Protocol review

A review of undergraduate research programs aimed at underrepresented students

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SUMMARY

It is well-understood that the science, technology, engineering, and mathematics (STEM) fields have unique challenges that discourage recruiting and retaining underrepresented minorities. Research programs aimed at undergraduates have arisen as a critical mechanism for fostering innovation and addressing the challenges faced by underrepresented minorities. Here, we review various undergraduate research programs designed to provide exposure to undergraduates, with a focus on underrepresented minorities in STEM disciplines. We provide insight into selected programs' objectives, key features, potential limitations, and outcomes. We also offer recommendations for future improvements of each research program, particularly in the context of mentorship. These programs range from broad-reaching initiatives (e.g., Leadership Alliance) to more specific programs targeting underrepresented students. By offering a nuanced understanding of each program's structure, we seek to provide a brief overview of the landscape of diversity-focused STEM initiatives and a guide on how to run a research program effectively.

INTRODUCTION

Within the science, technology, engineering, and mathematics (STEM) fields, the underrepresentation of certain ethnic groups, individuals with disabilities, and individuals from disadvantaged backgrounds remains a long-spanning issue.[1,2] The National Institutes of Health (NIH) recognizes the importance of addressing poor retention and recruitment across these groups, defined as underrepresented (UR) persons in STEM (see https://www.niaid.nih.gov/grants-contracts/underrepresented-person-definition), and has spurred the development of programs aimed at fostering a more inclusive scientific community. Indeed, reports have shown that, despite numerous initiatives aimed at increasing the representation of UR students,[3–5] these groups remain marked by poor recruitment and retention, with minimal progress made in increasing the relative ratio of UR persons within STEM.[6] According to the National Center for Science and Engineering Statistics, in 2021, while diversity has increased in the past ten years, UR individuals remain poorly represented, especially in non-technical jobs that require more than a bachelor's degree education, and the wages of many UR persons fall below that of their well-represented counterparts.[2] Similarly, the Pew Research Center found that Black and Hispanic individuals are less likely to pursue a degree in STEM than any other field. At the same time, women remain underrepresented in physical sciences, computing, and engineering.[4] At higher levels of leadership, implicit biases continue to persist, which leads to applications for individuals with non-English names and who were ethnic minorities receiving significantly fewer interview invites.[7] For groups with intersectionality of identities, such as Black women, this barrier to leadership positions is even further pronounced, thus perpetuating discriminatory outcomes and limiting the promotion of UR individuals.[8] Taken together, this persistent marginalization of UR individuals has numerous adverse effects on STEM fields, from a business perspective[9] and by limiting scientific innovation.[10]

The "leaky" pipeline for undergraduate students has arisen as one key aspect that contributes to the poor retention of UR students.[3,11,12] Undergraduate research opportunities have arisen as a mechanism for recruiting and retaining undergraduate students with potential for careers in a particular STEM field.[13–18] Even among pre-college students, out-of-school participation in STEM through summer research programs is effective, especially for more challenging programs that teach relevant STEM skills.[19] While undergraduate research opportunities vary in quality and type, they are generally marked by engagement in research practices, the generation of novel information, focus on significant problems, collaboration and teamwork, iterative refinement, mastery of research techniques, reflection on issues and work, communication of results, and structured mentorship.[20] Generally, undergraduate research opportunities help improve crucial skills, including experimental design, data management, safety, communication, networking, and ethics among well-represented and UR groups.[16] These skills gained in undergraduate research experiences further persist into graduate school.[21] Among all students, only 8% have a decreased interest in STEM following participation in a research experience.[14] Most students further report that their confidence in research skills and awareness of graduate school requirements increased after participating in research programs.[14] UR students are particularly impacted by gaining a scientific identity, dependent on solid mentor relationships and customizing program goals to support UR students.[15] Participation in research activities is one of the most significant predictors of future full-time faculty academic appointment among UR students.[22] Past student interviews regarding research experiences have exemplified that these experiences may help cultivate a scientific identity, clarify scientific passions, and prepare their future career goals.[23] Notably, these positive impacts may arise due to an internalization of science through "project ownership."[24] Recently, findings have shown that research programs at minority-serving institutions (MSIs) may be especially effective, with high student satisfaction and associated academic outcomes.[25–27] These positive effects at Hispanic serving institutions and historically Black colleges and universities (HBCUs) underscore the potential of these programs to increase UR student retention by increasing the self-efficacy and ambition of UR students.[27]

