



Evaluation of a Nine Year Summer Undergraduate Research Program in Biomedical Engineering

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Abstract

Interest and opportunities for undergraduate research programs continues to increase at universities throughout the United States. Despite the significant level of interest and support for these activities our understanding of the characteristics of a successful program and its long-term impact on student outcomes remains is limited. The purpose of this study is to examine the impact the relationships and interactions with faculty, graduate student mentors, and other undergraduate researchers in a summer program at the Illinois Institute of Technology had on the participants' career paths. Over the nine years, there have been 131 undergraduate students who participated. Ninety nine (76%) of these students were supported via funding from the National Science Foundation Research Experiences for Undergraduates program. The other 32 (24%) were supported through institutional funds. More than half of the students (56.5%) were female, 26.7% of the students were from underrepresented groups, and 52.7% students without previous research experience. The undergraduate research program understudy is a 10-week engineering research project working in research laboratories at the University or a collaborating Medical School. A tiered mentoring structure was developed within the participating laboratories that consisted of some combination of faculty, graduate students, undergraduate students, community college students, and high school students. A longitudinal survey was administered to all previous REU students to track post-program activities and collect data on their perceptions of the impact of the REU program on their educational and professional careers. Descriptive statistics and content analysis method was used to analyze the data. The response rate of the longitudinal survey was 78.8% (78/99). Of students who have completed their undergraduate studies, 57.3% are currently in/have completed graduate studies in a STEM field. The students

consistently expressed that the program experiences with the faculty, graduate students, and peers had an impact on their career choices. Students who had participated over 9 years ago consistently supported this finding. Program alumni discussed how the program confirmed their interest in pursuing graduate school, exposed them to the nature of graduate school, built their confidence and increased their enthusiasm for scientific research. A number of the program alumni are currently in/have completed medical school (14.7%), with 4 in MD/PhD programs. Some alumni found that while the research experience was valuable it allowed them to determine a non-research career was a better option (“Helped confirm that I was most comfortable working in...medicine.”). Some alumni (7.5%) have pursued other advanced degrees: Law, Pharmacy, Dentistry and Business. Overall, 74.7% of alumni pursued/are pursuing an advanced degree. The remaining REU alumni are either working in industry (22.6%) or K-12 teachers (2.7%). In this work we will provide a more comprehensive analysis of the results from the longitudinal assessment of the program.

Introduction

Undergraduate research has been identified as an educational practice that directly addresses challenges facing science, technology, engineering and mathematics (STEM) education^{1,7,8}. Specifically, engaging undergraduates in research is expected to increase interest in careers in STEM, improve retention of undergraduates in STEM fields and increase the number of people interested in advanced STEM degrees. The Council of Undergraduate Research (CUR), NSF-funded Research Experiences for Undergraduates (REU) program, and the Boyer Commission Report are major reform efforts advocating for undergraduate research, with the primary focus being the enhancement of undergraduate education.

The NSF has funded undergraduate research for over 30 years^{2, 4-6}. Specifically, undergraduate research has received strong support from the NSF through the development and funding of many research opportunities, including Research Experiences for Undergraduates (REU), Research in Undergraduate Institutions (RUI), Historically Black Colleges and Universities Undergraduate Program (HBCU-UP), and Louis Stokes Alliance for Minority Participation (LSAMP) Program. Of all the NSF-funded undergraduate research programs, the REU programs, established in 1984, are the main programs developed to increase the graduate degree production in the science and engineering fields. Support for undergraduate research in STEM has expanded well beyond NSF REU programs. Many institutions have programs that support undergraduate research activities internally and other funding agencies provide both programmatic support and individual fellowships for undergraduate research.

While undergraduate research has received substantial attention from funding agencies and academic institutions, fundamental understanding of the characteristics of a successful program is lacking. In addition, longitudinal tracking of participants that evaluate the influence of the experience on their long-term plans is lacking. In this paper we describe and evaluate our 9-year experience with a 10-week summer undergraduate program.

Methods

Overall Program Description

From 2006 - 2014, a research university in the U.S. Midwest (Illinois Institute of Technology) has delivered a 10-week, summer engineering Research Experience for Undergraduate (REU) program. The program focuses on engineering research in the understanding and treatment of diabetes and its complications. Students participating in the summer program were supported by two different mechanisms: 1) The National Science Foundation (NSF) REU program (EEC-1157041, EEC-0852048, and EEC-0552896) which primarily supports students from off-campus. 2) Institutional funding that only supported students from within the institution.

