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Examining the Variations in Undergraduate Students' Conceptions of Successful Researchers: A Phenomenographic Study

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ABSTRACT
Undergraduate education represents an important transitional stage in which students make career decisions, and undergraduate research experiences (UREs) play a critical role in training the next generation of science, technology, engineering, and mathematics researchers. Extensive studies have identified the different ways in which researchers and graduate students understand their profession, but little work has focused on undergraduate students. To contribute to this gap in literature, this study examines how undergraduate students conceptualize successful researchers. Data were collected using semistructured interviews with transfer students at a research-intensive university, in which participants articulated how they perceive a successful researcher and how their conception had changed based on their undergraduate experiences. Using phenomenography as the research approach, three conceptions of successful researchers were identified based on variations within the following aspects: process of research, interactions with other researchers, and scope of contribution. Retrospective conceptions were more simplistic, with little appreciation for the complex methodological processes and collaborations needed to meaningfully contribute to the research community. After UREs, participants reported conceptions with more nuanced understanding that successful researchers demonstrate proactive engagement, collaboration, and contribution. These findings can be applied to facilitate meaningful research experiences and target undergraduates' professional development as they are enculturated into the research community.

INTRODUCTION
Undergraduate research experiences (UREs) enculturate students into the scientific community by providing the social support network and resources needed to explore more advanced professional opportunities (Lopatto, 2007; Jones *et al.*, 2010; Thiry and Laursen, 2011; Bangera and Brownell, 2014) and by presenting a potential career pathway for the next generation of scientists (Seymour *et al.*, 2004; Hunter *et al.*, 2007; Russell *et al.*, 2007; Graham *et al.*, 2013; Linn *et al.*, 2015). These research experiences also provide opportunities for students to develop their critical-thinking and problem-solving skills and to contribute to novel research in science (Hunter *et al.*, 2007; Eagan *et al.*, 2013; Baiduc *et al.*, 2017). However, transitioning from the classroom setting to professional research environments is challenging for students. During their initial research experiences, students typically struggle with adapting to the learning environment and integrating into the unique social structures within the research community (Balster *et al.*, 2010).

For students to successfully pursue a science career, their ideas of the scientific profession need to be aligned with an informed view of the work done by scientists (Hunter *et al.*, 2007; Burgin and Sadler, 2013). This alignment is contingent upon the

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different ways in which students understand what it means to be a scientist. Existing literature on student conceptions of scientists has primarily focused on the K–12 educational contexts: Students often view science as a set of rigidly defined tasks that are performed by scientists with a narrow range of identities (Hodson, 1993; Brickhouse *et al.*, 2000; Calabrese Barton and Yang, 2000; Calabrese Barton *et al.*, 2008; Tan and Calabrese Barton, 2008; Gilbert and Yerrick, 2001). Many students may lack real-world references about who scientists are that allow them to counter these potentially marginalized conceptions (Ryder & Leach, 1999; Barman, 1999; Finson, 2002; Aschbacher *et al.*, 2010).

The call for a diverse and scientifically educated workforce also indicates a need for research training and literacy in a broad range of science, technology, engineering, and mathematics (STEM) disciplines as opportunities for education and discovery in STEM are often intertwined (PCAST, 2012; NGSS Lead States, 2013). At the postsecondary education level, there have been studies that have documented undergraduate student outcomes, experiences, and interactions in STEM research settings (Hunter *et al.*, 2007; Russell *et al.*, 2007; Sadler and Mckinney, 2010; Gilmore *et al.*, 2015; Linn *et al.*, 2015; Carter *et al.*, 2016; Bowman and Holmes, 2018). Because of the challenges associated with the transition to the research community, it is essential to understand the various ideas that undergraduates hold about the research profession to support a more seamless transition and enculturation into the research community. However, little work has directly examined undergraduate students' ideas and views of researchers and their practice. To complement the existing literature, we ask in this study: What are the qualitatively different ways that undergraduate students conceptualize success as a researcher?

Researchers as Members of a Community of Practice

Examining undergraduates' conceptions of successful researchers will establish insights into their ideas about what behaviors they believe must be adopted to achieve success within the research community. Individuals' conceptions of success can influence their goal orientation within STEM, thereby affecting their motivational and behavioral trajectories and outcomes (Nerstad *et al.*, 2020; Zuckerman and Lo, 2021). Identifying the different conceptions that students hold about success can be informative for developing or adapting UREs in targeted ways to address potentially incompatible expectations that may not align with the authentic practices of professional researchers in the research community.

We focus on conceptions of successful researchers, because researchers perform and perpetuate the practices of the research community. Research is a "community of practice" consisting of scholars who collectively uphold historically situated norms and values (Lave and Wenger, 1991). The community of practice is a shared social space in which members determine the standard practices and behaviors that constitute success (Wenger, 1998; Farnsworth *et al.*, 2016). Members and the practice cannot be separated when conceptualizing how the norms and values of a community are collectively constructed. Therefore, researchers and their practice are distinguishable but inseparable entities when investigating individuals' ideas of how success is achieved within the research community.

In the context of STEM research, a community of practice is formed when researchers regularly meet to help one another, expand access and knowledge in the community, and produce open and transparent results that will be beneficial to society (Stevens *et al.*, 2018). Research communities are dynamically evolving knowledge systems with rules that are not often explicitly stated but instead implicitly established through involvement in the researchers' practices that promote progress and impact (Mohan and Kelly, 2020). Viewing researchers as members of a community of practice is informative for understanding how they develop goals for their work, interact with others within the community, and negotiate meaning (Wenger, 1998; Jho *et al.*, 2016).

Members who are newcomers to a community of practice begin on the periphery, and the progression to becoming an established member occurs via "legitimate peripheral participation." Legitimate peripheral participants have limited knowledge and responsibilities but participate in authentic activities to acquire knowledge and skills that would ideally mobilize them from the periphery to the center of the community (Brown *et al.*, 1989; Farmer *et al.*, 1992; Hunter *et al.*, 2007; Balster *et al.*, 2010; Thiry *et al.*, 2011). Because undergraduate students often start as newcomers to the research, the community of practice framework has previously been applied to investigate how students pursue independent research and navigate the unique cultural and social structure of the research community (Thiry and Laursen, 2011; Vandermaas-Peeler *et al.*, 2015; Quan *et al.*, 2018). Studies on UREs have demonstrated that engagement in the research community provides students with an opportunity to learn about a researcher's practice by being situated in the authentic social and cultural context of the research enterprise (Sadler and McKinney, 2010; Thiry and Laursen, 2011; Linn *et al.*, 2015). Engagement in authentic experiences of the research practice is essential for developing the traits, attitudes, and habits necessary to be successful within the community (Thiry *et al.*, 2011).

Upon entry into the research community of practice as newcomers, undergraduate students hold their own values and behaviors based on their previous scientific experiences (Mohan and Kelly, 2020). As students begin on the periphery of the research community, they rely on more senior researchers for advice and feedback to gain a deeper understanding of what values are accepted and what behaviors are necessary to succeed. As undergraduate students are enculturated into the research community, their shifting understanding of research can be manifested in their conceptions of researchers whom they consider to be successful.

Understanding students' pre-existing ideas about how researchers achieve success is essential for providing targeted supports that could facilitate student development as emerging scholars within the community of practice. Although an extensive literature has investigated the different ways that professional researchers understand their practice, few studies have focused on undergraduate students. We will review existing research in this area to introduce our research approach and situate the existing gap in studies on undergraduates.

Research Approach and Literature Review

This study uses phenomenography as the research approach that guides the approach to the research question and interpretation of the results. Phenomenography investigates the qualitatively different ways that individuals experience, understand, or think about a phenomenon (Marton, 1981, 1986). The different awareness is organized into an "outcome space," which represents a set of descriptions, or conceptions, that are logically related to one another and reveal the distinctive ways in which individuals conceptualize the phenomenon (Marton and Booth, 1997). It is important to note that the use of the term "outcome" should not be conflated with traditional student outcome measures (e.g., course grades). Instead, the outcome space is constructed by defining specific features (called "aspects") that individuals attend to when describing the phenomenon, as well as the differences (called "variations") within each aspect that articulate how different individuals conceptualize the same phenomenon (Marton and Tsui, 2004; Supplemental Table S1). Variations across the different aspects are related to identify conceptions, considered to be the basic units of description in phenomenographic research that collectively describe the way that a phenomenon can be understood (Marton and Pong, 2005). In contrast to examining aspects individually, distinguishing conceptions across all aspects in an outcome space provides a more holistic and relational understanding of the various ways in which individuals experience, understand, and think about a phenomenon.

Phenomenography is conceptually different from phenomenology, even though both relate to human experience (Hasselgren and Beach,1997; Cibangu and Hepworth, 2016). Whereas phenomenology directly examines the essence of the phenomenon of interest, phenomenography describes the variations in participants' understanding of the phenomenon to generate collective meaning (Barnard *et al.*, 1999; Larsson and Holmström 2007). In the context of this study, the phenomenon is the practices and behaviors of a successful researcher. The phenomenological approach would study this phenomenon directly to describe the essence of being a researcher. In contrast, the phenomenographic approach examines the variations in how a group of individuals, in this case undergraduate students, understand what it means to be a successful researcher.

Phenomenography has been used to explore many aspects of higher education (Entwistle, 1997; Richardson, 1999; Åkerlind, 2005) and is especially suited for investigating and ultimately describing different conceptions of a phenomenon (Svensson, 1997; Marton and Pong, 2005). Specifically, a few studies have examined how researchers across disciplines perceive and understand the nature of research. For example, Åkerlind (2008a) identified a total of five aspects that university faculty in Australia attend to as they experience their research and academic work: researcher intentions; research process; anticipated outcomes; attitudes toward research; and the relationships among research questions, the field of study, and personal and societal issues. Variations within each of these aspects are based on an inclusive hierarchy in which each progressive categorical conception expands upon the previous conception, suggesting an increasing sophistication in the overall understanding of the nature of research.

Brew (2001) reported multiple qualitatively different ways by which faculty in Australia conceptualized research. The aspects of researcher intentions and research processes are differentiated by the degree to which researchers view their work as a personal journey with an internal process versus a pathway to an external product (Brew, 2001). Similarly, two other studies examined how faculty in Australia, New Zealand, South Africa, and the United Kingdom conceptualize research (Bills, 2004; Kiley and Mullins, 2005) in relation to the aspects of research process and anticipated outcomes. Åkerlind (2008a) summarized the variations in these conceptions by the extent to which researchers recognize research as: 1) methodological and systematic, 2) a platform to innovate new knowledge, or 3) an opportunity to achieve a more nuanced conceptual insight or understanding of their work.

Other studies identified variations in how researchers interpreted success based on impacts of their work on themselves individually, the research community, or a broader world (Åkerlind, 2008a). For example, Bruce *et al.* (2004) identified variations in which researchers in information technology attributed the significance of their work to 1) personal goals that foster professional gain, 2) broader academic research and industry goals, or 3) research outcomes that solve real-world problems and serve everyday technology users. Taken together, these aforementioned studies provide a fundamental understanding of how academics and industry researchers across the world conceptualize research and academic work.

Graduate education represents a critical developmental stage when students actively engage in research and develop their understanding of the profession. How graduate students conceptualize research has been hypothesized to be contingent upon these students' prior knowledge and beliefs regarding how and why research is conducted (Meyer *et al.*, 2005). Similar to the studies on faculty, Stubb *et al.* (2014) observed that doctoral students at a Finnish university conceptualized research based on variations in aspects related to the purpose, process, and outcomes of research. The four qualitatively different conceptions included viewing research as a personal journey with internal meaning, a process that can make an external difference, a pathway to obtain qualifications, or a job that fulfills duties and expectations (Stubb *et al.*, 2014).

