	6	3
Clinical scientist	3	3	3	3	6	3
Electrical engineer	0	0	5	6	5	3
Environmental scientist	5	6	0	0	5	3
Physician	2	2	3	3	5	3
STEM company founder	5	6	0	0	5	3
Computer or data scientist	1	1	3	3	4	2
Health or medical staff	1	1	3	3	4	2
Software developer	3	3	1	1	4	2
Faculty (within a STEM department)	2	2	2	2	4	2

Pharmacist	2	2	1	1	3	2
Research associate	3	3	0	0	3	2
Safety/security specialist (within a STEM department)	3	3	0	0	3	2
Bioengineer	1	1	1	1	2	1
Technician	0	0	2	2	2	1
Mathematician	0	0	1	1	1	0.6
Nuclear scientist	0	0	1	1	1	0.6
Physical therapist	0	0	1	1	1	0.6
Dentist	0	0	1	1	1	0.6
Other [b]	5	6	13	14	18	10

Note: This information is current as of December 2021. The job held by one individual may be described by more than one category. [a] This category includes those individuals who are currently attending a research-based graduate program and work as research assistants. [b] In order to protect the identities of study participants, any job or professional activity held by SULI or CCI alumni outside of the STEM or health career pathways will not be described outside of the “other” category.

Table A2.3

Academic achievements of study participants by career pathway

Academic achievements by career pathway	CCI alumni		SULI alumni		CCI/SULI alumni combined	
	n	%	*n*	%	*n*	%
Total	86	100	90	100	176	100
STEM						
currently on a "STEM career pathway"	**76**	**88**	**64**	**71**	**140**	**80**
some undergraduate work [a]	0	0	0	0	0	0
associate degree (e.g., A.A, A.S.)	35	39	0	0	35	20
bachelor's STEM degree (e.g., B.A., B.S.)	72	80	63	70	135	77
bachelor's non-STEM degree (e.g., B.A., B.S.)	3	3	0	0	3	2
master's STEM degree (e.g., M.A., M.S.)	21	23	14	16	35	20
master's non-STEM degree (e.g., M.A., M.B.A.)	1	1	0	0	1	0.6
Ph.D. STEM degree	7	8	22	24	29	16
Ph.D. non-STEM degree	0	0	0	0	0	0
health degree (e.g., M.D., D.D.S., Pharm.D.)	0	0	0	0	0	0
Health						
currently on a "health career pathway"	**5**	**6**	**12**	**13**	**17**	**10**
some undergraduate work [a]	0	0	0	0	0	0
associate degree (e.g., A.A, A.S.)	0	0	0	0	0	0
bachelor's STEM degree (e.g., B.A., B.S.)	4	5	12	13	16	9
bachelor's non-STEM degree (e.g., B.A., B.S.)	1	1	0	0	1	0.6
master's STEM degree (e.g., M.A., M.S.)	0	0	3	3	3	2
master's non-STEM degree (e.g., M.A., M.B.A.)	0	0	0	0	0	0

Ph.D. STEM degree	0	0	0	0	0	0
Ph.D. non-STEM degree	0	0	0	0	0	0
health degree (e.g., M.D., D.D.S., Pharm.D.)	4	5	7	8	11	6
Non-STEM						
currently on a “non-STEM career pathway”	**5**	**6**	**14**	**16**	**19**	**11**
some undergraduate work [a]	2	2	5	6	7	4
associate degree (e.g., A.A, A.S.)	2	2	0	0	2	1
bachelor’s STEM degree (e.g., B.A., B.S.)	0	0	10	11	10	6
bachelor’s non-STEM degree (e.g., B.A., B.S.)	2	2	0	0	2	1
master’s STEM degree (e.g., M.A., M.S.)	0	0	1	1	1	0.6
master’s non-STEM degree (e.g., M.A., M.B.A.)	0	0	1	1	1	0.6
Ph.D. STEM degree	0	0	0	0	0	0
Ph.D. non-STEM degree	0	0	0	0	0	0
health degree (e.g., M.D., D.D.S., Pharm.D.)	0	0	0	0	0	0

Note: This information is current as of December 2021. Each individual represented in this study was categorized as being on a STEM, health, or non-STEM career pathway. For example, graduate students enrolled in a STEM degree program and individuals employed in the STEM workforce would both be included in the “STEM career pathway” category. [a] These individuals are currently enrolled in an undergraduate program and/or they have completed some undergraduate-level coursework, but did not graduate with an associate or bachelor’s degree.

