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Theory and Research on STEM Undergraduate Research Experiences

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Undergraduate research experiences (URE) are considered to be high-impact practices that connect content knowledge from coursework to scientific innovation (Johnson & Stage, 2018). For instance, participation in undergraduate research experiences helps students look for underlying meaning and not just apparent knowledge, encourages students to search for relationships between pieces of information that come from reflection rather than engage in rote memorization, and involves applying knowledge to real-life situations and successfully integrating previous learning (Haeger, BrckaLorenz, & Webber, 2015).

It is important to note that existing scholarship often conflates "research experiences" with "research lab experiences." For the purposes of clarity, "research experiences" are broader in nature than experiences in the "research lab" (Burt, 2014). "Research experiences" may include reading scientific literature, designing aspects of a research project, working toward significant findings, and producing oral and written presentations of the results (Lopatto, 2004; Seago, 1992; Spell, Guinan, Miller, & Beck, 2014), whereas research done in the laboratory may be relegated to conducting experiments and writing lab reports (Luckie et al., 2004; Myers & Burgess, 2003; Rissing & Cogan, 2009). In this brief, we share key patterns of the predominant outcomes associated with participation in undergraduate research experiences. In doing so, we address the following questions: What and how do students learn from participating in undergraduate research experiences? What benefits are associated with participation in undergraduate research experiences?

Methods

To gain an understanding of the theoretical underpinnings associated with participation in undergraduate research experiences, we started by conducting a broad search of existing literature. We searched using phrases such as "undergraduate research experiences," "summer undergraduate research experiences (SURE)," "college undergraduate research experiences (CURE)," "students of color," "minorities," underrepresented minorities (and "URM")," and "STEM." This open search resulted in books, book chapters, peer-reviewed articles, and research briefs. Of these, we decided to primarily focus on peer-reviewed articles that were less than 10 years old; older articles were considered if they had a high impact or citation factor, as indicated by Google Scholar. Next, we conducted an initial analysis of each article's focus, looking at its research questions, theoretical or conceptual frameworks, and results. This initial analysis revealed that existing scholarship on undergraduate research experiences tends to focus exclusively on non-historically underrepresented populations. Below, we highlight some of the predominant outcomes of participating in undergraduate research experiences.

Outcomes Associated with Participation in Undergraduate Research Experiences

#1 Learning from URE Participation

Although describing similar processes, scholarship on student participation in undergraduate research experiences uses a variety of concepts to describe learning: community of practice (Auchincloss et al., 2014; Corwin, Graham, & Dolan, 2015); situated cognition (Kardash, 2000); situated learning (Wylie & Gorman, 2018); and social constructivist learning theory (Hunter, Laursen, & Seymour, 2007). Like other scholars, we will describe the previously listed terms under an umbrella concept: sociocultural perspectives on learning.

This body of scholarship tends to describe the contexts in which learning takes place and how these contexts result in specific kinds of learning. For example, Hunter, Laursen, and Seymour's (2007) study of faculty members' and undergraduate participants' perceptions of student development resulting from participation in a summer research program, found that both faculty members and students acknowledged students' research development (i.e., learning), and that as a result of participating in the program, students both became socialized and began seeing themselves as scientists. From a sociocultural perspective on learning (Burt, Lundgren, & Schroetter, 2017; Baker & Lattuca, 2010; Lave & Wenger, 1991; Wenger, 2010; Vygotsky, 1978; Wertsch, del Rio, & Alvarez, 1995), students' learning was "situated" in the research labs at their summer research sites. Further, the faculty supervisors facilitated collaborative interactions to promote learning how to do experiments and do the work of a scientist. In this regard, students' faculty research supervisors and peers in their research labs mediated students' participation and learning of research.

Once students engage in the practices of their community (i.e., the research lab), they begin to enact the same behaviors as community members and form an identity consistent with those of community members (i.e., scientist). This was illustrated in Brown, Lewis, and Bevan's (2016) assessment of undergraduate students in a biochemistry research program. They found that as a result of the practices of the program, students learned how to do research and contribute to publishable work, and thus became more confident in their ability to do science and in their preparation for graduate school and post-graduate careers in science.