These phenomenographic studies of researchers at the professional and graduate student levels collectively demonstrate how researchers understand their practice within the professional research community. Academics, industry professionals, and graduate student researchers are experts or developing experts who have progressed beyond the periphery within the community of practice. Further studies on student conceptions of the work done by researchers at earlier academic stages would be beneficial to understand student expectations and ideas about a researcher's practice, which will be foundational for informing practices and further research that increases persistence or retention of students in STEM (Meyer *et al.*, 2005).

Undergraduate education represents yet another important transitional stage, where students make critical decisions concerning their careers. A wealth of literature has focused on the value of UREs in supporting academic and professional development of students, as mentored UREs are intended to increase students' understanding of STEM practices and culture (Russell *et al.* 2007; Sadler and Mckinney, 2010; Gilmore *et al.*, 2015; Linn *et al.*, 2015; Carter *et al.*, 2016). Linn *et al.* (2015) summarized that UREs are often given high ratings by undergraduates, but the specific benefits obtained from these experiences have been poorly documented. To optimize UREs, it is essential to understand the range and breadth of student ideas of the work done by researchers and allocate program resources and instruction time to target student development in these areas. UREs aim to advance students' understanding of science and research, yet there have been few comprehensive investigations of the ways that undergraduate students conceptualize different aspects of the practices that are needed to achieve success as a researcher.

This study uses phenomenography to examine how undergraduate students conceptualize successful researchers in their STEM disciplines, with the goal of defining an outcome space that describes the variations and aspects across these conceptions. This study expands upon existing applications of phenomenography by applying this research approach to the underexplored study population of undergraduate students compared with graduate students (Meyer *et al.*, 2005; Stubb *et al.*, 2014), researchers (Brew, 2001; Bills, 2004; Bruce *et al.*, 2004; Bowden *et al.*, 2005; Kiley and Mullins, 2005) and university faculty (Åkerlind, 2008a), and expanding the geographic location to the United States, in contrast to African (Bills, 2004; Kiley and Mullins, 2005), European (Stubb *et al.*, 2014; Luukkonen and Thomas, 2016), and Oceanian (Brew, 2001; Bowden *et al.*, 2005; Åkerlind, 2008a,b) countries. Our goal is that the outcome space defined in this study, together with insight from other studies, will provide a more comprehensive understanding of how researchers and their practice are conceptualized across different academic stages and sociocultural contexts.

METHODS

Study Site and Participants

Study participants were selected from a summer bridge program designed to introduce incoming transfer students to research in the biological sciences and other professional opportunities in STEM. Although the same participant sample is used, this study is unique from Zuckerman and Lo (2021). While the participants are transfer students, this current study does not seek to interpret the findings directly in relation to this academic identity. The previous study (Zuckerman and Lo, 2021) examined the participants' perceptions of success and navigation across different educational spaces to understand how these students constructed their identities as transfer students. The students' conceptions of successful researchers did not fit directly within these spaces, and descriptions of their ideas about researchers was not salient in the emerging themes in the previous study (Zuckerman and Lo, 2021). Therefore, these two studies have the potential to offer complementary insights on students' experiences in STEM but are unique in their theoretical applications, qualitative analytical approaches, findings, and implications.

The program was offered at a large, primarily residential, public doctoral university in United States in the category of very high research activity described by the Carnegie Classification of Institutions of Higher Education (McCormick and Zhao, 2005). Choosing such a summer bridge program made the participants a convenient sample, with ease of recruitment ensuring a high response rate (Patton, 1990). However, there are also important qualities of the sample that makes it suitable for this study. First, the program focused on UREs, which provided a form of intensity sampling with information-rich cases that are more likely to have experienced the phenomenon of research and interacted with researchers extensively. While we acknowledge that sampling students of various backgrounds from other research programs could have been advantageous, our use of a convenience sample still aligns with the sampling methods adopted in phenomenographic inquiry (Han and Ellis, 2019). Second, transfer students were selected, because they are a substantially understudied undergraduate student population in STEM education (Lo *et al.*, 2019; Kanim and Cid, 2020), yet they represent a broad demographics range (Ma and Baum, 2016). For example, transfer students generally are disproportionately first-generation college students and/or from racially or ethnically minoritized backgrounds, which is representative of a diversifying undergraduate population (Bahr *et al.*, 2013; Ma and Baum, 2016; Quaye *et al.*, 2019). While the findings may not be broadly generalizable, this sample of students is an informative group to study, because their diverse backgrounds and lived experiences could provide more variations in how they conceptualize researchers and their work.

The summer bridge program took place before the participants' first quarter at the university. Completion of introductory biology course work and an interest in pursuing graduate studies in STEM were prerequisites for admission. A total of 31 students were accepted across three cohorts. Program activities included talks by different researchers and faculty members, research training focused on learning laboratory methods in neuroscience and reading primary literature, and preparation for graduate school (e.g., Graduate Record Examination preparation). A primary objective of the program was to prepare students for undergraduate research opportunities after the summer, and about 90% of the students had secured a research position in a faculty laboratory following the program. The program faculty continued to be accessible for advising and mentorship for the remainder of the students' academic careers at the university. Research experiences following the summer bridge program were typically for academic credit under the mentorship of a university faculty member, generally requiring about 10–12 hours per week.

A total of 29 participants were interviewed out of the 31 students who completed the summer bridge program. Some participants had switched majors after the program, but all remained in a STEM discipline (Table 1). Participants pursuing disciplines not commonly categorized as STEM (i.e., cognitive science, psychology, and health sciences) all had a STEM focus, such as cognitive science with a neuroscience specialization. Collectively, the participants completed a median of four academic quarters of independent research during their undergraduate education. We reasoned that the wide variety of majors and independent STEM research experiences would provide more comprehensive descriptions of successful researchers. Demographics of the participants (Table 1) reflect the diversity of community college populations (Ma and Baum, 2016) and greater diversity for students who participate in UREs (NASEM, 2016; NSF, 2021).

Throughout the summer bridge program, students were provided with activities that supported their development as researchers, and these resources may have influenced or narrowed how they conceptualize successful researchers and their practice. Moreover, because students in this program were required to submit a letter of recommendation from a science instructor, they arguably had the necessary navigational

TABLE 1. Demographics of study participants[a]

Demographics	Number
Gender	
Women	16
Men	12
Transgender man	1
Race or ethnicity	
Hispanic or Latinx	9
Middle Eastern	6
Asian	5
Asian and White	3
Hispanic or Latinx and White	3
White	2
African American or Black	1
College generation status	
First generation	22
Continuing generation	7
Field of study	
Biological sciences	13
Cognitive science	7
Engineering or computer science	4
Social sciences	2
Physical sciences	1
Health sciences	1
Mathematics	1

[a]The 29 participants represented a wide range of demographics, including gender, race or ethnicity, college generation status, and STEM majors (or majors with a STEM specialization). Collectively, the participants completed a median of four academic quarters of independent research during their undergraduate educations. First-generation status is designated as neither parent nor guardian having received a 4-year university degree in the United States.

capital and resources to recognize the importance of pursuing opportunities in undergraduate research. Given the unique characteristics of our study participants, we do qualify that this study is not intended to provide broadly generalizable insights. Although the sociodemographic characteristics of our sample are diverse, we acknowledge that students from other institutions with different identities or characteristics may hold different conceptions.

Despite the unique study context being a limitation when interpreting the implications of the findings, it is also a factor that mitigates threats to validity. Phenomenography investigates the different ways that individuals experience a phenomenon, and the source of variations should therefore be derived from the individual and not the context. Thus, the limited generalizability of our study is at least partially offset by a core methodological tenet of phenomenography that emphasizes the importance of studying individuals in a specialized context (Marton and Pong, 2005).

Data Collection

Study participants were recruited from three iterations of the summer bridge program who were transitioning into the university from community colleges. Each study participant was interviewed once, in the Spring quarter of the second academic year at the university, and data collection spanned 3 years. The questions administered were part of a larger interview protocol, including those published previously (Zuckerman and Lo, 2021). To examine how the participants conceptualized researchers and their practice, the semistructured interview protocol included the following main questions:

1. How would you define success as a researcher in your discipline of study?
2. What makes a successful researcher or what does a researcher do to be successful?
3. Has your definition of success in this regard changed since you have been at the university? How?

A semistructured interview protocol is the preferred method for phenomenographic studies, typically with a small number of broad guiding questions that allow for more open-ended follow-up discussions, where the interview participants can freely describe the aspects of a phenomenon that are most relevant to their conceptions (Marton, 1986; Marton and Booth, 1997; Richardson, 1999; Han and Ellis, 2019). In phenomenographic studies, the interview data typically come from only a few key questions, and the semistructured nature of the interview allowed the interviewers to prompt the participants to elaborate on certain aspects of their responses whenever necessary by reformulating questions or asking follow-up questions (Reed, 2006; Stenfors-Hayes *et al.*, 2013). Previous phenomenographic studies have also used interviews with only three questions or have focused on a few key questions within a larger protocol (Larsson and Holmström, 2007; Light and Calkins, 2015; Salberg *et al.*, 2019).

We chose to focus on "researcher" as opposed to "research" in our interview questions, because in preliminary focus groups with another sample of undergraduate students, we found that prompts with "research" generated vague responses, whereas "researcher" resulted in more descriptive responses. Additionally, researchers perform and perpetuate the norms and behaviors enacted within the research community, giving insight into how research operates within the community of practice. Differences in foci across previous phenomenographic studies have included emphasis on conceptions of what research is (Brew, 2001) and conceptions of being a researcher (Åkerlind, 2008a). Studies of conceptions of research typically conflate ideas about research methods and conceptions that individuals hold by describing researchers and their practice (Kiley and Mullins, 2005; Meyer *et al.*, 2005; Brew *et al.*, 2016). We reasoned that our study participants, who are undergraduate students, may be more able to articulate details about concrete researchers with whom they interact versus the more abstract notion of research. For example, a follow-up question promoted participants to describe a specific researcher whom they considered successful. The term "researcher" was also purposefully used instead of "scientist" to be more inclusive of a broader range of STEM disciplines.

As informed by the community of practice framework, researchers and their practice are distinguishable yet inseparable. Although the first interview question focuses directly on the attributes of the researcher and the second question focuses on the practice of research, these questions are complementary. Responses to the second question directly expanded upon responses from the first question, thereby providing more holistic and detailed descriptions of the variations that participants attended to in our construction of the outcome space.

The third interview question prompted participants to indicate whether their conception of successful researchers had changed from their university experiences and to describe their retrospective conceptions. Articulation of this change relied on a retrospective account of their conceptions before the summer bridge program. We included this additional retrospective prompt to capture a potentially wider range of variations in the outcome space, as the current conceptions of the study participants may be limited or have converged based on their shared UREs. Although one might argue that this retrospective prompt may be influenced by cognitive distortion or recall bias, these distortions are still part of how students understand ideas and stereotypes related to researchers (Säljö, 1996, 1997). Stereotypes and distortions are part of their interpretations, and while we cannot deduce whether these were truly their predominating conceptions at the time, these retrospective reflections still give insights into the ideas about researchers that participants have been exposed to along their educational trajectories. Therefore, these stereotypes and distortions further saturate the variations captured in the outcome space by describing other potential conceptions of researchers that participants may directly have had or been exposed to before and throughout their university educations.