Figure A2.1

Selection of questions from the Community College Internship (CCI) Alumni Survey

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Questions

First Name

Last Name

Contact email address(es)

Please select the term in which you first participated in the CCI program at Berkeley Lab:

If you completed a second CCI term at Berkeley Lab, please select the term:

If you participated in another internship program at Berkeley Lab (e.g., 1st term of SULI), please select the term:

If you participated in additional terms of another internship program at Berkeley Lab (e.g., 2nd term of SULI), please select the term:

Did you graduate from community college? (Select all that apply)
- ☐ Yes, I obtained an A.A. or A.S. degree (STEM field).
- ☐ No, I'm currently attending community college (majoring in a STEM field).
- ☐ Yes, I obtained an A.A. or A.S. degree (non-STEM field).
- ☐ No, I'm currently attending community college (majoring in a non-STEM field).
- ☐ No, I transferred to a 4-year university without obtaining an A.A. or A.S. degree.
- ☐ No.
- ☐ I decline to state.

Did you attend a 4-year university? (Select all that apply)
- ☐ Yes, I obtained a B.A. or B.S. degree (STEM field).
- ☐ Yes, I attended a 4-year university (majoring in a STEM field), but did not graduate.
- ☐ Yes, I'm currently attending a 4-year university (majoring in a STEM field).
- ☐ Yes, I obtained a B.A. or B.S. degree (non-STEM field).
- ☐ Yes, I attended a 4-year university (majoring in a non-STEM field), but did not graduate.
- ☐ Yes, I'm currently attending a 4-year university (majoring in a non-STEM field).
- ☐ No, I'm currently attending community college.
- ☐ No.
- ☐ I decline to state.

Did you attend graduate school? (Select all that apply)
- ☐ Yes, I obtained an M.A. or M.S. degree (STEM field).
- ☐ Yes, I obtained a Ph.D. degree (STEM field).
- ☐ Yes, I attended graduate school (STEM field), but did not graduate.

- ☐ Yes, I’m currently attending graduate school (STEM field), with the goal of obtaining an M.A. or M.S. degree.
- ☐ Yes, I’m currently attending graduate school (STEM field), with the goal of obtaining a Ph.D. degree.
- ☐ Yes, I obtained an M.A. or M.S. degree (non-STEM field).
- ☐ Yes, I obtained a Ph.D. degree (non-STEM field).
- ☐ Yes, I attended graduate school (non-STEM field), but did not graduate.
- ☐ Yes, I’m currently attending graduate school (non-STEM field), with the goal of obtaining an M.A. or M.S. degree.
- ☐ Yes, I’m currently attending graduate school (non-STEM field), with the goal of obtaining a Ph.D. degree.
- ☐ Yes, I am currently attending graduate school or a professional school not represented by the choices given (e.g., medical school, law school, business school).
- ☐ Yes, I completed graduate-level studies or a professional school not represented by the choices given (e.g., medical school, law school, business school).
- ☐ No, I’m currently attending community college or a 4-year university.
- ☐ No.
- ☐ I decline to state.

Briefly describe your recent educational, professional, extracurricular, and/or personal activities.

In the future, in which of the following fields are you interested in working? (Select all that apply)

- ☐ Academia
- ☐ Industry
- ☐ Government
- ☐ Research
- ☐ STEM policy
- ☐ STEM field, which requires use and/or knowledge of technical skills
- ☐ STEM field, which does not require use and/or knowledge of technical skills
- ☐ U.S. Department of Energy national laboratory
- ☐ U.S. Department of Energy facility (not a national laboratory)
- ☐ STEM education and/or outreach
- ☐ Science media and/or communication
- ☐ Non-STEM field, which requires use and/or knowledge or technical skills
- ☐ Non-STEM field
- ☐ None of these

Since participating in the CCI program, in what capacity have you worked at Berkeley Lab? (Select all that apply)

- ☐ Intern in another program
- ☐ Undergraduate researcher
- ☐ Post-baccalaureate researcher
- ☐ Research associate or research assistant
- ☐ Graduate student researcher
- ☐ Post-doctoral researcher
- ☐ Employee

- ☐ Technical staff
- ☐ None of these

In the future, in which ways are you interested in working at Berkeley Lab? (Select all that apply)

- ☐ Intern in another program
- ☐ Undergraduate researcher
- ☐ Post-baccalaureate researcher
- ☐ Research associate or research assistant
- ☐ Graduate student researcher
- ☐ Post-doctoral researcher
- ☐ Employee
- ☐ Technical staff
- ☐ None of these

Since participating in the CCI program, in what capacity have you worked at any U.S. Department of Energy national laboratory or facility? (Select all that apply)

- ☐ Intern in another program
- ☐ Undergraduate researcher
- ☐ Post-baccalaureate researcher
- ☐ Research associate or research assistant
- ☐ Graduate student researcher
- ☐ Post-doctoral researcher
- ☐ Employee
- ☐ Technical staff
- ☐ None of these

Note: The *Community College Internship (CCI) Alumni Survey* contains additional questions, but Study 2 only includes data generated from the analysis of this subset of questions.