#2 Retention through URE Participation

Participation in UREs aids in various forms of retention (e.g., to undergraduate degree completion; advanced degrees; STEM workforce) (Carpi, Ronan, Falconer & Lents, 2017)) because participation strengthens students' confidence in their research abilities, enhances their sense of belonging, and expands their supportive networks through mentoring relationships, all of which contribute to retention in STEM pathways.
Research shows that participation in UREs bolster students' confidence in their academic abilities. For instance, studies focused on structured URE programs highlighted significant increases in GPAs and retention in math- and science-related courses (see examples: Undergraduate Research Opportunity Program at the University of Michigan (Gregerman, Lerner, Von Hippel, Jonides & Nagda, 1998); Meyerhoff Scholars Program at the University of Maryland, Baltimore County (Maton, Hrabowski & Schmitt, 2000); and, Biology Undergraduate Scholars Program at the University California at Davis (Jones, Barlow, & Villarejo, 2010)). In fact, some evidence suggests that participation in URE programs may be especially crucial for students at the greatest risk of attrition (Carpi et al., 2017). Bowman and Holmes (2018) found that when students participated in UREs, they increased in their capacities of critical thinking, scientific writing, and communication skills (see also Lopatto, 2010). Thus, students' participation in the practical, deep learning, and hands-on experiences of UREs not only influences their learning, but also increases their confidence and research competence (Hunter et al., 2007; Laursen, 2010).

#3 Sense of Belonging Occurs through URE Participation

Mahatmya et al.'s (2017) study contends that when institutions create rigorous and successful UREs, they can increase their retention of students across disciplines; moreover, these students will perceive and replicate a sense of social belonging and intellectual camaraderie within their college and or university. Students can feel that same sense of connection from peers within their research labs, writing groups, and study groups. Participation in UREs often provides opportunities for students to share essential institutional ideas (Mahatmya et al., 2017), thus building alliances among other aspiring peer scientists, establishing a sense of belonging and community (Bowman & Holmes, 2018). In addition, Seymour, Hunter, Laursen, and DeAntoni (2004) assert that students find pleasure in "belonging to a community," such as a research lab with others thinking, working, and discovering new knowledge in similar ways.

For example, undergraduate research programs (e.g., Louis Stokes Alliance for Minority Participation [LSAMP]; McNair; Summer Research Opportunities Program [SROP] emphasize a collective learning experience. In these types of programs, students not only build confidence, but also build community and feel more connected (Parsons, 2012). Students complete research projects with faculty members, and in doing so, they may collect original data and engage in analysis, assist a faculty member with existing research, present at a conference and/or symposium, and possibly co-author a paper. Each senior scholar acts as a mentor to new scholars, and thus enacts retention through example (Parsons, 2012). Finally, when students also engage with undergraduate peers, and/or graduate students, they may feel an increased sense of belonging (Wilson et al., 2012).

#4 Mentorship and URE Participation

Working with faculty members is a key component for long-term success and retention, especially in fields like STEM (Houser, Lemmons & Cahill, 2013). In fact, the National Science Foundation (NSF) asserts that the “involvement of undergraduate students in meaningful research with faculty members [is] one of the most powerful instructional tools,” (NSF, 2000). Faculty mentorship is necessary to help students understand scientific inquiry; this relationship between scholar and emerging scholar influences retention. For instance, Waller et al. (2018) reported that faculty can be significant role models who help students to learn more about STEM, graduate school, academic professions, and the research process. In another example, Wilson et al. (2012) found that mentoring through undergraduate research experiences played critical roles in helping students to successfully complete their undergraduate studies and prepare for graduate study or entrance into the STEM workforce. Further, studies have shown the value and impact that faculty can have on underrepresented students (May & Chubin, 2003). May and Chubin (2003) suggest that such students are more likely to pursue a career in their field if they have positive experiences with faculty and other professionals. In fact, evidence suggests that the more meetings students have with their mentors, the more their confidence and interest in continuing into a STEM career are enhanced, while students who lack that connected mentorship are more likely to switch majors and/or career paths (Linn, Palmer, Baranger, Gerard & Stone, 2015). Some scholarship suggests that undergraduate students who are not mentored tend to have lower GPAs, lower retention, and fewer units completed per semester in comparison to their mentored colleagues (Campbell & Campbell, 1997; Wilson et. al., 2012), and may be more likely to switch majors and/or career paths (Linn et al., 2015. Similarly, Haeger and Fresquez’s (2016) study of 348 students found that a mentored URE provides students with hands-on learning experiences that increase their academic success, as measured by cumulative GPA, and does not elongate the time they spend in college.