Past reviews of course-based undergraduate research experiences have shown their applicability,[18,28] but we seek to highlight faculty-mentored-based research programs, which fundamentally differ in several ways. These programs are predicated on steadfast mentorship, which necessitates mentor training.[29] We have previously discussed how various forms of mentorship including intentional mentoring,[30] casual mentoring,[31] virtual mentoring,[32] shadow mentoring,[33] and mentoring groups[34] can help address challenges faced by minority trainees.[35] Notably, these forms of mentorship can reduce the need for increased retention of UR students within the academic pipeline.[3,11] As previously written, proactive care, holistic support, community building, and catalysts for STEM identity development are all attributable to summer support programs.[36] While mentoring has been extensively reviewed,[37] one key aspect that remains relevant for summer research programs is the mentoring structure, such as laboratory hierarchies or non-dyadic mentoring relationships.[38,39] Regardless of mentoring type, a longitudinal analysis of national undergraduate panels shows that quality mentorship paired with research experiences leads to increased scientific efficacy and a more well-developed science identity and values in students, both of which continue to aid in persistence following undergraduate graduation.[40–42]

Further findings highlight that while undergraduate research programs are valuable for expanding diversity within the STEM workforce, their efficacy depends on several factors, such as long-term faculty-mentored research.[43] Furthermore, the laboratory environment is one of the most significant determinants of student persistence within undergraduate research programs.[44] An extensive survey of UR members from several professional societies reported that undergraduate research opportunities were an important determinant of their success. Additionally, UR faculty in academia specifically recognized mentorship as the single most important factor of their success.[45] Thus, research programs, especially those targeting UR students, are intrinsically linked to the mentorship quality of said students.

As previously reviewed, summer bridge programs in STEM are relatively unique from other fields, often being necessitated due to the rigorous workload of STEM fields paired with resultant low retention rates.[46] Generally, these bridge programs provide an avenue to help students adjust to the workload of STEM by acting as short programs, typically with research components, during the summer between high school and college.[46,47] Previously, a meta-analysis has considered how STEM bridge programs vary in effectiveness.[47] Yet, meta-analyses more broadly considering different STEM programs and comparing relatively different formats still need to be expanded. Articles have been written to say to UR undergraduate students that "you are welcome here" and encourage participation in undergraduate research programs[48]; however, the hallmarks and quantification of successful programs remain varied and seemingly program dependent. The National Academies of Sciences, Engineering, and Medicine recently wrote a beneficial, in-depth, and insightful report on various undergraduate research experiences with extensive future recommendations.[49] Yet, few reviews have considered these experiences from a lens of mechanisms to restore the leaking STEM pipeline of UR students. Notably, while the importance of undergraduate research experiences is explicated for UR students, reports demonstrate that administrators often do not receive training in conducting education research and often do not incorporate all available literature to improve undergraduate research programs.[20] While past reviews have highlighted potential barriers to UR students getting involved with undergraduate research opportunities,[50] few reviews have critically evaluated existing undergraduate research programs. In this review, we seek to investigate many programs to both interrogate their efficacy and examine diversity within undergraduate research programs.

SUMMARIES OF SELECTED UNDERGRADUATE RESEARCH PROGRAMS

Nationally, the National Institutes of Health's Maximizing Access to Research Careers (MARC)[51] and the National Science Foundation's Louis Stokes Alliances for Minority Participation (LSAMP)[52] represent major undergraduate research programs, both of which follow a similar prototypical pattern, typically combining mentoring, financial assistance, assistance to participate in conferences, and research experiences. Broadly, MARC and LSAMP programs can vary considerably. Notably, the Meyerhoff Scholarship Program is among the most recognizable, successful, and widely published MARC programs.[53] Recently, we developed a comprehensive undergraduate research known as Project Strengthen, which seeks to provide comparable benefits to MARC, albeit at a lower cost due to no funding for aspects such as conferences. Project Strengthen[54] has a separate pillar based on professional development, teaching skills such as leadership,[55] and the power of saying "no" to unreasonable requests.[56] We have compared Project Strengthen with other smaller and previously defined undergraduate research programs (Table 1). Given the heterogeneity in these programs (see practical considerations), amplified by some shifting to an online format following the COVID-19 pandemic (reviewed in Erickson et al.[57]), it is not easy to make comparisons. However,