Figure A2.2

Selection of questions from the LBNL Internship Alumni Survey

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Questions

Name

Contact email address(es)

Check any of the following that apply to you:
- ☐ First generation to college (no parent/guardian in the household is a college graduate)
- ☐ Near-first generation to college (a parent/guardian is a college graduate, but you had little to no exposure to information about how to succeed in college)
- ☐ Attended community college
- ☐ Graduated from a 4-year school (in a STEM field)
- ☐ Graduated from a 4-year school (in another field)
- ☐ Attended graduate school (in a STEM field)
- ☐ Graduated with an M.A./M.S. (in a STEM field)
- ☐ Graduated with an M.A./M.S. (in another field)
- ☐ Graduated with a Ph.D. (in a STEM field)
- ☐ Graduated with a Ph.D. (in another field)
- ☐ Attended another school type (e.g., medical school, law school)
  Write-in ________________
- ☐ None of these
- ☐ Decline to state

Check any of the following that apply to you:
- ☐ After the internship, worked at Berkeley Lab (in some capacity)
- ☐ After the internship, worked at another DOE laboratory (in some capacity)
- ☐ Currently working at Berkeley Lab
- ☐ Currently working at another DOE laboratory
- ☐ In the future, interested in working at Berkeley Lab
- ☐ In the future, interested in working at another DOE laboratory

Please select the term in which you first participated in the internship program (e.g., SULI, CCI, BLUR, VFP, BLUFF, etc.) at Berkeley Lab:

Briefly describe your recent educational, professional, extracurricular, and/or personal activities.

Note: The *LBNL Internship Alumni Survey* contains additional questions, but Study 2 only includes data generated from the analysis of this subset of questions.

Table A3.1

BURET-TaM *instrument*

Category	Code	Description
Teaching	Goal	Subject explains their goals, plans, and ideas about teaching practices that they would like to use in the future. This code does not include activities that have already happened.
Teaching	Practice	Subject explains the teaching practices that they have used in the past, with the student(s) they are currently working with, or the student(s) they have worked with in the past on research projects. This code would not be used to describe students they have worked with while teaching a “traditional” course, for example. While using this code, select one or more of the Domains of Scientific Knowledge aligned with the teaching practices described.
Teaching	Conceptual Domain	Practices that engage students with science as a body of knowledge. This content knowledge includes scientific facts, theories, and principles. Teachers provide students with explicit opportunities to learn about the scientific content knowledge needed to understand the project and check student comprehension; provide students with potential or actual definitions; apply, relate, compare, and contrast concepts and others’ definitions of these concepts; discuss content knowledge behind the “experimental setup” or project; and discuss how the project relates to the material that students have learned from their classes or previous projects. Students explain how the concepts they have learned apply to the project; and share their own ideas and mental models. Additionally, the teacher can provide students with conceptually oriented feedback on their work to support students in developing a more sophisticated understanding of the content, and connecting this to their prior knowledge.
Teaching	Procedural Domain	Practices that utilize the methods of discovery. Students receive training and engage in hands-on activities for the project; independently work in the lab or on a protocol; ask questions about the protocols or techniques based on what they know about scientific concepts or principles; collect and/or record project data; read scientific papers in the discipline and/or research topic; learn the methods, calculations, etc., needed to complete the project (and how to properly apply them); create charts or graphs to represent project data visually; discuss the rationale behind the “experimental design” used in the project; design their own experiments. Additionally, the teacher can provide students with feedback on their work, based on the protocols or techniques needed to complete project work; provide training to “check their work” with respect to data, calculations, parameters, etc. Note