All students were paired with an engineering faculty member from the host institution. Over the 10 weeks they performed an engineering research project focused on the study or treatment of diabetes or its complications. In addition to research activities, undergraduates took part in ethics training, weekly seminars and a K-12 outreach activity. While the activities were the same for students in both programs, the overall goals, recruitment, and targeted students varied as described below.

NSF REU Program

Students were recruited via postings on the NSF REU website, advertisements sent to all biomedical engineering chairs, and announcements on the institution websites. Applicants provided transcripts, two letters of recommendation and two essays. In the first essay they were asked to describe their interest in diabetes research and the second essay addressed the relationship of this program to their career goals. Between 100 and 200 applications were received annually. Students were selected based on their academic background and performance,

research experience (preference is given to students without previous experience) and relevance of the program to their career aspirations.

Institutional Program

Students from within the institution were selected primarily based on recommendation from engineering faculty within the institution. In the majority of cases the undergraduates were already working in faculty labs. This program did not target particular groups. The overall goal was to provide support for the students who had the greatest potential to contribute to faculty research programs.

Longitudinal Survey

In 2014 a survey was developed and sent to all previous participants that could be contacted. E-mail contact information for participants were identified through established relationships with faculty, graduate students and the program director or through LinkedIn. The survey was designed to evaluate 1) the academic and career plans and actual trajectories and 2) influences and roles of the mentoring relationships with faculty and graduate students.

Results

Demographics

In nine years of this program, the NSF has provided support for 99 undergraduate students and institutional funds supported an additional 32 students. Of these 131 students, 56.5% (74) were women and 96.2% (5) were domestic students (defined as permanent residents or citizens). Students without research experience and students from institutions with limited research opportunities made up 52.7% (69) and 18.3% (24), respectively. Students from groups traditionally underrepresented in STEM fields made up 26.7% (35) of the domestic students. The overall demographics and demographics for each program are provided in Figure 1.