Table 1. Comparison of selected undergraduate research programs

Program title	Target population	Duration	Outcomes	Key mentoring features	Key curriculum features	Potential limitations and areas for improvement	References
Project Strengthen	STEM undergraduates, UR students principally	minimum 1 year, up to 4 years	improved educational development skills, a variety of career outcomes within STEM, but not limited to graduate school; positive outcomes in preparedness for graduate school (comparable to levels in MARC programs)	heavy focus on individualized mentoring at an HBCU for a relatively low cost	workshops on personal statements, grad school applications, and GRE prep	limited reach; non-specific curriculum; no guaranteed funding for conferences and other opportunities; focused more heavily on explicating mentoring portion than research involvement	Barongan et al.[54]; Marshall et al.[59–62]
George Washington Carver Internship Program and Alliance for Graduate Education and the Professoriate Iowa State University	UR STEM undergraduates	summer	mostly positive mentoring experience	seven mentoring functions model	limited details of programs	the relatively small sample size and unclear usage of this program in aiding students beyond simply providing an avenue for mentorship; students wished for more clarity of project, training, contact, and role modeling functions	Glenn et al.[63]
National Summer Undergraduate Research Program	Black, Indigenous, and people of color in microbiology	summer	enhanced research experience; high number of students go on to present at organized mini-symposium; high amount of first generation and MSIs	online format, which increases accessibility and mentoring focus; virtual matchmaking of mentors and mentees	anti-racist and diversity training	not tailored for graduate school; virtual mentoring may introduce new challenges in networking; student experiences are not highlighted	Johnson et al.[64]; Knox et al.[65]
Meyerhoff Scholars Program	UR STEM undergraduates	summer, with some individuals participating across multiple summers	participants accepted for this program five times as likely to earn a PhD as their non-accepted counterparts	fosters Meyerhoff Program community; diverse research opportunities at various US and international universities, private corporations (such as Apple), government agencies (including NIH), and pharmaceutical companies (such as AstraZeneca)	non-specific curriculum	unique nature of the Meyerhoff Program may limit the generalizability; while lower in cost, does not discuss outcomes in conferences and other student outcomes	Pender et al.[66]
Scholars Committed to Opportunities in Psychological Education	BIPOC psychology students	flexible	GRE prep, application knowledge	anti-racist, culturally informed mentoring and curriculum	specifically targeting and asks about presence of microaggressions	focused only on psychology; lacks defined research component	Silverstein et al.[67]

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Table 1. *Continued*

Program title	Target population	Duration	Outcomes	Key mentoring features	Key curriculum features	Potential limitations and areas for improvement	References
UMBC Cyber Training initiative	advanced graduate students, junior researchers, and select undergraduates	summer	long-term social contacts with higher-career-level students	online team-based training	interdisciplinary with individuals from many career levels; employs LinkedIn, Google Drive, and Webex as online collaboration platforms; team-based projects alongside curricula	poorly defined mentorship roles; outcomes of undergraduates not explicated	Gobbert and Wang [58]
Penn Access Summer Scholars (PASS)	UR undergraduates interested in healthcare	two consecutive summers	increased healthcare workforce diversity	focus on healthcare careers; multiple well-defined avenues for mentoring	allows direct entry to Perelman School of Medicine; biomedical skills (research), paired with regular shadowing and healthcare-related activities	limited to healthcare field; relatively smaller and limited to certain institutions; appeal of "guaranteed" admission may not be as appealing at smaller institutions	Zhou et al.[68]
Southern California Bioinformatics Summer Institute	bioinformatics students	summer	specialization in bioinformatics, with many graduates going on to pursue bioinformatics	includes undergraduates and graduates; off-site placements; implemented at institution with no existing bioinformatics infrastructure	highly focused curriculum; includes distinct phases for both learning (didactic) and research	highly specialized, not diverse in subject matter; mentoring mechanisms unclear	Krilowicz et al.[69]
The Leadership Alliance	diverse undergraduates	summer	improved research skills; clear positive outcomes in improving scientific identity	research skill development in combination with professional development mentoring	broad scope, multiple disciplines	broad focus may lack depth in specific areas; limited to certain "leading" institutions; well-funded program that may not be realistic at certain institutions	Ghee et al.[70]
Summer Undergraduate Research Experience (SURE) Emory	STEM undergraduates at Emory	summer	broad exposure to research, leading to increased science class load than non-SURE peers; one-third of alumni went on to get graduate degrees	weekly professional development meetings; variety of career interests within STEM, not limited to graduate school, following participation	ethic training, including information about publication process and GRE; evaluation through rigorous and pluralistic metrics	may lack personalized focus due to size; only one-third of alumni went on to get graduate degrees	Junge et al.[71]
Loma Linda University (LLU) Summer Health Disparities Research Program	UR high school and undergraduate students	summer	relatively high rates (∼66% for high school and ∼90% for undergraduate students) of STEM degree obtainment; students increasingly attended LLU	wide diversity in class standing; mentorship is key tenant	primarily focused on research with supplemental group learning activities	could be better implemented to allow for undergraduates to act as mentors to high school students; limited activities outside of research	Salto et al.[72]