		that this code does not include the evaluation of data, which is part of the epistemic domain.
Teaching	Epistemic Domain	Practices that engage students in learning about how scientific knowledge is generated, through their direct involvement with scientific investigation. Students learn about how a particular scientific field generates new knowledge, and that this knowledge is subject to change; compare and contrast observations, data, or procedures used in the project (or those from another project); interpret project data to develop explanations; collect data from and/or generate new scientific knowledge from their own experiment or a modified version of a previously used design; generate and revise their own predictions, hypotheses, theories related to the project or field of study; generate or suggest their own short- or long-term next steps for the project, or a new project; and critically think about and evaluate published work (and existing data) in this field. Additionally, the teacher can discuss with students how to select different experimental designs for use in different situations, for different reasons, etc.; others' ideas or explanations about this work (and allow students to compare, contrast, or evaluate these); what is normal in this field, in terms of these types of research studies or experiments (nature of science); and the role/rate of failure in this type of research setting, using these tools and/or protocols.
Teaching	Social Domain	Practices that engage students in discussions with group members about the project, research, or work, in a way that allows the student to "work things out," make an argument, or reach a decision. Students express their thoughts about the success or challenges with the project; argue or debate scientific ideas; compare and contrast the STEM content knowledge (learned for or applied to the project) with emerging knowledge that may not be agreed upon by all researchers in this field; work collaboratively with other group members on the project; present in group meetings, poster sessions, conferences, etc.; participate in journal club-style discussions to familiarize themselves with literature and studies relevant to the project; write a research abstract, project proposal, summary, etc., about the project (regardless of the stage of the project); contribute to writing a paper for a conference and/or for publication. Additionally, the teacher can provide students with feedback on their ideas about how to advance this field, and provide students with the opportunity to communicate these ideas publicly with others through talks, papers, and other modes. In this dimension, the act of sharing their ideas with others is a mechanism for students to examine and evaluate their own developing understanding of science. Note that this code does not include the critical analysis of papers and published results, which is part of the epistemic domain.
Teaching	Teacher-centered pedagogy	Practices that involve showing, telling, explaining, or "lecturing." This code includes instances when a teacher asks a student to

		answer a question or provide an explanation.
Teaching	Student-centered pedagogy	Practices that involve active learning, such as positioning a student to "do" the task themselves (sometimes described as working “independently” on a task), with the level of support that the teacher believes is needed; engaging a student in critical thinking about the scientific knowledge or processes needed to participate in research; and allowing the student to make contributions (these could be actions or ideas).
Mentoring	Goal	Subject explains their goals, plans, and ideas about mentoring practices that they would like to use in the future. This code does not include activities that have already happened.
Mentoring	Practice	Subject explains the mentoring practices that they have used in the past, with the student(s) they are currently working with, or the student(s) they have worked with in the past on research projects. While using this code, select one or both of the mentoring codes aligned with the mentoring practices described.
Mentoring	Career development	Practices related to academic/career goals, professional development, (physically doing things related to) entering the scientific community. A mentor could support a student by discussing plans for graduate school; supporting their efforts to apply for jobs; preparing them to work independently as a scientist or professional; or enabling them to engage in activities characteristic of scientists (i.e., doing what scientists do). This code could be used if support is offered to students while they are studying for an exam or certification; reaching out to employers or professors (potential advisors); taking active steps toward achieving academic or career goals. When using this code to indicate a mentor’s support of student independence, the student could be showing this through leading a subproject (at a higher level than just working independently on tasks), or other activities related to professional development and leadership.
Mentoring	Psychosocial development	Practices related to psychosocial support, community-building, inclusion, getting to know the mentee better. A mentor could support a student by encouraging them to “feel” like a scientist (or other role); feel confident while engaged in research, professional development, presentations, etc.; fostering their sense of belonging, self-efficacy (feeling as though they can do the activities characteristic of scientists). When using this code, mentors are engaged in activities with a goal to impact the way that a student feels (e.g., happiness, satisfaction, confidence, self-efficacy, belonging, curiosity, ownership).

Note: This instrument is designed to categorize the teaching and mentoring practices of faculty or professionals working with undergraduate researchers.

Table A3.2

Overview of BURET-TaM *instrument development*

Transcript	Coders	Instrument development stage
URG040	A.M.B., E.M.S., L.E.C., M.R.H.	Generating initial themes, codebook development
URG024	A.M.B., E.M.S., L.E.C., M.R.H.	Generating initial themes, codebook development
URG036	A.M.B., E.M.S., L.E.C.	Generating initial themes, codebook development
URG047	A.M.B., E.M.S., L.E.C., M.R.H.	Codebook development
URG043	A.M.B., E.M.S., L.E.C.	Codebook development
URG047	A.M.B., E.M.S., L.E.C.	Coding, codebook refinement
URG034	A.M.B., E.M.S., L.E.C.	Coding, codebook refinement
URG046	A.M.B., E.M.S., L.E.C.	Coding, codebook refinement
URG040	A.M.B., E.M.S., L.E.C.	Coding, codebook refinement
URG043	A.M.B., E.M.S., L.E.C.	Coding, codebook refinement
URG025	A.M.B., L.E.C.	Coding, finalization of individual code definitions
URG031	E.M.S., L.E.C.	Coding, finalization of individual code definitions
URG039	A.M.B., E.M.S, L.E.C.	Coding, finalization of individual code definitions
URG047	A.M.B., L.E.C.	Coding, intercoder agreement (κ) = 0.46, discussion
URG034	A.M.B., L.E.C.	Coding, intercoder agreement (κ) = 0.74, discussion
URG046	A.M.B., L.E.C.	Coding, intercoder agreement (κ) = 0.63, discussion
URG047	A.M.B., L.E.C.	Coding, intercoder agreement (κ) = 0.60
URG034	A.M.B., L.E.C.	Coding, intercoder agreement (κ) = 0.82
URG046	A.M.B., L.E.C.	Coding, intercoder agreement (κ) = 0.80