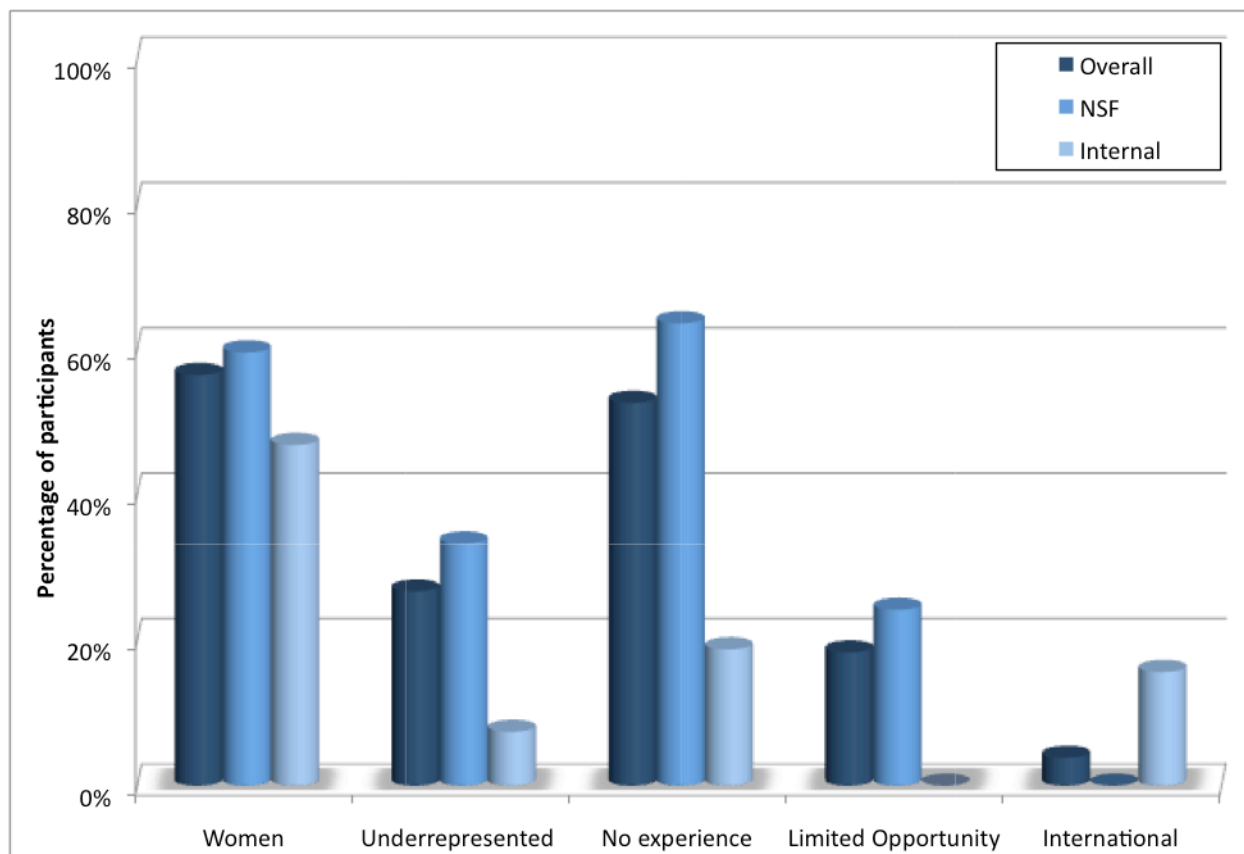


Figure 1: Data for the percentage participation by groups targeted by the REU component of the summer research program. The overall participation and the results from each funding mechanism (NSF and internal) are provided.

The NSF program specifically targeted three student populations: 1) women, 2) underrepresented groups, and 3) students without previous research experience. Acceptance was

not limited to students from these populations, but applications from these groups are targeted in our recruitment. Over the 9 years of funding the program consisted of 59.6% women, 33.3% underrepresented groups, and 63.6% students without previous research experience. In addition, 6 students were type I diabetics and one was a veteran. When examining program participation over the past 9 years 24.2% of students were from colleges and universities where research opportunities in STEM are limited (defined as community colleges or predominantly undergraduate institutions). The development of programs for community college student participation resulted in 30% of students from limited STEM research opportunities each year from 2012-2014. NSF funding is limited to domestic students so 100% of students were permanent residents or citizens.

All undergraduate students supported by institutional funds were from the host institution. The program consisted of 46.9% women and 18.8% students without previous research experience overall. Unlike the NSF support, the institutional funds did not require domestic students. Therefore, 15.6% of students were international. Of the domestic students 7.4% were from underrepresented groups.

Longitudinal Survey

In 2014 we implemented a longitudinal survey with all previous REU students to track post-program activities and evaluate their perceptions of the impact of the REU program on their educational and professional careers. At this time, 78.8% (78/99) of students have completed their undergraduate studies, with the remaining 14% still pursuing their BS degrees. The tracking of student careers is based on information from 80.9% (106/131) of students as career paths were

identified and confirmed through surveys, networking services and/or alumni information. The narrative feedback is provided from 59.5% (78/131) of the participants who completed the longitudinal survey.