Data Analysis

Interview transcripts were analyzed using qualitative coding methodologies following Saldaña (2015). First, preliminary analytic codes were developed, in which segments of the transcripts were given conceptual labels. After iterative close reading of the interview transcripts, analytical memos took the form of in vivo codes generated using participants' own phrases (Saldaña, 2015) that captured critical yet broad interpretations of successful researchers. Aspects and variations noted in data were given tentative conceptual labels, and emerging memos were constantly compared against earlier labels for similarities and differences before a set of codes was determined.

Second, after codes were applied to individual responses, broader categories were developed inductively as aspects of the phenomenon. Grouping similar codes gave rise to these aspects, and the transcripts were further scrutinized to identify the range of variation within each aspect. Specific aspects and variations were identified and ultimately organized into an outcome space that described the different conceptions of successful researchers (Marton and Pong, 2005). Using the constant comparative method, we compared descriptions and definitions for each aspect with those from previously analyzed transcripts to confirm or disconfirm conjectures and delineated the variations within each aspect.

Finally, the data for each intersection of aspect and variation were first revisited to further refine the definitions in the outcome space using two approaches. The first is the decontextualized approach, which treats the isolated segments of transcripts as collections of interpretations. This approach emphasizes the collective experiences of all the participants and minimizes the danger of placing analytic focus on individual participants, as individuals will not comprehensively represent the variations of the broader sample (Marton 1986; Åkerlind, 2005). This is accomplished by treating all segments from the interview transcripts as one set of data to interpret within the larger interview context (Åkerlind, 2005). Conversely, the second approach is contextualized to each individual interview transcript. Each transcript was coded as representing one of the three conceptions by identifying aspect(s) and assigning the conception that described the variation of that aspect in the outcome space. Multiple conceptions could be applied to one interview transcript if variations of aspects from different conceptions were described. This contextualized approach treats the whole transcript as a set of interrelated meanings and considers the larger context of the individual when interpreting the transcripts (Bowden, 1994a,b). Åkerlind (2005) argued that both the decontextualized and the contextualized approaches are important and complementary in phenomenography.

Reliability and Trustworthiness

In phenomenography, reliability describes consistency when interpreting and applying the conceptions in the outcome space to the data (Sandbergh, 1997; Han and Ellis, 2019). Åkerlind (2005) described two forms of reliability for phenomenographic research: dialogic reliability and coder reliability. Dialogic reliability refers to agreement between researchers "through discussion and mutual critique of the data and of each researcher's interpretive hypotheses" (Åkerlind, 2005, p. 331). The research team met regularly to iteratively discuss and critique the initial analytical memos, the in vivo codes, and the emergent aspects and their variations until consensus was reached on the structural relationships of the outcome space.

For coder reliability, two researchers (A.L.Z. & S.M.L.) coded 12 out of the 29 interviews (41%) in the contextualized phase of selective coding, achieving substantial interrater agreement of 87.5% and a Cohen's kappa of 0.82 (Cohen, 1960; Landis and Koch, 1977). All disagreements within the subset were resolved through dialogic discussions to reach consensus. Given the high initial reliability, we proceeded with one researcher coding the remaining transcripts. When the first researcher was unsure of a certain code assignment, such interview segments were also discussed with the second researcher to reach consensus.

Åkerlind (2005) describes validity for phenomenography to include communicative and pragmatic validity. Rather than searching for the singular correct interpretation, phenomenographic research should result in an outcome space regarded as defensible (communicative) and useful (pragmatic) by the relevant research communities (Åkerlind 2005). There is no rigid criterion in the literature for determining sufficient demonstrations of these validity measures. However, communicative validity is based on the relevant research communities judging the persuasiveness of the methods and findings, and pragmatic validity describes the extent to which useful insights from the findings can be applied to teaching and learning (Van Rossum and Hamer, 2010; Hajar, 2020). Throughout the iterative coding process, preliminary aspects, variations, and outcome spaces were presented to different communities of researchers in STEM and education. The findings were presented on multiple occasions at a variety of venues over the course of 2 years, including three departmental research meetings with 15–20 faculty, postdoctoral scholars, and graduate and undergraduate students who conduct discipline-based education research; a graduate thesis defense evaluated by three committee members with expertise in education and STEM research; an oral presentation at a national education research conference with an audience of about 50 people; and a poster presentation at a campus research symposium that was judged by two STEM faculty and observed by other communities of faculty and students conducting research in the sciences. Communicative validity for this study stems from the refinement of the outcome space through these repeated cycles of critique and feedback.

Analogously, pragmatic validity emerges from the perceived usefulness of the outcomes space, especially by STEM researchers, as Entwistle (1997) argued that the value of phenomenography in postsecondary education is to produce actionable and useful insights into learning and teaching. This perceived usefulness can be demonstrated by articulating how the outcome space can be used to develop understanding of learning experiences and plan new educational interventions when considering the practical implications of the findings (Åkerlind, 2005).

Theoretical saturation in this study was achieved by following recommendations synthesized in Aldiabat and Le Navenec (2018): collecting data over a sufficient length of time (3 years total in this case) and concurrently collecting and analyzing the data through the constant comparative method. Preliminary descriptions of the distinct aspects and variations emerged from the data collected in the first year and were confirmed and refined by the new data from the second and third years. No new patterns emerged from data collected in the third year, indicating that, at least within our sample of participants, no additional codes and meanings were identified from an iterative threefold data collection. The number of interviews conducted also fell within the estimated range that would achieve code and meaning saturation (Hennink *et al*., 2017).

Consistency in data collection is important in phenomenography to mitigate random influences in the research process (Walther *et al.*, 2013; Fila *et al.*, 2019). To mitigate this concern as we collected data across multiple years, both interviewers received identical training in implementation of the same interview protocol by the principal investigator (S.M.L.). Although a different interviewer (L.W.) conducted the pilot interviews in the first year, the second interviewer (A.L.Z.) listened to recordings of these interviews to mimic the style and patterns of follow-up questions before conducting the interviews in the second and third years. The two authors of this paper conducted the entire analysis of the interview data, thereby ensuring consistent applications of the coding schemes while simultaneously incorporating feedback to reinforce communicative and pragmatic validity.

Positionality of Authors

We include a statement of positionality to situate the identities of the authors in relation to the participant sample and establish credibility for researching the phenomenon of investigation, as our own experiences have influenced how we conduct the research and interpret its outcomes (Rowe, 2014). The first author (A.L.Z.), a graduate student, was not involved in the program and did not interact with the participants before the interviews. He has an undergraduate and graduate degree in biological sciences and had research experience in both biological sciences and disciplinary-based education research at the time of this study. The second author (S.M.L.) is an associate teaching professor who primarily works in discipline-based education research after having earned a PhD in biochemistry. He attended program social events sporadically over the years and presented his research once as a faculty speaker in an iteration of the summer program. The authors' professional experiences as researchers and different degrees of involvement in the program positioned them to provide enriched and objective interpretations of the data.

FINDINGS AND ANALYSIS

Three aspects were identified with variations that distinguish the different conceptions of researchers:

1. process (or how researchers approach their work): the complexity of methodological approaches and the perceived importance of the research product;
2. interactions (or how researchers work with others): the extent to which researchers collaborate with other researchers and provide mentorship to developing colleagues; and
3. contribution (or who benefits from the researcher's work): the scope to which researchers use their research to advance the research field and serve societal needs.

Variations within each of these aspects revealed three qualitatively different ways in which undergraduate students in STEM conceptualize successful researchers. The aspects are three conceptually overlapping constructs that converge to form three conceptions in the outcome space: conception I (disconnected), conception II (involved), and conception III (engaged). We will present these conceptions individually, highlighting the variations in the three aspects within each conception to provide a holistic description of how undergraduates view the procedural and social dimensions of successful researchers and their practice (Table 2).

Conception I (Disconnected)

Process: Driven by the Final Product. Researchers described in this conception are defined by the tangible end products in research rather than the personal journey in academic work. The process of research is not emphasized, as several participants directly described success as "just the ending [when you] accomplish something." After publishing their work, researchers are perceived to accept the results as final and do not attempt to expand upon their findings. Therefore, the research process and products are disconnected from each other. For example, one participant described a researcher's success: "I guess I always thought of success as just getting that one result and saying, 'Hey, this is it,'" with the emphasis on the "one result" devaluing the potential of the researcher to broaden the scope and impact of their work. Research accomplishments are believed to occur immediately with few complications in the process. As one participant said: "I also was one of those people that thought, well, it means having your research be successful. The project works. You're done. You publish a paper, and that's good, you know?" An expectation that the "project works" underestimates the potential challenges or failures that may arise during the process and assumes that project goals are always seen to completion. The assumption that "you're done" once the initial product is obtained indicates an emotional disconnection from the research journey and further undermines the potential of the researcher to broaden the impact of the work beyond the initial product.

Interaction: Working Alone. In addition to being disconnected from the research process, researchers in this conception are

TABLE 2. Outcome space for different conceptions of successful researchers with relationships among the three conceptions illustrated by specific variations across three aspects

Aspect	Conception I (disconnected)	Conception II (involved)	Conception III (engaged)
Process: How researchers approach their work	A researcher's work is defined by the final products, not the process.	A researcher's work has a structured and established methodology.	Research is iterative, and researchers frequently refine and adapt approaches.
Variations	NA	Conception II is distinct from conception I by shifting the focus from product to process.	Conception III expands on conception II by focusing on an iterative instead of a linear process.
Interactions: How researchers work with others	Researchers work alone and limit their interactions with other researchers.	Researchers collaborate extensively with other researchers.	Researchers strive to expand access to the community through mentoring.
Variations	NA	Conception II is distinct from conception I by shifting the focus from individualistic to the collaborative nature of research.	Conception III expands on conception II to include mentoring developing colleagues in addition to collaborations.
Contribution: Who benefits from the researcher's work?	A researcher's work is primarily used to enhance their status and self-interests.	A researcher's work advances knowledge in the field of study.	A researcher's work ultimately addresses broader social issues.
Variations	NA	Conception II is distinct from conception I by shifting the focus from individual advancement to contributions to the research field.	Conception III expands on conception II to include broader social contributions in addition to contributions to the research field.

described as working independently and as disconnected from other researchers. They do not seek feedback or collaboration, and they show little regard for the existing work in their disciplines. For example, one participant described successful researchers as working in isolation, disconnected from others who are not part of their own projects: "I always felt that researchers work on their projects, and they don't care about everyone else." Another participant also described a researcher as socially distant from other members of the research community. Their description of a researcher as "a guy" who is "in the lab all the time just working with test tubes" is consistent with common stereotypes of scientists as socially inept, eccentric males (Haynes, 2003; Losh, 2010):

> I honestly thought a researcher was just a guy that was in the lab all the time just working with test tubes and stuff like that. I honestly didn't, like, in the beginning, before I was even involved with a lot of research, I didn't know that they made presentations and posters. I didn't really, like, think about all that. I kind of just thought it was a guy that was in the lab all the time and didn't really go out.