Table A3.3

Teaching practices that graduate students reported using when working with undergraduate researchers

Practice type	Count (%)	Representative quotes
Teacher-centered	46 (100%)	*One strategy that I have found useful … is to ask them questions as they are learning and performing new techniques, in order to gauge their understanding and identify [knowledge] gaps. … I did ask her if she was familiar with traditional PCR (in which you can't reliably quantify concentration) and explained that this method allows for absolute quantification of your samples.*
Student-centered	46 (100%)	*I challenged him to explain design decisions more often rather than telling him what to do. One example was on device size – he asked how large of capacitors to use, I asked him to justify why he wanted to use one over the other, and eventually he came to the same conclusion I would have told him from the start.*
Procedural Domain	46 (100%)	*… I have found a progression from shadowing to side-by-side benchwork to independent research to be an effective strategy. Because different skills and protocols take each person different amounts of time to become proficient at, I check in with my undergraduate each time to see if she feels like she can do something herself or if she would like me to demonstrate it again or perform it in parallel.*
Epistemic Domain	46 (100%)	*I gave them "news and views" articles from journals like nature and science. These usually do a good job of tailoring the points to a general audience while still maintaining precision and staying true to the physics. ... I think it was helpful to my mentee, because it got them engaged in the broader picture, which can make the more mundane or tedious components of what they are doing exciting. It also gives [them a] fresh perspective on research, and emphasizes that what they are doing is truly novel, and that failure is to be expected.*
Conceptual Domain	45 (98%)	*I have given my undergraduate researcher his own project that is conceptually related to my own research … I often ask questions about what [he] is doing and, more importantly, why he is doing something, to test his understanding of the techniques we use in lab ... For example, if we want to make a new molecule, I will have him look through the chemical literature himself and come up with a proposed way to make the molecule, even if I already know a way [or] have an idea in mind.*
Social Domain	44 (96%)	*From my own experiences with research, having coworkers to troubleshoot, discuss, and practice with leads to a huge growth in understanding and in preparation for future work environments. Towards this goal, I ask students to attend our sub-group and group meetings, which allows them to observe and participate in the nitty-gritty discussions of unfinished data and the broad conversations about a whole research project.*

Table A3.4

Mentoring practices that graduate students reported using when working with undergraduate researchers

Practice type	Count (%)	Representative quotes
Career development mentoring	46 (100%)	*I think that initial part of the meeting is always good to have, that check-in of academic goals, professional goals, things that they're looking forward to, and having that space is critical to establishing a strong rapport in which you're not just a “boss,” … the students are individuals you care about, and you want them to grow into professionals and to graduate students, into whatever they might want to do … I've tried to be as open as possible. I want them to know that I see them as a colleague, not "my undergrad." I've invited them to larger group meetings ... Talking less, allowing the undergrads to speak up as much as possible. Hearing from them, asking them questions I myself have about the research. ... skills include hypothesis generation and testing, critical thinking and questioning, perseverance, troubleshooting, failure analysis, always thinking about "the next step," communication, and a bunch more. I consider these skills to really be critical 21st century skills that are needed in many professions of today and the future.*
Psychosocial development mentoring	40 (87%)	*I often see [the] undergraduates asking questions such as, "is this right?" and "does this look okay?" which understandably comes from a lack of confidence. I try not to just give a straight yes-no answer to these and instead try to reflect it back to them and just guide the conversation until they reach the answer themselves. Often they already know the answer. I think this is a good way to build confidence and make undergraduates more aware of what they actually know.* *Two strategies I have found effective are connecting topics back to students' lives, or to topics they've learned about in the past, and administering different types of assessments so students are not always in high-stress or high-stakes environments when they are being evaluated ... I also make my assignments flexible, so if students need extensions for religious, cultural, or personal reasons, they feel comfortable coming to me and asking for them ... I value making the environment comfortable and open so students feel welcome to ask questions and make mistakes without judgment.*