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Table 1. *Continued*

Program title	Target population	Duration	Outcomes	Key mentoring features	Key curriculum features	Potential limitations and areas for improvement	References
A Student-Centered, EntrepreNeurship Development (ASCEND)	undergraduate students	eight weeks	development of research skills; increase in STEM undergraduate self-efficacy at HBCU	student-centered, entrepreneurship-focused, group-based training model	course-based undergraduate research experience; curriculum focused on research	short duration, limited to one discipline; does not involve "apprenticeship" model; may not cultivate scientific identity in the same capacity of traditional student placement within laboratories	Jackson et al.[73]
Program for Excellence in Education and Research in the Sciences (PEERS)	first- and second-year science majors from UR backgrounds	summer	relative to non-PEERS, more scientific classes, higher GPA, and higher persistence	Treisman-style collaborative-learning workshops; holistic academic counseling	focus on bridging gap to higher education; more comprehensive than traditional bridge programs; research seminars	limited to transition period only; does not provide mentored research experience	Toven-Lindsey et al.[74]
Penn State Biomaterials and Bionanotechnology Summer Institute	undergraduates with interest in biomaterials; one of several "Biomaterials and Bionanotechnology" summer institutes that incorporate didactic techniques	summer	mutual student and faculty satisfaction and professional development improvement	training in and about microscopy techniques, with workshops led by research mentors; includes analysis of student dissatisfaction with the program	focus on practical skills for biomaterials, student-led learning including budgeting project and project implementation	dominantly composed of caucasian students; mentoring styles are not discussed; career and professional development are limited to didactic learning skills	Butler et al.[75]
Meharry SURP	undergrad students and medical students	ten weeks in summer	obtain hands-on training in basic, translational, clinical, community-based, and bioinformatics-based cancer research and learn about cancer-related job opportunities via career development seminars	Interaction with faculty and students and presentation opportunity at a national conference	Participate in cancer biology mini-course and weekly cancer research seminar series	N/A	Motley-Johnson et al.[76] and Marshall et al.[77]
The Tennessee Center for AIDS Research HIV Research Training Program for Minority High School and Undergraduate Students	high school and undergraduate students	ten weeks in summer	positive student self-reported feedback regarding mentoring quality and effectiveness; student reported continued interest in HIV-related research	mentoring specific to HIV-related study topics; one-on-one mentoring with HIV-related research scientists	seminars, didactic courses, and keynotes focused on virology and HIV research	N/A	Koethe et al.[78] and Greenberg et al.[79]
UNCF programs for biomedical research and bioentrepreneurship	HS, undergraduates, graduates students, and postdocs	varies	all participants found the program a good venue for learning and reported an improved professional network following involvement	dynamically includes alumni to broaden the mentoring network; variety of BIO I-Corps workshops to introduce a multitude of research topics	N/A	N/A	Maloy et al.[80]

certain aspects of successful programs may be examined. Of relevance, activities that enrich networking opportunities have been highly regarded among UR students participating in research opportunities.[15] Furthermore, while programs are commonly limited to undergraduate students, other students seek to expand this to other student classifications.[58] This relative heterogeneity in the structure and makeup of these undergraduate research programs, targeted at UR students, allows for significant analysis of key characteristics.