Contribution: Enhancing One's Own Status. Consistent with the idea that researchers work in isolation, researchers are described as using research to pursue their self-interests rather than to advance their disciplines or contribute to society. Aligning with the product-focused approach to the research process, the researchers' intent is to advance their research projects to gain tangible products that contribute to their prestige and status. This motivation is not necessarily driven by a desire to contribute to the broader success of the research field. Instead, the researcher is perceived to have agentic and egocentric motivations for pursuing research as a profession. For example, one participant stated that a researcher's motivation for pursuing a research career is to obtain fame: "I think when I first started to consider research, I was kind of like in that mindset, like, 'Oh I'm going to be a famous scientist.'" Similarly, another participant succinctly described that "if a scientist receives a prize for their research, that's the highest success."

Conception II (Involved)

Process: Defined and Linear Structure. In contrast to conception I, researchers in conception II are characterized by their focus on the overall process of research instead of the end products. This conception recognizes the importance of a structured methodology and the researcher's involvement in this defined process. For example, one participant described the proactive involvement of the researcher in learning the established methodologies of the research process: "You got to know everything that's happening, know all the tools and instruments and any procedures people have been doing in your field of study, and what they have been discovering, and how you can piggyback off that." Researchers are further perceived to understand that navigating the research process requires a significant time investment:

> Put in the hours. I remember this one graduate student in my lab that I was in. She was always working. She was always on the computer putting the hours in. Always talking a lot to other researchers. She was always going to other labs and ask[ing] questions. She wasn't shy about going to other labs. I liked her research, and she got a paper published and everything. I think just talking to people, asking for help, and just putting in the hours make you successful.

As this excerpt notes, "putting the hours in" and not being "shy about going to other labs" involves the researcher being highly proactive and seeking assistance within the research community. This enthusiasm about being involved in the research community is consistent with a need to proactively learn the tools and methodologies of the broader field to learn and execute research processes that have been previously defined. Although this response describes a publication as a tangible product, the product does not overshadow the active involvement of the researcher in the technical and social dimensions needed to navigate the process.

Interactions: Collaborating with Other Researchers. Because learning the established tools and methodologies often requires consultation with others in the field, involved researchers are described as building connections with colleagues to broaden their scope of knowledge. It is recognized that researchers regularly present their findings to the research community and seek constructive feedback from other researchers to better understand their own projects and methodologies. By networking with others, researchers are involved in connections with others to drive their research forward. As one participant stated: "Even the most brilliant people crowdsource information, and they ask other people for advice and feedback, and they incorporate that feedback."

Contribution: Advancing the Research Field. In contrast to the agentic and egocentric motivations for pursuing research in conception I, collaborative and scholarly motivations for pursuing their work are attributed to researchers in this conception. The researchers are perceived to be motivated to use their research to advance their disciplines by expanding upon previous work by themselves and others. Aligning with the proactive involvement in learning the methodologies to progress through a defined research process, the researcher's contribution is built on the established knowledge and methodologies from other researchers in the field "to go to the next step," as noted by one participant: highlighted that a researcher's contribution is built on the established knowledge and methodologies from other researchers in the field "to go to the next step":

> You need to, I feel like I need to read or know what others are doing in whatever project I'm working on. So, it's not just me because, what they, whatever other researchers or scientists are working on, it's very beneficial to have, like, because they already have found things that I need to kind of grasp on there and continue on. Kind of develop that research from there. It's not just repeat whatever that they did but taking that information and kind of build it on to go to the next step.

Similarly, another participant described researchers as individuals who find intrinsic values in contributing to their fields, specifically in contrast to external rewards and prestige:

> But just contributing really, just contributing to the body of knowledge that we're creating in [my discipline]. It's such an incredible field of work. I really love it. But as far as, I mean, that would be my definition of success. I know that other people have different definitions of success like publishing in prestigious journals etcetera, getting a faculty position, or something like that. But for me, just to be able to contribute to the research feels like success.

The value placed on "contributing to the body of knowledge" rather than tangible products such as "publishing in prestigious journals" describes a researcher who is genuinely motivated by scholarly contributions that expand the research field rather than using the field primarily for personal advancement.

Conception III (Engaged)

Process: Persevering through an Iterative Process. In conception III, researchers are perceived to engage in an iterative research process rather than a simplified linear procedure that yields successful results immediately. This conception has a focus on achieving personal growth as a scholar by embodying perseverance and resilience in the research process and revising one's approach accordingly. As one participant noted, it is important for researchers to "look into different possibilities for [their] research. Don't just be focused on one track, and not to be discouraged, but just keep going because it might take a while." Failure is used by the researcher as a building block to augment the research approach and further develop critical-thinking skills, described by another participant as the research process entailing more than "just following a protocol":

> You really have to be proactive about thinking about what you're doing and what it means to run this kind of experiment versus just following a protocol. I think that's really important as a researcher, and then also, resilience is really important because the experiments fail so many times, and it can get frustrating if you're trying to get results quickly.

Research products are not perceived to be obtained immediately, as complexities and obstacles are expected, "because the experiments fail so many times." The research process is defined yet adaptable, as researchers are perceived to address their research questions from multiple perspectives. As another participant stated:

> They work a lot and hard. They are very focused, and they make sure that they approach a question from as many angles as they can think of. So, they don't just ask a question and say, "This will be the right way," but, "What would make this way confounded? What would make it wrong? What else could be contributing?"

Finally, progress in research is fueled by the researcher's creativity and curiosity to discover the unknown. For example, one participant described engaging in the research process as "a hunger for knowledge and just wanting to learn, and just the curiosity to be like, 'I get to go and explore this thing because we're curious about it.'" Taken together, these responses describe a conception of successful researchers that is more comprehensively aligned with an informed view of the scientific method, as demonstrated by the recognition of a researcher's work as a creative and iterative process with multiple possible outcomes.

Interactions: Building Community through Mentorship. In contrast to the researchers described in conception II, researchers in conception III build connections beyond other professionals and engage developing colleagues in mentoring relationships. Researchers are recognized as being eager to teach others about the norms and practices of the research community and are willing to devote their time to training the next generation of scientists:

> Professor [Name] has been doing research for years. And I think one thing that makes him different from a lot of other people is he actually wants to teach the kids science. He works with a lot of undergrad students. And I think that's just helpful for a lot of people. And he actually enjoys it. And you can tell he enjoys it. So, I think that's good for a researcher to have that quality.

In this conception, successful researchers are perceived to understand the importance of expanding access to the research community and providing mentorship on the pathway to careers in STEM. By increasing access to the research community, researchers are perceived to view these mentorship opportunities as a means of addressing complex problems from multiple perspectives. For example:

> I think it's important to have a lot of a diverse staff. And a diverse input into your research. I think that they also work together with colleagues a lot you know just to [not] box themselves in their lab and never expose themselves to their colleagues or students. I think a good researcher is invested in training the next generation. So, taking on interns and giving back that way as well.

A willingness to "train the next generation" demonstrates the researcher's desire to make the research community more accessible. It is perceived that the "diverse input" resulting from interactions with individuals from different backgrounds or levels of experience has the potential to provide enriched perspectives in a researcher's work, thus broadening the scope of potential research directions and contributions.

Contribution: Addressing Societal Issues. Aligning with a desire to make research accessible to the next generation, researchers in this conception are engaged in broadening the impact of their research by simultaneously contributing new knowledge to the research community and using this knowledge to serve a broader societal purpose. Therefore, the motivations for pursuing research are perceived to be altruistic to a broader society rather than egocentric or restricted to promoting collegiate success within the research community. For example:

> I think good research isn't just done for the sake of research. I think there should be some sort of, you know, goal, whether it's to, you know help elucidate the answer to a problem or address some sort of social issue, medical issue, something like that.

Another participant emphasizes that, while research should be meaningful to the researcher, it is only successful when it also benefits others in the world:

> I think having your research be meaningful and important to you and also to other people in the world so that it's benefiting the world in some aspect, I think that's the most important thing, and I think that's what defines success in research.

Self-fulfillment in this case is not focused on the opportunity to gain personal status or prestige. Instead, the second excerpt illustrates that researchers' desire to explore their interests is rooted in a genuine ambition to promote public good by "benefiting the world in some aspect."

Different Conceptions of Researchers

Variations within the aspects of process, interactions, and contribution together constitute the qualitatively different ways in which undergraduate students in STEM conceptualize successful researchers, and a total of three different conceptions are identified within this phenomenographic outcome space (Table 2). Conception I (disconnected) is mainly characterized by disconnections: Researchers described in this conception are disconnected with the research process in favor of research products, and they do not interact other researchers or contribute to the research community. In conception II (involved), researchers are perceived to be involved in a defined research process; they are also involved in collaborations with colleagues and contribute to their research communities. Researchers described in conception III (engaged) have deeper involvements in the scientific community characterized by emotional, professional, and societal engagements. They persevere through challenges in the iterative research process, mentor developing colleagues through professional interactions, and consider broader societal implications of their research.

Hybrid Conception II and III. In several interviews, participant responses described both conception II and conception III variations, but in different aspects. For example:

> I'd say, having a good grasp of the background of your field is absolutely fundamental. On top of that, what's the word for it? Commitment? Perseverance? Research is very difficult at times. Things never go the way you want them to go. Just being able to continue with an idea that you have. I'd say collaboration as well. Research isn't done in a vacuum. You kind of need to focus on not just what other researchers are doing but what other people in your lab are talking about and what they're doing as well.

The emphasis on a researcher's flexibility in their methodological approach, as well as their commitment and perseverance, is aligned with research as an iterative process (conception III), whereas collaboration with other scientists indicates interactions within the research community (conception II). It is possible that research mentorship as a type of interaction (conception III) was also present in this participant's conception, but this feature was not explicitly described. Alternatively, these results could be indicative that participants with this hybrid conception demonstrate a developing, yet incomplete idea of a researcher's practice within the research community.

No Conception. The third question in the interview protocol prompted participants to retrospectively define their conceptions of researchers before their UREs to saturate the outcome space. Likely because of a lack of prior exposure to research, some participants were not able to clearly articulate any of the critical features related to the different aspects in the current outcome space. These participants claimed that their previous

TABLE 3. Retrospective versus current conceptions demonstrating frequencies of conceptions that participants described as possessing before ("retrospective") and following ("current") their research experiences

Conception	Retrospective	Current
Not codable[a]	3	0
No conception	3	0
Conception I	18	1
Conception II	2	4
Conception II/III	3	14
Conception III	0	10

[a]Ambiguous responses that could not be coded were marked as not codable.

conceptions were either groundless or nonexistent. Such responses were coded as "no conception." For example:

> To be honest, I had never been exposed to research before I got here. I had never been exposed to research before the [summer bridge] program. So, I didn't really have any idea of what success for researchers looked like before that. So, I can't say that it changed, but now it actually exists.

Retrospective versus Current Conceptions

Participants were asked if their conceptions had changed over the course of their research experiences, and retrospective and current conceptions were coded individually for each participant (Table 3). Because the objective of this study was to collectively examine variations in student conceptions about researchers rather than position individual students in the outcome space, we will not focus on experiences that may have facilitated change. However, given that our sample was unique and had a common summer research experience, we coded these conceptions to demonstrate that the participants displayed sufficient variations in their experiences and were able to capture this variation through articulation of both their current and retrospective conceptions. Between the current and retrospective conceptions, all three conceptions are well represented by our participant sample. A majority of participants described their respective conceptions as conception I, with little appreciation for the complex methodological processes, broad social interactions, and contributions possible within a researcher's work. Their current conceptions were coded primarily as aligning with conception II and conception III, indicating an overall perceived shift in their understanding of research as a profession following their participation in mentored research experiences.