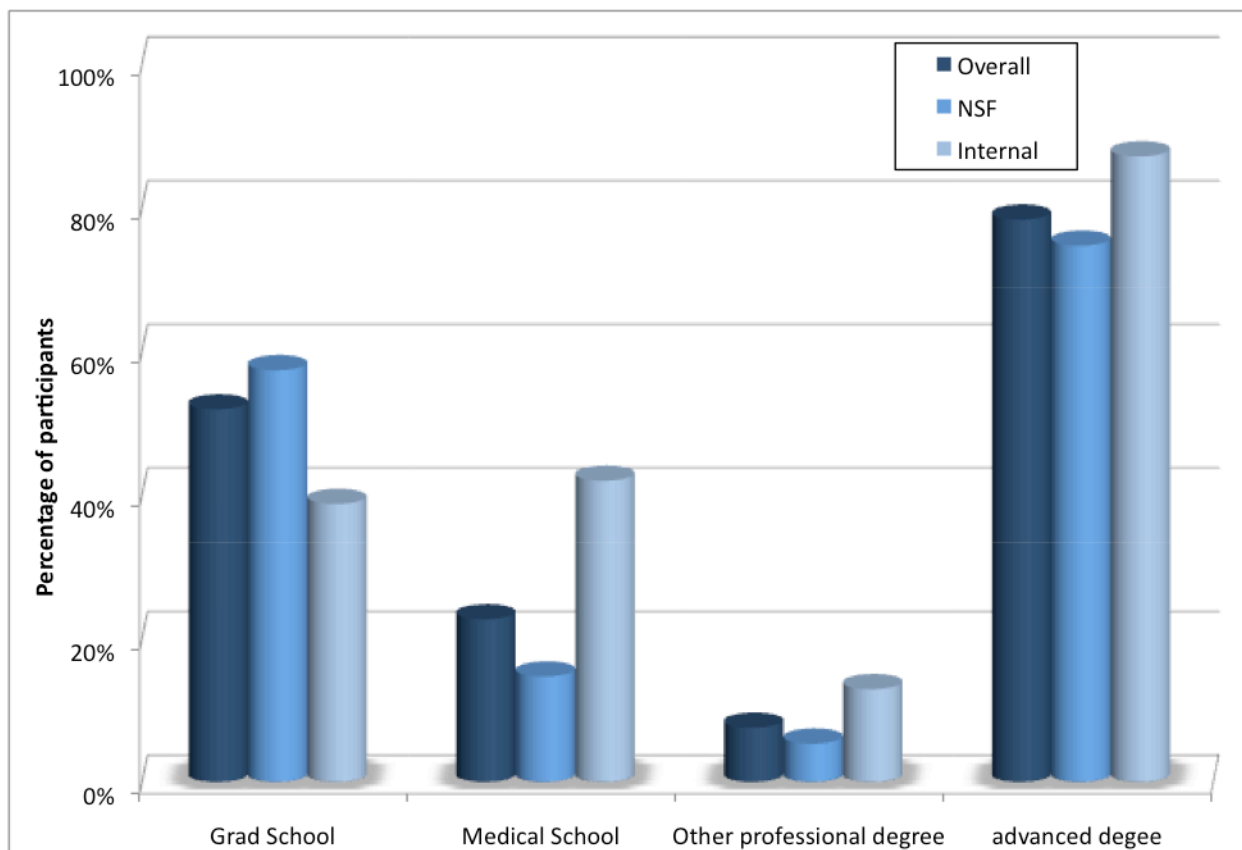


Figure 2: Data for the career paths of undergraduates involved in the summer research experience. The overall participation and the results from each funding mechanism (NSF and internal) are provided.

NSF

When evaluating NSF REU alumni who had completed their BS 57.3% are currently in/have completed graduate studies in a STEM field. Four of these alumni were NSF Graduate Research Fellowship recipients. In the longitudinal evaluation, students consistently expressed the REU program had an impact on their career choices. While we consistently receive positive reviews in exit surveys, the longitudinal surveys were encouraging as they were consistent from

students who had participated 9 summers ago. REU alumni discussed how the program confirmed their interest in pursuing graduate school (2007 REU: “*Participation in the REU at IIT ...definitely made an impact on the decision I made to pursue graduate school*” and 2010 REU: “... *validated my reason to attend graduate school.*”), exposed them to the nature of graduate school (2013 REU: “*(the REU) really made the whole process (graduate school) seem more accessible...like something I could do*” and 2010 REU “...*better understanding of what it is to be a graduate student.*”), built their confidence (2011 REU: “...*very positive and empowering experience...*”, 2007 REU: “...*confidence that...I had the skills to succeed...*”, and 2008 REU: “...*awarded me the confidence to set my career goals high...*”) and increased their enthusiasm for scientific research (2006 REU: “*performing cutting edge research...was very exciting*” and 2008 REU: “...*excitement about science and contributing to science was very contagious.*”).

A number of the REU alumni are currently in/have completed medical school (14.7%). Two of these students are in MD/PhD programs with one from 2006 already successfully defending his thesis. Interestingly, none of the students who are still pursuing their undergraduate degrees expressed an interest in attending medical school. The REU program targets applicants who express an interest in evaluating research as a career path. However, some of these students are choosing between different career options. Some REU alumni found that while the research experience was valuable it allowed them to determine a non-research career was a better option (2013 REU: “*Helped confirm that I was most comfortable working in...medicine.*”). Some alumni (7.5%) have pursued other advanced degrees: Law, Pharmacy, Dentistry and Business. Overall, 74.7% of REU alumni pursued/are pursuing an advanced degree

of some sort (Note: some students count in more than one category (e.g. MD/Ph.D., MS/DMD)). An additional 2 REU alumni are K-12 teachers (2.7%).