Within these programs, the structure of mentoring can play an important role. A large study across undergraduate life science researchers who participate in research programs shows that two mentoring structures primarily exist with undergraduate research programs: open triads (i.e., postgraduate or direct supervisor and students interact, but with little or no direct interaction between the principal investigator and student) and closed triads (i.e., interdependence with a tri-directional relationship between the student, supervisor, and principal investigator).[81] Men and UR students are more likely to have direct ties to faculty members through closed triads, with these closed triad relationships having outcomes such as increased scientific identity and intentions to pursue a PhD in STEM.[81] This suggests that direct mentorship from the principal investigator is a positive factor for increased UR student retention. It is important to note that female students often tend to have open triads with a lack of direct mentorship, resulting in lower STEM interest and productivity.[81] However, another research program has rebuked the necessity of these direct mentoring relationships.[82] Due to the limited quantity and time of research mentors, Behavioral Research Advancements in Neuroscience (BRAIN), an undergraduate research program at Georgia State University, has utilized collaborative learning models that group students in a larger collaborative laboratory environment with several instructors.[82] Yet, this study shows that these collaborative learning environments have no significant differences in students in the short term. Additionally, long-term outcomes compared to the traditional apprenticeship model were minimal, despite a much smaller burden on faculty time commitments.[82] The context of faculty relationships may differ based on institutional type, with faculty at more selective institutions having less frequent interactions with students.[83] These conflicting results underscore the importance of further investigation of the most effective mentorship forms in these programs, and how best to optimize the time commitment, relative to student benefit, associated with these mentorships.

While most studies often describe student and faculty mentor characteristics, few investigate or question student and faculty motivational factors. A wide-scale survey of over 150,000 combined students and faculty across nearly 500 institutions has investigated these joint perspectives of undergraduate research.[84] This study found that student characteristics, which include being full-time-status students of color below 24 years of age, actually influenced undergraduate research participation. In addition, faculty characteristics such as being faculty of color (particularly African American), having a doctorate, and being a younger age predicted faculty involvement[84] with mutual success for both student and faculty participation. More STEM faculty than non-STEM faculty found graduate research to be important, which also correlated to their finding that STEM students were more likely to participate in undergraduate research.[84] Furthermore, demographic similarity or shared values between students and their research mentors are positive factors in STEM retention.[42] Yet, only some studies investigate or critically ponder the driving factors between their demographical makeup, as well as the potential implications of such a demographical makeup.

Generally, while undergraduate research programs are widely successful at increasing student interest within STEM,[14] some students may have negative experiences. These experiences may not always cause them to lose interest in STEM. For example, past interviews have shown how students in undergraduate research programs began to notice and critically dissect the role of race and social stigma in STEM while often still appreciating the empowering culture of science.[85] Thus, research programs may serve unique roles in highlighting the dark side of academia.

PRACTICAL CONSIDERATIONS

Funding for the program

Institutional factors like selectivity and faculty engagement in undergraduate research programs play a role in their success.[84] Large-scale surveys have demonstrated that these programs are highly valued by faculty and students, underscoring the need to devote proper funding to these programs.[84] While the importance of funding seems obvious, limited studies have directly examined the relationship between funding and the success of programs. Some investigating specific programs through a benefit-cost analysis have found that these research programs offer a positive net financial value.[86] Additionally, the type of funding may be a determinant of program success, with National Science Foundation-funded research experiences for undergraduates outperforming their university-sponsored counterparts, potentially due to a slightly longer summer research program duration.[87] Still, as Pike et al. excellently discuss, the relationship between funding and program success remains complex.[88] For example, their findings show that attending a research university was negatively related to student engagement, with the role of campus culture and support for student-centered policies proving far more critical.[88] These findings underscore the complex relationship between monetary funding for programs and their success, which must be further clarified.