#5 Preparation for Graduate School and/or Future Research Activity

Participation in research provides students with the skills necessary for future research activity (e.g., graduate school, careers utilizing research) (Haeger & Fresquez, 2016; Thiry et al., 2012). For example, in Thiry et al.’s (2012) study of the experiences and benefits of participating in undergraduate research, some of the skills developed were communication and critical thinking. These skills were learned when students engaged in interactions with faculty members, and analyzed data during their research experiences. Similarly, studies by Lopatto (2004 & 2007) reported that undergraduate students from a variety of fields (i.e., biology, chemistry, physics, earth and planetary science, mathematics, computer science, biochemistry, bioinformatics, neurobiology, engineering, education, social science, humanities, natural science) who engaged in research experiences gained better understandings of the research process, including scientific techniques needed to make progress in their research.

According to this scholarship, participating in research provides students with abilities to become scientists by building and developing their skills. Further, when students participate in these experiences, they are better able to see themselves engaging in research in the future.

#6 URE Participation Informs Interest in research-related STEM Careers

Existing literature has shown that there is a relationship between participation in undergraduate research experiences and interest in future careers in STEM (Haeger & Fresquez, 2016). Haeger and Fresquez's (2016) study of 348 undergraduate students attending a minority serving institution found that students gained skills and knowledge often associated with success in STEM fields such as research competency. Increased research competence, according to the authors, later influenced students' further involvement in research, improved academic performance, and led to higher probabilities that students would remain in STEM (e.g., graduate school, research careers). Similarly, Strayhorn's (2010) study of underrepresented STEM students' research participation and post-baccalaureate degree aspirations found that engagement in research experiences positively shaped students' interest in graduate school and careers in STEM. While some underrepresented students of color have succeeded in having strong careers in STEM, there is still a need to increase their representation (May & Chubin, 2003).

#7 Timing of URE Participation in May Matter

Some scholarship suggests that the timing of undergraduate students' participation in research experiences may influence the outcomes that they experience. If undergraduate research allows students to "sink their roots in the culture of the discipline" (Merkel 2003, p. 41) as well as to explore potential career aspirations or graduate degree pursuits, then engaging in these experiences early might be beneficial (Bowman & Holmes 2017). Gasper and Gardner (2013) suggest that introducing undergraduate students to research experiences in their first year provides them with an early introduction to science and discovery, and foundational skills necessary for later complicated scientific techniques. In addition, early participation provides students with increased opportunities to engage in their respective STEM field vis-a-vis hands-on experience (Wolkow, Durrenberger, Maynard, Harrall, & Hines, 2014) (citation). Key, according to Gasper and Gardner (2013), is that undergraduate research experiences should be organized and structured with learning outcomes in mind. This recommendation is consistent with other scholarship on learning that takes place in team-based research settings (see for example Burt, 2014 & 2018; Burt et al., 2017).

Conclusion

This research brief is not an exhaustive summary of all existing scholarship related to participation in undergraduate research experiences. However, it does begin to recognize patterns (e.g., theoretically, conceptually, thematically) in existing scholarship related to participation in undergraduate research experiences. A key take-away from the patterns identified in this brief should be that learning from and engagement in STEM UREs influences students' long-term interest and participation in STEM. That is, what is learned and how it is learned shapes who students come to be. In efforts to broaden participation – and simultaneously improve students' experiences – in STEM, the patterns identified in this brief should be considered by those who create and implement policies. We also acknowledge that more research on the wide range of characteristics (e.g., gender, race, ethnicity, country of origin, socioeconomic status, motivation) would provide greater nuanced understandings of learning from undergraduate research experiences and its implications for long-term participation in STEM. Further research could examine the effect of undergraduate research experiences on students' academic trajectories post-graduation.

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