DISCUSSION

Situated in the existing literature on UREs, this study fills an important gap by exploring variations in students' collective ideas about successful researchers through the development of a phenomenographic outcome space that describes three different conceptions. Previous literature has identified students' understanding of the research process (Thiry *et al.*, 2011) and social dimensions of research (Cartrette and Melroe-Lehrman, 2012) as significant features that evolve following engagement in UREs (Linn *et al.*, 2015). Thiry *et al.* (2011) described instances wherein students' images of the research process had shifted from a linear to an iterative approach. Our outcome space identified an additional product-driven focus that overshadowed the process of research. In previous descriptions of the social interactions in research, students in UREs have articulated an initial conception of research being conducted in isolation; their ideas about the social dynamics of research had shifted after their research experiences exposed them to the collaborative nature of science and research (Cartrette and Melroe-Lehrman, 2012). Our outcome space not only highlights this dichotomy but also identifies mentorship beyond the immediate research community as being potentially important to a researcher's development. To the best of our knowledge, contribution has not been previously highlighted as a salient aspect in studies that have examined shifts in undergraduates' understanding of research following participation in UREs, even though it has been described as an aspect for how university faculty conceptualize research (Åkerlind, 2008a).

The three aspects identified in this study (process, interaction, and contribution) are similar yet distinct compared with those in the outcome spaces constructed in previous studies (Table 4). As summarized by Åkerlind (2008a), shared themes emerging across earlier phenomenographic studies include variations in how research is conducted (Bills, 2004; Kiley and Mullins, 2005; Meyer *et al.*, 2005) and who is affected by the research (Brew, 2001; Bruce *et al.*, 2004; Bowden *et al.*, 2005). These two themes are analogous to the aspects of a researcher's process and contribution in the current study. To the best of our

TABLE 4. This study identifies three conceptions that are novel and not entirely captured in any previous phenomenographic study; this outcome space also includes similar variations identified in previous phenomenographic studies examining other career stages

Aspect	Conception I (disconnected)	Conception II (involved)	Conception III (engaged)
Process	End product: Brew, 2001; Kiley and Mullins, 2005; Stubb *et al.*, 2014	Linear process: Bills, 2004; Kiley and Mullins, 2005; Meyer *et al.*, 2005; Åkerlind, 2008a; Stubb *et al.*, 2014	Iterative process: Variation not explicitly identified or described previously
Interaction	Alone: Variation not explicitly identified or described previously	Colleagues: Variation not explicitly identified or described previously	Community: Variation not explicitly identified or described previously
Contribution	Oneself: Brew, 2001; Bruce *et al.*, 2004; Bowden *et al.*, 2005; Åkerlind, 2008a; Stubb *et al.*, 2014	Research field: Brew, 2001; Bruce *et al.*, 2004; Bowden *et al.*, 2005; Åkerlind, 2008a; Stubb *et al.*, 2014	Society: Brew, 2001; Bruce *et al.*, 2004; Bowden *et al.*, 2005; Åkerlind, 2008a; Stubb *et al.*, 2014

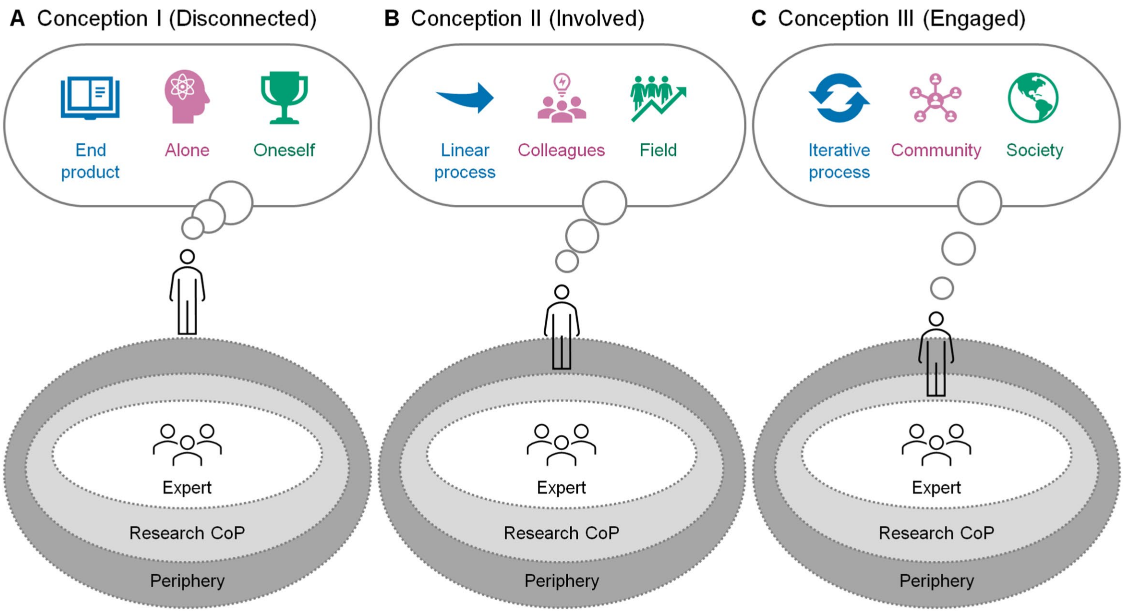

FIGURE 1. Different conceptions of researchers within the research community of practice. (A) A researcher described in conception I (disconnected) is emotionally and socially disconnected from the research community. (B) Conception II (involved) views researchers as legitimate peripheral participants who are immersed but not fully engaged in the community of practice. (C) Conception III (engaged) is most aligned with an informed view of researchers being engaged as central members in the community of practice. The variations in a researcher's process (blue), interaction (pink), and contribution (green) are indicated for each conception. CoP, community of practice.

knowledge, a researcher's interaction with other researchers was not explicitly described as an emerging aspect in these previous studies. However, other aspects identified in the existing literature did not emerge or were not as salient in this study. For example, Prosser *et al.* (2008) found that researchers' understanding of their profession is dependent on incorporating knowledge from outside their fields, and Brew (2001) found that research can be conceptualized as: 1) a process of creating underlying meanings, 2) a personal journey of discovery, or 3) a marketplace where products are exchanged. These variations are not explicitly defined within the current outcome space but may be broadly incorporated across the three aspects of process, interaction, and contribution.

As this paper leverages the community of practice framework in the interpretation of the findings, models that include a researcher's positioning in the community of practice are from the undergraduates' perspectives (Figure 1). Researchers described in conception I (disconnected) are aligned with the stereotypic view of scientific researchers held among adults and K–12 students (Chambers, 1983, Barman, 1999; Finson, 2002; Losh *et al.*, 2008; Losh, 2010) and are conceptualized as socially and emotionally positioned outside the community of practice (Figure 1A). Because this conception was coded primarily in participants' retrospective reflections (i.e., before their UREs; Table 3), these stereotypes were significant to for participants before obtaining the mentorship experiences that immersed them in the processes and social norms of the research community (Gormally and Inghram, 2021). In contrast to conception I, conception II (involved) views researchers as legitimate peripheral participants who are involved in the practice but are not as connected to the nuanced processes and broader social impacts that drive the community of practice (Figure 1B). Participants likely derived conception II from their own legitimate peripheral participation in research experiences where their ideas began to deviate from the stereotypes described in conception I.

Because researchers described in conception III (engaged) have the many characteristics that predict persistence into research training, including a curiosity to discover the unknown, flexibility in their approach and goals in research, and a desire to help others in society through research (McGee and Keller, 2007), conception III is most aligned with views of researchers as engaged in a community of practice (Figure 1C). In a community of practice, experts promote an accessible and inclusive research community by providing support and mentorship to emerging researchers (Lave and Wenger, 1991; Wenger, 1998; Akerson *et al.*, 2009). The distribution of knowledge and mentorship is intended to expand access to this community and to share a more nuanced understanding of the research enterprise with individuals of varying experiences in research (Akerson *et al.*, 2009).

Åkerlind's (2008a) synthesis of previous phenomenographic studies implies that conceptions I, II, and III (disconnected, involved, and engaged) would be part of an inclusive hierarchy in which each conception includes and expands upon the defining variations in the previous conception. In this study, some participants were coded as holding a hybrid of conceptions II and III. These two conceptions share similar features with the naïve and informed views of nature of science, respectively (Lederman, 1992; Lederman *et al.*, 2002, 2013; Miller *et al.*, 2010; Mohan and Kelly, 2020) and thus may represent a continuum. However, no participants were coded as having overlap between conception I and the other conceptions. Additionally, participants' retrospective conceptions were most frequently coded as conception I, whereas nearly all current conceptions

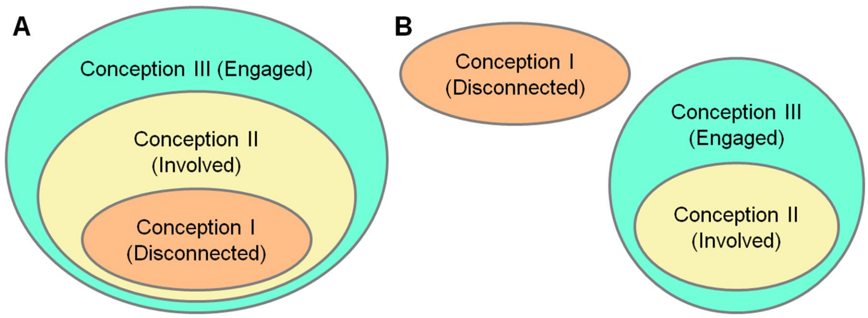

FIGURE 2. **Models for the relationships among the three different conceptions of researchers. (A) The conceptions are represented as an inclusive hierarchy, in which each conception progressively increases in complexity by including and expanding upon the previous conception in each of the three aspects. This model follows what was proposed in Åkerlind's (2008a) synthesis of phenomenographic studies on researchers' conceptions of the research profession. (B) In this alternative model, conception III (engaged) includes and expands upon conception II (involved) in each of the three aspects, whereas conception I (disconnected) is distinct and features little to no overlap with the other two conceptions.**

were aligned with aspects in conceptions II and III (Table 3). It is possible that the defining variations of conception I may be distinct and not included within an inclusive hierarchy with the other two conceptions. However, a revised interview protocol that prompts participants to clearly distinguish among the variations in each of the three aspects will be required to identify the distinction between these two models (Figure 2).

Limitations

This study provides fundamental insights into undergraduate students' conceptions of successful researchers in STEM; however, there are some limitations. First, interview questions in the protocol were not structured to prompt participants to address each of the individual aspects that varied across the different conceptions. Therefore, it was not always feasible to identify the variation that each individual participant held for all three aspects of process, interaction, and contribution, resulting in potentially ambiguous results. However, the open-ended nature of the semistructured interview protocol was advantageous and arguably essential for constructing the outcome space in this study without a priori assumptions.

Second, study participants were asked to provide responses that were retrospective. This retrospective design is limiting because of the challenge in capturing the social and contextual factors that may have influenced the participants' prior conceptions, as well as the cognitive demand for providing descriptive recollections. To measure change, a longitudinal study would have provided a more systematic comparison on if and how participants' conceptions of researchers and their work had developed across the three aspects over time. In addition, methodologies such as the critical incident technique (Butterfield *et al.*, 2005) would have captured important experiences that promote the development from conception I to the other conceptions of successful researchers. Nonetheless, the retrospective questions in the protocol allowed for expanded discussions with the participants in the interview process that captured a wider range of variations and thus a more comprehensive outcome space than would otherwise be possible.