Faculty recognition

Beyond only traditional funding for students, the costs for principal investigators should be addressed.[89] Critically, the ''minority tax'' has been termed to refer to additional duties that UR faculty often take on, typically relating to increasing equity, despite offering no additional pay or professional advantages.[90,91] Since shared identity is crucial for mentoring,[42,92,93] UR faculty may often serve as mentors in undergraduate research programs.[84] Indeed, this participation may often have positive effects, including increasing job satisfaction and reducing faculty turnover.[84] Yet, the emotional, time, financial, and professional costs of serving as a principal investigator for undergraduate research programs cannot be neglected.[89]

Webber et al. suggest that, based on their study examining the importance of undergraduate research, ''institutional emphasis on bringing students of color into [undergraduate research] may be working, but institutions may be disporportionately relying (intentionally or unintentionally) on faculty of color to get students of color involved.''[84] The faculty who chose to mentor in these programs are driven by a want to increase diversity within the field despite the poorly recognized, time-consuming nature of mentoring in research programs.[94,95] Thus, there should be considerations about how faculty members are appropriately compensated and recognized for their efforts in mentoring during undergraduate research programs.

Metrics of program ''success''

A major challenge in making inter-program comparisons is the tremendous heterogeneity in defining whether programs are successful due to varied goals and associated metrics to measure such goals. General undergraduate students' challenges and experiences may vary tremendously based on their institution, such as between primarily white institutions (PWIs) and HBCUs.[96] Thus, while some studies have specifically examined undergraduate research programs at MSIs,[25] most studies are conducted at PWIs, which may have separate metrics of success from MSIs. Similarly, as previously discussed,[20] many past STEM research experiences report positive outcomes from their programs. Yet, it may be equally helpful to recognize and publish negatively received research programs as avenues to improve in the future. It was found that students most often leave undergraduate research experiences if there is a hostile laboratory environment or they do not feel they are learning from the program.[44] Factors determining whether students persist in STEM programs were often not discussed in the reviewed research programs. Often, program evaluations are focused exclusively on students' opinions on research within the program but not on their general enjoyment of life across the duration of the program. While this may be subject to many more variables, it may still be valuable to understand what the hallmarks of undergraduate research programs are that do not just encourage students to go into STEM but aid them in feeling more holistically fulfilled.

Mentoring with the program

As previously and extensively discussed, mentoring is multifaceted, with the ability to create hierarchies,[38] which can be cultivated within institutions (e.g., classrooms, laboratories) for systems of interdependence.[39] Results have found that mentoring is one of the single largest effectors of positive research program experiences, with research mentorship helping to increase students' scientific identity, especially if students share an identity (e.g., demographic or shared values) with their mentor.[16,42] However, many publications and past undergraduate research programs we reviewed do not comprehensively discuss how mentorship is performed, or whether mentorship training is given to research mentors. Notably, the identity of students may aid in explaining whether students go on to have direct mentor relationships with their students (i.e., mentoring triads involving the student, supervisor, and principal investigator), which are associated with higher student productivity and scientific identity.[81] However, more research should seek to understand how the identity of mentors within programs defines the mentor relationship type. We have previously discussed and provided guides for several forms of mentoring, including intentional mentoring,[30] casual mentoring,[31] virtual mentoring,[32] shadow mentoring,[33] and mentoring groups.[34]

Furthermore, minority writing accountability groups can serve as unique avenues that facilitate peer mentoring, reverse mentoring, and mentoring triads while also helping UR students and early faculty to dedicate time to writing.[97,98] Mentoring may further be supported by techniques including mentoring maps[99] and individual development plans,[100] as well as a variety of other mentoring methods that have been extensively covered previously.[20,37,101] Mentoring may further be evaluated through established techniques, such as comparing output, outcome, and impact.[102] Finally, previous reviews have evaluated mentoring training,[29] which may further be implemented within undergraduate reviews to bolster mentoring in response to mentoring evaluations.

Opportunities within the program

Consideration of opportunities surrounding the training program is equally important. While research can be an essential mechanism to increase student retention and interest in STEM,[16,103] aspects of student development may extend far beyond simply existing within the classroom and/or laboratory. For example, participation in an undergraduate conference is shown to increase extracurricular engagement through improving confidence and skills in research and presentation, ultimately leading to more of a scientific identity.[104] While there may not be gendered differences in conference participation, there may be ethnic differences, particularly for African-American students.[105] In one study, Mabrouk found that unlike their caucasian counterparts, African-American students were not motivated to attend conferences for purposes of having fun. Rather, all of the African-American students attended conferences to hone their presentation skills, and some indicated cultivating professional self-identity, meeting prospective advisors, and networking as additional reasons for their attendance.[105] Similarly, the publishing of papers provides students with greater insight into whether they have a passion for scientific fields, with past studies showing that while a majority of students gain an interest in scientific careers, a significant number (approximately 30%) have a dampened interest in STEM following the publishing of a paper.[106] Even publishing in an undergraduate research journal may positively affect students' literacy and understanding of scholarly aspirations,[107] demonstrating that even if students cannot complete a peer-reviewed publication, another publishing opportunity may be effective at increasing their interest in STEM.