The survey was also provided insight into deficiencies in the program. Only a few alumni identified negative influence of the program. There were statements in regards to limited impact on their career (2009 REU: “*Although, I really enjoyed my work...my career path was probably not influenced by it*”). In the early years of the program there were issues with advisor commitment (2008 REU: “*I would have liked to have more contact with a professor...* ”). We have eliminated advisors who do not commit time and energy to the REU activities and have now identified a strong, dedicated cohort of faculty advisors. In addition, we believe that training and development of the role of graduate student mentors has helped further reduce negative experiences. In some cases the graduate students were perceived as overcoming deficiencies in the faculty mentor (2009 REU: “*the PhD student...may as well have been faculty*”).

Institution

The institutional program did not emphasize or target students considering graduate programs in engineering but selected students based primarily on previous experience with faculty mentors. From the alumni 38.7% are currently in/have completed graduate studies in a STEM field. Unlike the NSF program many of these students had established plans to attend medical school with 41.9% currently in/have completed medical school with one in an MD/PhD program. Thirteen percent of the students pursued professional degrees in other fields (MBA, law, optometry). When combined, 80.5% of the students completed a post-baccalaureate degree.

The students involved in the institutional program identified similar gains from the research experience as the REU students. In some cases students identified the program had a direct impact on their decision to attend graduate school (2012: “*I decided to go to graduate school, because I really enjoyed my experience with research during my undergraduate career.*”). In addition, undergraduates expressed that the experience inspired them (2008: “*My research mentors really inspired me in their commitment to their work*”) and exposed them to the life of a graduate student (2008: “*I was also able to appreciate the day-to-day schedule of what it would be like being a graduate student...*”).

The students also identified graduate student mentors as critical to the experience (2010: “*...helped me tremendously...*”; 2008: “*...played a vital role...*”). Interestingly, the students in the internal program appear to provide more emphasis on the significant impact of their faculty mentors in their long-term academic plans and careers (2008: “*...personal adviser to best help me make career decisions.*”; 2008: “*conversations...about life in academia and about the challenges associated with it*”; 2011: “*...a one of a kind professor, researcher, and mentor.*”).

The REU program selected students based on an expressed interest in research careers. However, the internal program did not have such goals, selecting students based primarily on previous experience with faculty mentors. This was reflected in student comments (2009: “*I wanted to become a practicing physician even prior to starting undergraduate school.*”; 2011: “*...great experience doing research...did not change my desire to become a patent lawyer. Research moves too slowly for my liking.*”). The selection criteria may contribute to the findings

that a higher number of students entered medical school following completion of the internal program. In some cases basic research stimulated a specific interest in another profession, altogether a stated by a student studying retinopathy who was inspired to go to optometry school (2009: “*The research I was involved in with the REU peaked my interest in ocular health*”).

Publications and Presentations

The oral and written presentation of research results is a critical aspect of undergraduate research training. From 2006-2011 over 50% of students had abstracts accepted for presentations at national meetings. From 2012-2014, the budget for the NSF REU program included support for travel to present at national meetings. Due to this financial support and the existence of sessions at the Biomedical Engineering Society Annual Meeting reserved for summer undergraduate researchers, more than 70% of students presented at annual meetings. Another measure of productivity in an undergraduate research experience is the ability to make contributions substantial enough to merit authorship on a peer-reviewed manuscript. While a number of factors contribute to success in this regard, 15% (20/131) of the undergraduates co-authored a peer-reviewed manuscript. A higher percentage of students supported via the internal program (31.3%) published relative to REU students (11.1%) of REU students. When applying a more liberal measure of significant contributions (i.e. including manuscripts published in campus undergraduate research journals and acknowledgements of contribution in peer reviewed manuscripts), 20.6% (27/131) of students were identified as contributing to peer-reviewed manuscripts. This consisted of 34.4% of internal students and 16.2% of REU students. In general, these numbers should be considered as minimums due to the time lag between research

performed and publication. Three to four students are currently preparing manuscripts based on their work.