Third, we acknowledge that relying on postprogram interviews as a single data source is limiting for gathering a rich corpus of description and variation in the phenomenographic outcome space and comparing participants' conceptions at different stages along their trajectories in research. It would have been beneficial to triangulate different data sources, especially data collected when the participants were engaging in the summer research experience. In addition to interviews before and/or during their summer research experience, descriptive field notes and observations, artifacts obtained from research activities, and open-ended questionnaires could capture additional variations in how undergraduates conceptualize success as a researcher at different stages along their trajectories in research. Collecting these additional data could provide further insights into the research environments and interpersonal interactions that may influence students' perception of success as they navigate and become enculturated into the research community. Although our timeline for data collection did not permit us to triangulate these additional data sources for this current study's participant sample, the implementation of a postprogram semistructured interview protocol still aligns with the sampling methods, process validity, and sample size that have been described as sufficient for generating an outcome space representing individuals' collective interpretations of a phenomenon (Marton, 1986; Richardson, 1999; Han and Ellis, 2019).

Fourth, the results from this study are not intended to provide universally or broadly generalizable information. The outcome space resulting from this study is intended to illustrate a range of conceptions of researchers that may be held by students pursuing STEM. Other relevant aspects of the successful researchers and their practice may emerge in studies that examine other populations of students, especially for students who do not have experience in undergraduate research. Notably, our study sample represents students from a summer bridge program that provided mentorship experiences and resources. We acknowledge that students entering a university during their first term are unlikely to have access to this form of structured support. These resources may have consequently narrowed the participants' conceptions of successful researchers, as they may have adopted values that were implicitly communicated through the program curriculum or directly by faculty with whom they interacted extensively. However, even with resources that helped them overcome the barrier of accessing the research community, the participants provided a range of conceptions across the different aspects that saturated our outcome space.

Fifth, our sample of undergraduates was transfer students from a single institution, so their conceptions and interpretations may not be fully generalized to all undergraduate students. Additional samples of undergraduate students from different backgrounds, programs, or institutions may hold conceptions that are not represented in our outcome space. However, while we do not claim broad generalizability, there is also no evidence in the existing literature—as far as we understand—indicating that transfer students experience research substantially differently from non-transfer students. Therefore, we attribute the lack of full generalizability with the current data to sampling undergraduate students in a single program and institution rather than the participants' identities as transfer students.

Sixth, one should be cautious when comparing the aspects and variations in our outcome space to those identified in previous phenomenographic studies. We have identified both novel and overlapping variations in comparison to the outcome spaces described in these previous studies (Table 4). However, it cannot be discerned whether these commonalities and differences are due to career stage, geographic affiliation, or time periods in which the studies were conducted.

Despite these limitations, our intent for this study was primarily to highlight a range of student conceptions of researchers rather than focus on experiences that facilitate change. We see the outcome space resulting from this study as a starting point for informing future triangulation of data sources that explicitly investigate the identified aspects to further saturate the variations in the outcome space. Despite the limited availability of other data sources, the aspects and variations identified in this study provide preliminary and fundamental insights for practitioners to consider when facilitating meaningful experiences and targeting undergraduates' professional development in the research community. The conceptions in this outcome space provide a theoretical basis for future work and implications for improving students' understanding of researchers and their practice.

Implications and Future Work

In this study, many participants perceived they had retrospective conceptions that reflected an incomplete or stereotypical understanding of what a career in research would entail. Students pursuing STEM disciplines need to develop a critical and realistic view of researchers and their practice to develop a stable trajectory toward a STEM career pathway (NASEM, 2016). However, a conception of researchers as product driven and holding an individualistic and mundane view of their profession may establish unrealistic expectations or discourage students from pursuing research opportunities. Students who enter research experiences with simplified expectations may not be prepared to engage in an authentic research culture. Because pursuing research experiences requires student initiative to seek existing opportunities, students who are exposed to images of researchers that do not adequately reflect the collaborative and creative nature of the profession could develop a resistance to pursuing research opportunities in the first place. Such resistance is counteractive to the recruitment of STEM professionals needed to support a growing STEM workforce.

A mentored research experience is a common mechanism of enculturation into the research community of practice at the university level, as mentors are more established members who have more experience with the processes and social norms of the community (Thiry and Laursen, 2011; Linn *et al.*, 2015; Ceyhan and Tillotson, 2020). Our results indicated variations in the extent to which students recognized failure and iteration as central to the research process, so students may experience shock and instability if their expectations are incompatible with this authentic nature of the process. Students entering research are often immersed into unfamiliar experiments and methodologies and thus could benefit from instructors and mentors explicating their own challenges and frustrations in the research process. This strategy helps students understand the thought processes of senior researchers and apply scientific reasoning to explain ambiguous results and adapt their research approaches (NASEM, 2016). Similarly, cultivating well-designed research activities wherein students collaborate with other students and senior researchers can acclimate students to the social and cultural norms of the research environment (NASEM, 2016). Research mentors are responsible for cultivating experiences that develop and expand students' existing skill sets, so it is important for mentors to assess students' prior knowledge and conceptions and adapt the research experiences accordingly.

As demonstrated by our outcome space, the three aspects of a researcher's work are conceptually interrelated. Practitioners, research mentors, and program coordinators could use this outcome space as a tool to develop learning objectives that target the maturation of student conceptions of researchers across all three aspects. Existing learning objectives in the *Entering Research* curriculum model have focused on activities and resources that help undergraduate research trainees develop the professional skills and knowledge needed to navigate the culture of the research community (Balster *et al.*, 2010; Branchaw *et al.*, 2020). This curriculum could be adapted or expanded to include seminars and workshops that explicitly engage students' ideas about successful researchers, which could tie into other topics such as developing a researcher identity and research comprehension and communication skills (Branchaw *et al.*, 2020). The excerpts presented in our findings can be the basis for group discussion or implemented in a card-sorting activity in which students explore stereotypes about researchers and identify aspects that align with more nuanced and informed views of the research profession. These sessions would also provide space for students to collectively reflect upon and consolidate their ideas about successful researchers and establish expectations for their research experiences with their mentors.

Phenomenographic research has contributed to reconceptualizations of teaching and learning by providing educators and practitioners with opportunities to reflect on and implement curricular reforms to change the focus of students' awareness of concepts and phenomena (Entwistle, 1997; Marton and Booth, 1997). The outcome space generated in this study is a mapping of students' collective ideas about successful researchers. This outcome space is foundational for future work that might investigate individual students' positions in the outcome space and map their trajectories over time after engaging in UREs or participating in curricular reforms that develop their ideas about researchers (e.g., Schinske *et al.*, 2016). Providing students with opportunities to reflect on and become aware of the variations in the procedural and social aspects of the research profession may be critical for facilitating shifts in their conceptions (Light and Calkins, 2015).

As demonstrated by the two hypothetical relationships between the conceptions (Figure 2), it remains unknown whether there is a hierarchical relationship between the conceptions. Based on the current evidence supporting the nonhierarchical model in Figure 2B, it cannot be assumed that students move in linear manner from conception I to conception II to conception III, nor can it be assumed that increased amount of time being involved in a research experience correlates with increased shifts toward conception III. Future work that maps students' positions in the outcome space before, during, and after engagement in UREs is essential for supporting or refuting these two models. The discernment between these models is crucial for determining the cognitive and psychosocial mechanisms that facilitate shifts in students' conceptions, which will be informative for the development of quality research experiences that strategically target students' professional development as legitimate peripheral participants in the research community of practice. Although our study sample was sociodemographically diverse, it will be important to include other populations of students within different institutional contexts in future work to capture the diversity of undergraduate STEM students' experiences and development.

Given the breadth of research that highlights variations in the quality and nature of undergraduates' research experiences (Dolan and Johnson, 2010; Thiry *et al.*, 2012; Aikens *et al.*, 2016), future work could also investigate how the research environment that students work in can influence their conceptions about what it means to be a researcher. A direct examination of the interpersonal interactions and discourse that students have with their research mentors can provide insights into how students' mentoring relationships can influence their understanding of the social and procedural norms of research as they are enculturated into the research community. Additionally, an examination of interpersonal interactions and relationships that students have with individuals outside the immediate research community, such as with peers or their families, can be triangulated in this future work to comprehensively investigate how different social networks and capital can influence students' ideas about researchers and navigational processes through the research community (Aikens *et al.*, 2016).

Although phenomenographic data and findings provide information on how to facilitate conceptual change, future studies warrant the use of complementary theoretical frameworks to investigate the critical experiences that facilitate change (Butterfield *et al.*, 2005). Examining how conceptual changes restructure knowledge and beliefs about successful researchers can provide insight into the experiences that influence students' understanding of the operational and sociocultural dimensions of the research profession (Duit and Treagust 2003; Vosniadou, 2008). Before crossing the conceptual threshold needed to gain an informed view of how and why research is conducted, students without prior exposure to the research world may feel unprepared, challenged, or unmotivated to pursue research as a profession (Meyer and Land, 2003; Kiley and Wisker, 2009). It is therefore essential to understand the critical experiences that may transform students' conceptual knowledge of a researcher's practice and the corresponding institutional practices that would foster such experiences (Meyer and Land, 2003).

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REFERENCES

Aikens, M. L., Sadselia, S., Watkins, K., Evans, M., Eby, L. T., & Dolan, E. L. (2016). A social capital perspective on the mentoring of undergraduate life science researchers: An empirical study of undergraduate–postgraduate–faculty triads. *CBE—Life Sciences Education*, *15*(2), ar16. https://doi.org/10.1187/cbe.15-10-0208

Åkerlind, G. S. (2005). Variation and commonality in phenomenographic research methods. *Higher Education Research and Development*, *24*(4), 321–334. https://doi.org/10.1080/07294360500284672

Åkerlind, G. S. (2008a). An academic perspective on research and being a researcher: An integration of the literature. *Studies in Higher Education*, *33*(1), 17–31. https://doi.org/10.1080/03075070701794775

Åkerlind, G. S. (2008b). Growing and developing as a university researcher. *Higher Education*, *55*(2), 241–254. https://doi.org/10.1007/s10734-007-9052-x

Akerson, V. L., Cullen, T. A., & Hanson, D. L. (2009). Fostering a community of practice through a professional development program to improve elementary teachers' views of nature of science and teaching practice. *Journal of Research in Science Teaching*, *46*(10), 1090–1113. https://doi.org/10.1002/tea.20303

Aldiabat, K. M., & Le Navenec, C.-L. (2018). Data saturation: The mysterious step in grounded theory methodology. *Qualitative Report*, *23*(1), 245–261. https://doi.org/10.46743/2160-3715/2018.2994

Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), 564–582. https://doi.org/10.1002/tea.20353

Bahr, P. R., Toth, C., Thirolf, K., & Massé, J. C. (2013). A review and critique of the literature on community college students' transition processes and outcomes in four-year institutions. In Paulsen, M. B. (Ed.), *Higher education: Handbook of theory and research* (pp. 459–511). New York: Springer.