Similarly, seminars for career and professional development may help students develop as individuals beyond only being researchers in the duration of these programs, as well as help expose them to the steps beyond graduate school, such as becoming a junior faculty member.[108–110] However, if research programs implement goals such as publishing or conferences, it is important to keep realistic goals that do not lead to student burnout. Notably, a study exploring the impact of a motivational intervention on STEM students showed paradoxical effects, with students who had higher expectations also having lower grade point averages, highlighting the potential risks associated with unrealistic expectations.[111] The most promising of all the programs may be those such as Penn Access Summer Scholars (PASS), which guarantees medical school entry for UR students who participate in the research program.[68] More schools adopting this model in the future, especially for graduate schools, may help shift away from admissions based on non-predictive admissions tests, guarantee spots for diverse individuals, and allow them to better focus on research for the betterment of themselves as opposed to worrying about graduate or medical school acceptance.

Student participation and publicity

An essential past reference has evaluated undergraduate research access at a psychology department.[112] They found that with several key improvements and changes, their student participation in research tripled (with approximately 20% of students participating in research), and faculty mentoring of students increased to approximately 95% of all faculty.[112] These changes included expanding the application to allow the admission of more students, increased advertisements and departmental newsletters paired with regular communication to students, and increased faculty time allotment.[112] While these interventions were for a social science research program, they still highlight the importance of advertisement and ensuring that students know about research programs. For many of these programs, publicity should be discussed. One study conducted by the UCLA Cooperative Institutional Research Program and Your First College Year surveys showed that peer networks and the availability of structured opportunities on campuses are significant determinants in the likelihood of students, especially Black students, participating in research opportunities during their first year.[113] While a lack of funding may be more common than a lack of interested students, mechanisms of publicity and strategies to ensure equity in distribution are essential considerations in establishing and evaluating an undergraduate research program.

FUTURE PERSPECTIVES

The landscape in which STEM exists is continuously undergoing significant changes, which must be considered and responded to through changes in research programs. Currently, the rate at which students may be interested in STEM may be transformed by their viewing of STEM media (e.g., television shows, video games, and other popular media), which positively affects students' identity without modulating STEM career interest.[114] Nonetheless, this suggests that how students view STEM in the coming years may continue to be morphed. Thus, research programs must continue to readily adapt to appeal to students and adequately expose them to a representative view of pursuing STEM fields. Beyond this, as we move forward, the impact of identity, especially intersectionality, on the outcomes of these summer programs cannot be neglected. Notably, many research programs we reviewed have focused on differential impacts and retention of persons excluded by their ethnicity or race within STEM. However, the NIH also recognizes that groups, including those with disabilities[115,116] and first-generation college students,[117,118] face unique challenges and obstacles that must be considered in developing and administering research programs. However, for UR students specifically, the mechanisms of research programs targeting UR individual retention may change. Increasingly, diversity, equity, and inclusion policies have come to be perceived as a threat, especially among well-represented groups.[119] Thus, in the future, the ability of research programs to specifically target UR students may change, highlighting the importance of creating pieces of training designed for everyone. As programs become composed of more diverse students, the importance of stereotype management[120] and avoiding stereotype threats, or diverse individuals' fear of being judged based on biases, must be added to the curriculum.[121] Similarly, as the structure and reception of these research programs change, extra considerations must continuously evolve in managing emotions and relationships upon potential microaggressions[122,123] and toxic stress[124,125] faced by UR individuals.