Discussion

In this paper we describe our 9-year experience with a summer 10-week engineering research experience for undergraduates. The participation of students in this program was supported via two mechanisms: funding as and NSF REU site and internal funding from the institution. While the student activities and research projects were similar regardless of funding, the results in regards to the demographics of students participating and the long-term academic paths chosen post participation.

The NSF REU site has specific goals and targets three primary groups: 1) students without previous research experience, 2) women and 3) students from groups traditionally underrepresented in STEM fields. NSF funding supported 59.6% women, 33.3% underrepresented groups, and 63.6% students without previous research experience. The internal program did not target specific groups and instead focused on promoting opportunities for internal students regardless of demographics. The number of women involved was lower in the internal program (46.9% vs 59.6%) but higher than the overall representation in biomedical engineering programs (38.9%)⁹. The number of students without previous research experience (18.8% vs 63.6% for internal and NSF, respectively) and from underrepresented groups (7.4% vs 33.3%) was substantially lower in the internal program. The NSF REU solicitation states that “*the NSF is particularly interested in increasing the numbers of women, underrepresented minorities*” in research”³. These results suggest that these goals help drive undergraduate research programs to

include specific groups that may otherwise have a low representation in the non-targeted internal program.

Unlike the NSF support, the institutional funds did not require that participants be domestic students, resulting in 15.6% participation by international students. Anecdotally, campuses with significant levels of international undergraduates are often challenged to find mechanisms to support their research activities due to restrictions on much of the government funding available. The continued growth of international students in undergraduate programs provides both a challenge and opportunity for undergraduate research programs.

Studies suggest that undergraduate research experiences are dominated by students with previous experience and with those who would have already determined their career path^{3, 4, 6}. Clearly, the NSF program had significantly more participation by new researchers (18.8% vs 63.6% for internal and NSF, respectively). In addition, students in the internal program had increased matriculation into non-research careers (primarily MD programs). These students also stated that, in many cases, their career plans were determined prior to entering the summer. While the students enjoyed the research, if the goals of undergraduate research are to promote research careers this may not have been accomplished. However, this was also observed in the NSF funded students. The identification and selection of students who will benefit most from the research experience and the definition of what the targeted “benefit” of participation is should be clearly articulated.

Summer research programs continue to increase in popularity on many university campuses and research centers. The break from classes in the summer provides students with the opportunity to immerse themselves full time in research activities. This may provide a more committed research experience that cannot be accomplished during the academic year. However, these short (typically 8-10 weeks) summer programs may not allow students the time to get a thorough exposure to research. Research productivity in regards to co-authoring peer-reviewed manuscripts was clearly higher in the internal students who typically experienced longer research training. In addition, they may not be able to establish strong mentoring ties with the faculty mentors. Students supported by NSF funding were primarily from off-campus, and therefore were only involved in the research activities for the summer. The internal program typically funded students with a more long-term commitment to research with multiple semesters working in the same laboratory. Student comments suggested a far more personal and impactful relationship with faculty in these students that spent greater time in the laboratory. The internal program allowed for sustained student involvement in research that may provide additional benefits above and beyond a single summer experience. Future studies should investigate the impact of research duration on the undergraduate research experience.

Nine years of running a summer undergraduate students has provided significant quantitative and anecdotal evidence in regards to the nature of the student experience. Based on this experience, some critical components to a successful research experience have emerged. The graduate student mentor appears to play an important role in the experience. Graduate students often play a direct role in mentoring the undergraduate and drive the day-to-day experience. The faculty member plays a different but also critical role. They often provide a bigger picture view

of the research, coordinate activities amongst lab members, provide insight into papers and presentations and give significant career advice. Faculty members who rely completely on the graduate students with minimal undergraduate interactions were eliminated as mentors over the lifetime of the program. The time involved in research also seems to be an important aspect of the experience. While we believe that students can have a meaningful and productive experience in a 10-week summer experience, it is important to carefully think about the design and structure of the research activities. Undergraduates involved in a more sustained research activities can be allowed to develop their research in a process similar to graduate students with a sustained process of continuous development, research and refinement of the process. This process is not likely to be productive in a 10-week experience. Overall, these observations need to be studied in a more comprehensive manner.

Conclusions

Undergraduate research experiences have the potential to impact student academic and professional careers. By comparing two different funding structures with distinct goals, this study provides evidence that the goals of the programs may influence program demographics and student outcomes. This information could be used to inform the design and structure of undergraduate research programs.

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