Baiduc, R. R., Drane, D., Beitel, G. J., & Flores, L. C. (2017). A research preparatory program for first-year college students: Student selection and preparation lead to persistence in research. *Innovative Higher Education*, *42*(3), 269–284. https://doi.org/10.1007/s10755-016-9377-4

Balster, N., Pfund, C., Rediske, R., & Branchaw, J. (2010). Entering research: A course that creates community and structure for beginning undergraduate researchers in the STEM disciplines. *CBE—Life Sciences Education*, *9*(2), 108–118. https://doi.org/10.1187/cbe.09-10-0073

Bangera, G., & Brownell, S. E. (2014). Course-based undergraduate research experiences can make scientific research more inclusive. *CBE—Life Sciences Education*, *13*(4), 602–606. https://doi.org/10.1187/cbe.14-06-0099

Barman, C. R. (1999). Students' views about scientists and school science: Engaging K-8 teachers in a national study. *Journal of Science Teacher Education*, *10*(1), 43–54. https://doi.org/10.1023/A:100942471341

Barnard, A., Mccosker, H., & Gerber, R. (1999). Phenomenography: A qualitative research approach for exploring understanding in health care. *Qualitative Health Research*, *9*(2), 212–226. https://doi.org/10.1177/104973299129121794

Bills, D. (2004). Supervisors' conceptions of research and the implications for supervisor development. *International Journal for Academic Development*, *9*(1), 85–97. https://doi.org/10.1080/1360144042000296099

Bowden, J. (1994a). The nature of phenomenographic research. In Bowden, J., & Walsh, E. (Eds.), *Phenomenographic research: Variations in method* (pp. 1–16). Melbourne, Australia: RMIT: EQARD.

Bowden, J. (1994b). Experience of phenomenographic research: A personal account. In Bowden, J., & Walsh, E. (Eds.), *Phenomenographic research: Variations in method* (pp. 44–55). Melbourne, Australia: RMIT: EQARD.

Bowden, J., Green, P., Barnacle, R., Cherry, N., & Usher, R. (2005). Academics' ways of understanding success in research activities. *Doing Developmental Phenomenography*, 128–144.

Bowman, N. A., & Holmes, J. M. (2018). Getting off to a good start? First-year undergraduate research experiences and student outcomes. *Higher Education*, *76*(1), 17–33. https://doi.org/10.1007/s10734-017-0191-4

Branchaw, J. L., Butz, A. R., & Smith, A. R. (2020). Evaluation of the second edition of entering research: A customizable curriculum for apprentice-style undergraduate and graduate research training programs and courses. *CBE—Life Sciences Education*, *19*(1), ar11. https://doi.org/10.1187/cbe.19-04-0073

Brew, A. (2001). Conceptions of research: A phenomenographic study. *Studies in Higher Education*, *26*(3), 271–285. https://doi.org/10.1080/03075070120076255

Brew, A., Boud, D., Namgung, S. U., Lucas, L., & Crawford, K. (2016). Research productivity and academics' conceptions of research. *Higher Education*, *71*(5), 681–697. https://doi.org/10.1007/s10734-015-9930-6

Brickhouse, N. W., Lowery, P., & Schultz, K. (2000). What kind of a girl does science? The construction of school science identities. *Journal of Research in Science Teaching*, *37*(5), 441–458. https://doi.org/10.1002/(SICI)1098-2736(200005)37:5≤441::AID-TEA4≥3.0.CO;2-3

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42. https://doi.org/10.3102/0013189X018001032

Bruce, C., Pham, B., & Stoodley, I. (2004). Constituting the significance and value of research: Views from information technology academics and industry professionals. *Studies in Higher Education*, *29*(2), 219–238. https://doi.org/10.1080/0307507042000190804

Burgin, S. R., & Sadler, T. D. (2013). Consistency of practical and formal epistemologies of science held by participants of a research apprenticeship. *Research in Science Education*, *43*(6), 2179–2206. https://doi.org/10.1007/s11165-013-9351-4

Butterfield, L. D., Borgen, W. A., Amundson, N. E., & Maglio, A. S. T. (2005). Fifty years of the critical incident technique: 1954–2004 and beyond. *Qualitative Research*, *5*(4), 475–497. https://doi.org/10.1177/1468794105056924

Calabrese Barton, A., Tan, E., & Rivet, A. (2008). Creating hybrid spaces for engaging school science among urban middle school girls. *American Educational Research Journal*, *45*(1), 68–103. https://doi.org/10.3102/0002831207308641

Calabrese Barton, A., & Yang, K. (2000). The culture of power and science education: Learning from Miguel. *Journal of Research in Science Teaching*, *37*(8), 871–889. https://doi.org/10.1002/1098-2736(200010)37:8 <871::AID-TEA7>3.0.CO;2-9

Carter, D. F., Ro, H. K., Alcott, B., & Lattuca, L. R. (2016). Co-curricular connections : The role of undergraduate research experiences in promoting engineering skills. *Research in Higher Education*, *57*(3), 363–393. https://doi.org/10.1007/s11162-015-9386-7

Cartrette, D. P., & Melroe-Lehrman, B. M. (2012). Describing changes in undergraduate students ' preconceptions of research activities. *Research in Science Education*, *42*(6), 1073–1100. https://doi.org/10.1007/s11165-011-9235-4

Ceyhan, G. D., & Tillotson, J. W. (2020). Mentoring structures and the types of support provided to early-year undergraduate researchers. *CBE—Life Sciences Education*, *19*(3), ar26. https://doi.org/10.1187/cbe.19-09-0183

Chambers, D. W. (1983). Stereotypic images of the scientist: The Draw-a-Scientist test. *Science Education*, *67*(2), 255–265. https://doi.org/10.1002/sce.3730670213

Cibangu, S. K., & Hepworth, M. (2016). The uses of phenomenology and phenomenography: A critical review. *Library and Information Science Research*, *38*(2), 148–160. https://doi.org/10.1016/j.lisr.2016.05.001

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, *20*(1), 37–46. https://doi.org/10.1177/001316446002000104

Dolan, E. L., & Johnson, D. (2010). The undergraduate–postgraduate–faculty triad: Unique functions and tensions associated with undergraduate research experiences at research universities. *CBE—Life Sciences Education*, *9*(4), 543–553. https://doi.org/10.1187/cbe.10-03-0052

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*(6), 671–688. https://doi.org/10.1080/09500690305016

Eagan, M. K., Hurtado, S., Chang, M. J., Garcia, G. A., Herrera, F. A., & Garibay, J. C. (2013). Making a difference in science education: The impact of undergraduate research programs. *American Educational Research Journal*, *50*(4), 683–713. https://doi.org/10.3102/0002831213482038

Entwistle, N. (1997). Introduction: Phenomenography in higher education. *Education Research & Development*, *16*(2), 127–134. https://doi.org/10.1080/0729436970160202

Farmer, J. A., Jr (1992). Cognitive apprenticeship: Implications for continuing professional education. *New Directions for Adult and Continuing Education*, *55*, 41–49.

Farnsworth, V., Kleanthous, I., & Wenger-Trayner, E. (2016). Communities of practice as a social theory of learning: A conversation with Etienne Wenger. *British Journal of Educational Studies*, *64*(2), 139–131. https://doi.org 10.1080/00071005.2015.1133799

Fila, N. D., Zoltowski, C. B., Hess, J. L., Kim, D., Kerr, A. J., Brightman, A. O., & Loui, M. C. (2019, June). Work in progress: Considering the impact on research quality of a team approach to phenomenography. In *2019 ASEE Annual Conference & Exposition held at Tampa, FL*.

Finson, K. D. (2002). Drawing a scientist: What we do and do not know after fifty years of drawings. *School Science and Mathematics*, *102*(7), 335–345. https://doi.org/10.1111/j.1949-8594.2002.tb18217.x

Gilbert, A., & Yerrick, R. (2001). Same school, separate worlds: A sociocultural study of identity, resistance, and negotiation in a rural, lower track science classroom. *Journal of Research in Science Teaching*, *38*(5), 574–598. https://doi.org/10.1002/tea.1019

Gilmore, J., Vieyra, M., Timmerman, B., Feldon, D., Maher, M., Gilmore, J., ... & Gilmore, J. (2015). The relationship between undergraduate research participation and subsequent research performance of early career STEM graduate students. *Journal of Higher Education*, *86*(6), 834–863. https://doi.org/10.1080/00221546.2015.11777386

Gormally, C., & Inghram, R. (2021). Goggles and white lab coats: Students' perspectives on scientists and the continued need to challenge stereotypes. *Journal of Microbiology & Biology Education*, *22*(1), ev22i1–2273. https://doi.org/10.1128/jmbe.v22i1.2273

Graham, M. J., Frederick, J., Byars-Winston, A., Hunter, A. B., & Handelsman, J. (2013). Increasing persistence of college students in STEM. *Science*, *341*(6153), 1455–1456. https://doi.org/10.1126/science.1240487

Hajar, A. (2020). Theoretical foundations of phenomenography: A critical review. *Higher Education Research & Development*, *40*(7), 1421–1436. https://doi.org/10.1080/07294360.2020.1833844

Han, F., & Ellis, R. A. (2019). Using phenomenography to tackle key challenges in science education. *Frontiers in Psychology*, *10*(1414), 1–10. https://doi.org/10.3389/fpsyg.2019.01414

Hasselgren, B., & Beach, D. (1997). Phenomenography—a "good-for-nothing brother" of phenomenology? Outline of an analysis. *Higher Education Research & Development*, *16*(2), 191–202. https://doi.org/10.1080/0729436970160206

Haynes, R. (2003). From alchemy to artificial intelligence: Stereotypes of the scientist in Western literature. *Public Understanding of Science*, *12*(3), 243–253.

Hennink, M. M., Kaiser, B. N., & Marconi, V. C. (2017). Code saturation versus meaning saturation: How many interviews are enough? *Qualitative Health Research*, *27*(4), 591–608. https://doi.org/10.1177/1049732316665344

Hodson, D. (1993). In search of a rationale for multicultural science education. *Science Education*, *77*(6), 685–711. https://doi.org/10.1002/sce.3730770611

Hunter, A. B., Laursen, S. L., & Seymour, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. *Science Education*, *91*(1), 36–74. https://doi.org/10.1002/sce.20173

Jho, H., Hong, O., & Song, J. (2016). An analysis of STEM/STEAM teacher education in Korea with a case study of two schools from a community of practice perspective. *Eurasia Journal of Mathematics, Science and Technology Education*, *12*(7), 1843–1862. https://doi.org/10.12973/eurasia.2016.1538a

Jones, M. T., Barlow, A. E. L., & Villarejo, M. (2010). Importance of undergraduate research for minority persistence and achievement in biology. *The Journal of Higher Education*, *81*(1), 82–115. https://doi.org/10.1080/00221546.2010.11778971

Kanim, S., & Cid, X. C. (2020). Demographics of physics education research. *Physical Review Physics Education Research*, *16*(2), 20106. https://doi.org/10.1103/PhysRevPhysEducRes.16.020106

Kiley, M., & Mullins, G. (2005). Supervisors' conceptions of research: What are they? *Scandinavian Journal of Educational Research*, *49*(3), 245–262. https://doi.org/10.1080/00313830500109550

Kiley, M., & Wisker, G. (2009). Threshold concepts in research education and evidence of threshold crossing. *Higher Education Research and Development*, *28*(4), 431–441. https://doi.org/10.1080/07294360903067930

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159. https://doi.org/10.2307/2529310

Larsson, J., & Holmström, I. (2007). Phenomenographic or phenomenological analysis: Does it matter? Examples from a study on anaesthesiologists' work. *International Journal of Qualitative Studies on Health and Well-Being*, *2*(1), 55–64. https://doi.org/10.1080/17482620601068105

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*(4), 331–359. https://doi.org/10.1002/tea.3660290404

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521. https://doi.org/10.1002/tea.10034

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics, Science and Technology*, *1*(3), 138–147.