Recruitment of undergraduate research programs needs to continue to target MSIs in the future. As previously reviewed, UR individuals face unique challenges in accessing undergraduate research programs,[50] including common issues such as lack of student and faculty time and more complex barriers such as lack of student research readiness.[50] Uniquely, MSIs may serve to overcome some of these issues and offer research opportunities more readily to UR students. Notably, a past study at Winston-Salem State University, a small HBCU, shows that encouraging students to engage in research has several unique challenges.[126] In particular, to UR students, the research process needed to be better understood and was marred by distrust, with a culturally specific and direct appeal protocol alleviating some of these concerns.[126] Thus, HBCUs and other MSIs must be specifically targeted with consideration of their unique histories[96,127,128] and strategies to provide culturally sensitive research opportunities. The need for these strategies remains especially pertinent as research programs at HBCUs and other MSIs have generally been shown to be highly effective at increasing retention rates and student interest in pursuing research careers.[25,26] This may be due to the more significant amount of individualized mentoring time provided by faculty at HBCUs.[83] While HBCUs are recognized to train many outstanding scientists, their funding and access to resources are often much lower than that of PWIs.[96,129] However, the benefits provided by undergraduate research programs, especially for UR students, can help to act as an equalizer, thus helping to ensure greater equity in opportunities and outcomes for UR students and their well-represented counterparts.[27]

As previously recognized,[20] the development of future STEM programs will require collaboration between research mentors and administrators to acknowledge their contributions. Importantly, as with diversity, equity, and inclusion initiatives,[130] there is a need to shift the development of research programs to involve considerations of more previously available data.[20] Similarly, more data needs to be collected across organizational levels, including nationally, to better understand how many students are engaged in undergraduate research and offer a platform to show unique techniques and ways to leverage existing assets to bolster undergraduate research experiences.[20] Thus, there must be increased intra- and inter-institution collaboration in the future to ensure that evidence-based design decisions, data collection on undergraduate research experience (URE) participation, holistic evaluation of URE offerings, mentor professional development, and collaborative efforts are utilized together to develop a supportive culture for continuous refinement of UREs across institutions.[20] Notably, the cultural-historical activity theory method of data collection has recently been employed for Research Experiences for Undergraduates (REUs), providing a better mechanism to analyze research programs and consider potential barriers to success.[131]

Furthermore, institutions should consider and analyze the programs and their efficacy currently at the institution, akin to Hampton University's programs.[132] This analytically backed approach is constructive in continuing to evolve our understanding of what type of mentoring relationships may be the most valuable component within these research programs. Alongside this, a greater quantification of research programs may also allow the institution's reward structures to recognize and reward the efforts of faculty.[94,95]

While funding may not be the largest determinant of undergraduate research success,[88] its importance cannot be understated. Traditional grant mechanisms exist to provide funding for undergraduates, such as through formalized REUs funded by the National Science Foundation (see https://www.nsf.gov/pubs/2023/nsf23601/nsf23601.htm) as well as NIH Research Enhancement Awards (i.e., R15, see https://grants.nih.gov/grants/funding/r15.htm). Yet, future research programs should continue exploring mechanisms to guarantee funding in unique ways. In many cases, low-cost alternatives for research focus on providing research opportunities, such as in laboratories, without necessarily providing the other vital components of traditional programs, such as mentoring.[133] For example, Georgia Gwinnett College shifted away from directly mentored experiences and implemented a lower-cost undergraduate research program made available to all STEM undergraduates.[134] While these can be beneficial, limited resources are available on low-cost alternatives that still provide mentored experiences. Snow et al. highlighted low-cost strategies for promoting undergraduate research at research-intensive universities, emphasizing the importance of faculty-mentored research experiences and centralized campus offices.[135] Similarly, Loyola Marymount University has utilized industry collaborations to bridge the gap between academia and industry for research experiences while allowing students to engage in contract work, thus offering students familiarity with multiple arenas within STEM.[136] In the future, innovative techniques such as these, which either utilize a low budget or employ creative funding opportunities, are important to explore.

CONCLUSIONS

In conclusion, the landscape of undergraduate research programs, which we only briefly covered, is diverse and multifaceted. While there is a clear import of targeting UR students in these programs to repair the "leaky" pipeline of STEM, inconsistent reporting and quantification of student outcomes limit the ability to make inter-program comparisons. While the development of these programs is highly complex, we sought to highlight several practical considerations for establishing and supporting undergraduate research programs, including funding, program success metrics, mentorship, opportunities within the program, and publicity. In the future, there is a greater need to address UR students' unique challenges and emphasize evidence-based design decisions to maximize the impact of undergraduate research programs. We hope this exploration of various programs, practical considerations, and future perspectives serves as a template to compare the operation of multiple programs and inform the effective development and evaluation of current and future undergraduate research programs.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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