Light, G., & Calkins, S. (2015). The experience of academic learning : Uneven conceptions of learning across research and teaching. *Higher Education*, *69*(3), 345–359. https://doi.org/10.1007/s10734-014-9779-0

Linn, M. C., Palmer, E., Baranger, A., Gerard, E., & Stone, E. (2015). Undergraduate research experiences: Impacts and opportunities. *Science*, *347*(6222), 1261757. https://doi.org/10.1126/science.1261757

Lo, S. M., Gardner, G. E., Reid, J., Napoleon-Fanis, V., Carroll, P., Smith, E., & Sato, B. K. (2019). Prevailing questions and methodologies in biology education research: A longitudinal analysis of research in *CBE—Life Sciences Education* and at the Society for the Advancement of Biology Education Research. *CBE—Life Sciences Education*, *18*(1), ar9. https://doi.org/10.1187/cbe.18-08-0164

Lopatto, D. (2007). Undergraduate research experiences support science career decisions and active learning. *CBE—Life Sciences Education*, *6*(4), 297–306. https://doi.org/10.1187/cbe.07-06-0039

Losh, S. C. (2010). Stereotypes about scientists over time among US adults: 1983 and 2001. *Public Understanding of Science*, *19*(3), 372–382. https://doi.org/10.1177/0963662508098576

Losh, S. C., Wilke, R., & Pop, M. (2008). Some methodological issues with "Draw a Scientist tests" among young children. *International Journal of Science Education*, *30*(6), 773–792. https://doi.org/10.1080/09500690701250452

Luukkonen, T., & Thomas, D. A. (2016). The "negotiated space" of university researchers' pursuit of a research agenda. *Minerva*, *54*(1), 99–127. https://doi.org/10.1007/s11024-016-9291-z

Ma, J., & Baum, S. (2016, April). *Trends in community colleges: Enrollment, prices, student debt, and completion* (College Board research brief). Retrieved August 15, 2021, from http://trends.collegeboard.org/sites/default/files/trends-in-community-colleges-research-brief.pdf

Marton, F. (1981). Phenomenography—describing world around us conceptions. *Instructional Science*, *10*(2), 177–200. https://doi.org/10.1007/BF00132516

Marton, F. (1986). Phenomenography: A research approach to investigating different understandings of reality. *Journal of Thought*, *21*(3), 28–49. https://doi.org/10.4324/9780203645994-17

Marton, F., & Booth, S. (1997). *Learning and awareness*. Mahwah, NJ: Erlbaum.

Marton, F., & Pong, W. Y. (2005). On the unit of description in phenomenography. *Higher Education Research and Development*, *24*(4), 335–348. https://doi.org/10.1080/07294360500284706

Marton, F., & Tsui, A. B. (2004). *Classroom discourse and the space of learning*. Hillsdale, NJ: Erlbaum.

McCormick, A. C., & Zhao, C.-M. (2005). Rethinking and reframing the Carnegie Classification. *Change: The Magazine of Higher Learning*, *37*(5), 51–57. https://doi.org/10.3200/chng.37.5.51-57

McGee, R., & Keller, J. L. (2007). Identifying future scientists: Predicting persistence into research training. *CBE—Life Sciences Education*, *6*(4), 316–331. https://doi.org/10.1187/cbe.07-04-0020

Meyer, J. H. F., & Land, R. (2003). Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practising within the disciplines. In Rust, C. (Ed.), *Improving student learning* (pp. 412–424). Oxford, England: Oxford Centre for Staff and Learning Development.

Meyer, J. H. F., Shanahan, M. P., & Laugksch, R. C. (2005). Students' conceptions of research. I: A qualitative and quantitative analysis. *Scandinavian Journal of Educational Research*, *49*(3), 225–244. https://doi.org/10.1080/00313830500109535

Miller, M. C. D., Montplaisir, L. M., Offerdahl, E. G., Cheng, F. C., & Ketterling, G. L. (2010). Comparison of views of the nature of science between natural science and nonscience majors. *CBE—Life Sciences Education*, *9*(1), 45–54. https://doi.org/1187/cbe.09-05-002910

Mohan, A., & Kelly, G. J. (2020). Nature of science and nature of scientists. *Science & Education*, *29*(5), 1097–1116. https://doi.org/10.1007/s11191-020-00158-y

National Academies of Sciences, Engineering, and Medicine. (2016). *Barriers and opportunities for 2-year and 4-year STEM degrees: Systemic change to support students' diverse pathways*. Washington, DC: National Academies Press.

National Science Foundation, National Center for Science and Engineering Statistics. (2021). *Women, minorities, and persons with disabilities in science and engineering: 2021 (NSF 21-321)*. Alexandria, VA.

Nerstad, C. G., Buch, R., Dysvik, A., & Säfvenbom, R. (2020). Stability of individuals' definitions of success and the influence of perceived motivational climate: A longitudinal perspective. *Frontiers in Psychology*, *11*, 1326. https://doi.org/10.3389/fpsyg.2020.01326

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press.

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. Newbury Park, CA: Sage.

President's Council of Advisors on Science and Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering and mathematics*. Washington, DC: U.S. Government Office of Science and Technology.

Prosser, M., Martin, E., Trigwell, K., Ramsden, P., & Middleton, H. (2008). University academics' experience of research and its relationship to their experience of teaching. *Instructional Science*, *36*(1), 3–16. https://doi.org/10.1007/s11251-007-9019-4

Quan, G. M., Turpen, C., & Elby, A. (2018). Interactions between disciplinary practice and joint work in undergraduate physics research experiences. *Physical Review Physics Education Research*, *14*(2), 020124. https://doi.org/10.1103/PhysRevPhysEducRes.14.020124

Quaye, S. J., Harper, S. R., & Pendakur, S. L. (2019). *Student engagement in higher education: Theoretical perspectives and practical approaches for diverse populations*. New York, NY: Routledge.

Reed, B. (2006). Phenomenography as a way to research the understanding by students of technical concepts. *Nucleo de Pesquisa Em Technologia Da Arquiterura e Urbanismo (NUTAU): Technological innovation and sustainability, Sao Paulo, Brazil* (pp. 1–11).

Richardson, J. T. E. (1999). The concepts and methods of phenomenographic research. *Review of Educational Research*, *69*(1), 53–82. https://doi.org/10.3102/00346543069001053

Rowe, W. E. (2014). Positionality. In Coghlan D., & Brydon-Miller M. (Eds.), *The Sage encyclopedia of action research* (pp. 628). London, England: Sage.

Russell, S. H., Hancock, M. P., & Mccullough, J. (2007). Benefits of undergraduate research experiences. *Science*, *316*(5824), 548–549. https://doi.org/10.1.1.686.3476

Ryder, J., & Leach, J. (1999). University science students' experiences of investigative project work and their images of science. *International Journal of Science Education*, *21*(9), 945–956. https://doi.org/10.1080/095006999290246

Sadler, B. T. D., & Mckinney, L. (2010). Scientific research for undergraduate students: A review of the literature. *Journal of College Science Teaching*, *39*(5), 43–49.

Salberg, J., Bäckström, J., Röing, M., & Öster, C. (2019). Ways of understanding nursing in psychiatric inpatient care—a phenomenographic study. *Journal of Nursing Management*, *27*(8), 1826–1834. https://doi.org/10.1111/jonm.12882

Saldaña, J. (2015). *The coding manual for qualitative researchers* (4th ed.). Sage.

Säljö, R. (1996). Minding action: Conceiving of the world versus participating in cultural practices. In Dall'Alba G. & Hasselgren B. (Eds.), *Reflections on phenomenography: Towards a methodology?* (Vol. 109, pp. 19–33). Goteborg: Goteborg Studies in Educational Sciences.

Säljö, R. (1997). Talk as data and practice: A critical look at phenomenographic inquiry and the appeal to experience. *Higher Education Research and Development*, *16*(2), 173–190. https://doi.org/10.1080/0729436970160205

Sandbergh, J. (1997). Are phenomenographic results reliable? *Higher Education Research & Development*, *16*(2), 203–212. https://doi.org/10.1080/0729436970160207

Schinske, J. N., Perkins, H., Snyder, A., & Wyer, M. (2016). Scientist spotlight homework assignments shift students' stereotypes of scientists and enhance science identity in a diverse introductory science class. *CBE—Life Sciences Education*, *15*(3), ar47. https://doi.org/10.1187/cbe.16-01-0002

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

Stenfors-Hayes, T., Hult, H., & Dahlgren, M. A. (2013). A phenomenographic approach to research in medical education. *Medical Education*, *47*(3), 261–270. https://doi.org/10.1111/medu.12101

Stevens, S. L., Kuzak, M., Martinez, C., Moser, A., Bleeker, P., & Galland, M. (2018). Building a local community of practice in scientific programming for life scientists. *PLoS Biology*, *16*(11), e2005561. https://doi.org/10.1371/journal.pbio.2005561

Stubb, J., Pyhältö, K., & Lonka, K. (2014). Conceptions of research: The doctoral student experience in three domains. *Studies in Higher Education*, *39*(2), 251–264. https://doi.org/10.1080/03075079.2011.651449

Svensson, L. (1997). Theoretical foundations of phenomenography. *Higher Education Research & Development*, *16*(2), 159–171. https://doi.org/10.1080/0729436970160204

Tan, E., & Calabrese Barton, A. (2008). Unpacking science for all through the lens of identities-in-practice: The stories of Amelia. *Cultural Studies of Science Education*, *3*(1), 43–71. https://doi.org/10.1007/s11422-007-9076-7

Thiry, H., & Laursen, S. L. (2011). The role of student-advisor interactions in apprenticing undergraduate researchers into a scientific community of practice. *Journal of Science Education and Technology*, *20*(6), 771–784. https://doi.org/10.1007/s10956-010-9271-2

Thiry, H., Laursen, S. L., & Hunter, A. B. (2011). What experiences help students become scientists? A comparative study of research and other sources of personal and professional gains for STEM undergraduates. *Journal of Higher Education*, *82*(4), 357–388. https://doi.org/10.1080/00221546.2011.11777209

Thiry, H., Weston, T. J., Laursen, S. L., & Hunter, A. B. (2012). The benefits of multi-year research experiences: Differences in novice and experienced students' reported gains from undergraduate research. *CBE—Life Sciences Education*, *11*(3), 260–272. https://doi.org/10.1187/cbe.11-11-0098

Vandermaas-Peeler, M., Miller, P. C., & Peeples, T. (2015). "Mentoring is sharing the excitement of discovery": Faculty perceptions of undergraduate research mentoring. *Mentoring & Tutoring: Partnership in Learning*, *23*(5), 377–393. https://doi.org/10.1080/13611267.2015.1126163

Van Rossum, E. J., & Hamer, R. (2010). *The meaning of learning and knowing*. Rotterdam, Netherlands: Sense Publishers.

Vosniadou, S. (2008). The framework theory approach to the problem of conceptual change. In Vosniadou, S. (Ed.), *International handbook of research on conceptual change* (pp. 31–62). New York, NY: Routledge.

Walther, J., Sochacka, N. W., & Kellam, N. N. (2013). Quality in interpretive engineering education research: Reflections on an example study. *Journal of Engineering Education*, 102(4), 626–659. https://doi.org/10.1002/jee.20029

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. New York, NY: Cambridge University Press.

Zuckerman, A. L., & Lo, S. M. (2021). Transfer student experiences and identity navigation in STEM: Overlapping figured worlds of success. *CBE—Life Sciences Education*, *20*(3), ar48. https://doi.org/10.1187/cbe.20-06-0121