Diversifying STEM: Underrepresented Students' Perceived Learning Gains from Structured Research Programs

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Abstract

Colleges and universities have invested in structured undergraduate research experiences (SUREs) as a mechanism for broadening participation among underrepresented racial/ethnic minorities (URMs), yet few studies focus on the perceived benefits that URMs gain from their participation in SUREs. Using survey data from a national sample of 2,079 URMs enrolled at various 4-year institutions, path analysis results indicate: (a) URMs engagement with faculty in research had a positive direct effect on learning, (b) age and type of STEM major had positive direct effects on learning, (c) race and transfer status had positive, albeit modest, indirect effects on learning through engagement in faculty research, (d) sex and degree aspirations had both direct and indirect effects on learning, although sex was negative while aspirations was positive, and (e) improved goodness of fit as additional paths were tested, although the residual variance for learning suggests that variables unexamined in the present model explain science/technology learning. Implications for policy, practice, and research are highlighted.

Introduction

Increasing the number of students who complete advanced scientific degrees that lead to scientific research careers is a major education policy issue and a national priority. A declining cadre of highly skilled workers for technical fields and research-related careers threatens the United States' ability to compete globally and fuels the exportation of such jobs to other countries, which, in turn, affects the U.S. economy. In response to such trends, colleges and universities, along with the federal government, have invested significant resources to provide historically underrepresented minorities (URMs [includes African Americans, Latinos, American Indian/Alaskan Natives]) with structured undergraduate research experiences (SUREs) in which they engage faculty members on research and scientific discovery. While we know a good deal about the general nature and structure of SUREs, relatively little is known about the perceived learning gains that URMs' report from their involvement in SUREs. This is the gap addressed by the study upon which this report is based.

The purpose of the study was to measure the perceived learning gains that accrue to URM undergraduates who participate in SUREs at 4-year institutions, as well as test the direct and indirect effects of background traits and engagement in SUREs on perceived learning gains about science and technology. This paper presents findings from a study, which is part of Investigating the Critical Junctures: Strategies that Broaden Minority Participation in STEM Fields funded by the National Science Foundation.

Literature Review

Undergraduates in STEM majors have been studied extensively to understand what leads students to choose a science or science-related major, persist to graduation in such fields, and ultimately choose a science or technical career. Surprisingly, Seymour and Hewitt found that approximately 50% of undergraduates that select science majors upon entry to college change to a non-science major before graduation. Evidence also indicates that the proportion of Black students who earn degrees in STEM (8%) pales in comparison to White and Asian counterparts (65%). That science and STEM-related careers are perceived as isolating, highly competitive, impersonal, and time-consuming exacerbates the problem of attracting students to science majors; especially URMs such as African Americans who tend to operate collaboratively, more "as a family," and express strong desires to use their college education in service to their community and members of their race. , A growing number of studies have shown that SUREs, however, increase students' increase in STEM, mitigate a few of the challenges that STEM majors face, and assist in their retention to graduation.

Research on SUREs can be organized into two categories: studies that describe the general nature and characteristics of SUREs and empirical studies that measure the benefits SURE students derive from their experiences. For instance, working with a faculty mentor on a research project during the summer, choosing or becoming familiar with the study's particular focus, reviewing the existing literature about a topic, learning statistics, and writing a formal, albeit usually brief, research paper are key components of SUREs. Some students also engage in actual data collection (via surveys or interviews), data analysis, or dissemination (via a professional conference or publication) during their experience.

Scholars have only just begun to conduct studies to identify an empirically-based set of benefits that accrue to students who participate in SUREs. , , For instance, Lopatto analyzed survey data from 1,135 undergraduate participants at 41 institutions to determine whether undergraduate research experiences enhanced the educational experience of science majors. Over 83% of the respondents indicated plans or continuing plans to pursue post-graduate education in the sciences. And, participants did not differ significantly in terms of sex or race on future career plans, reported levels of benefits, or plans to pursue graduate education. Other studies show that SUREs nurture students' interest in science careers by acclimating them to scientific culture, including understanding the research process and observing the multiple responsibilities of faculty members. The weight of evidence also suggests that SUREs and mentoring aid in the retention of students, facilitate purposeful engagement among students and faculty members, and promote students' confidence in their ability to pursue graduate education and to conduct empirical research. , ,

Despite existing research on the role that SUREs play in enhancing the collegiate experiences of students, few contemporary studies examine what undergraduates learn from structured UREs. Indeed, more research is needed to provide educators with information they can use to make sound decisions about student recruitment, admission, and program implementation. The present study was designed to fill this gap in the literature.

Method

As part of a larger study, Investigating the Critical Junctures: Strategies that Broaden Minority Participation in STEM Fields, funded by the National Science Foundation, this statistical analysis is based on secondary analysis of data provided by the Postsecondary Research Program at Indiana University that sponsors the College Student Experiences Questionnaire.

Sample

The sample consisted of 2,079 historically underrepresented minority undergraduates enrolled at 4-year degree-granting institutions. Twenty-seven percent were non-Black URMs, 61% were women, 24% were STEM majors (as defined by the National Science Foundation), 15% transfer students, while 29% had worked with faculty on a research project. Table 1 summarizes characteristics of the study's sample.

Table 1

Description of the sample

Variable	M	SD
Race	0.27	0.44
Age	0.09	0.28
Marital status	1.06	0.24
Sex	1.61	0.49
Degree aspirations	0.73	0.45
Academic preparation	4.13	1.25
Socioeconomic status	5.83	2.31
STEM major	0.24	0.43
Transfer status	1.15	0.36
Faculty-student research	0.29	0.45
Vocational preparation scale	8.30	2.16
Science and technology scale	7.09	2.60

Note. STEM = science, technology, engineering, math.

Data Collection

Data were collected during the 2004-2005 academic year using a combination of web-based and hardcopy versions of the College Student Experiences Questionnaire (CSEQ), a 191-item instrument developed to measure the frequency and nature of students' experiences in college. Responses to the national administration were collected and compiled by staff members at the Center for Postsecondary Research at Indiana University. Data were provided to the principal investigator as electronic data files.

The dependent (endogenous) variable in this analysis assessed students' perceived learning gains in terms of science and technology. It consisted of three items (alpha=0.87) that asked each student to rate the extent to which they felt they had gained in understanding science, technology, and the consequences of science and technology. Each item was placed on a 4-point scale ranging from 1 (very little) to 4 (very much). Based on results from a principal components factor analysis with varimax rotation, I calculated a single composite (or summated) scale combining all 3 items; scale scores ranged from 3 to 12.

Independent variables included age (in years; 0=23 years or less, 1=24 years or older), sex (0=male, 1=female), year in college (0=freshman/sophomore, 1=junior/senior), advanced degree aspirations (0=no, 1=yes), academic preparation (1=low preparation to 6=high preparation), type of STEM major (0=non-STEM/social science, 1=non-social science STEM), and transfer status (1=non-transfer, 2=transfer). Since socioeconomic status (SES) is highly correlated with students' academic performance and affects a number of college outcomes, I hypothesized that it may affect student engagement and/or learning about science. In the model, SES was measured using a combination of parents' level of education and the amount parents contributed to college costs (scale ranged from 2 to 9); precedent for measuring SES in this manner was set elsewhere. Although this estimate of SES is not a robust measure of one's SES, it is arguable the best proxy that can be constructed using variables included on the CSEQ.

Data Analysis

Given the study's purpose, path analysis was used to test the predictive and mediational role of background traits and engagement with faculty in research on perceived science/technology learning gains among STEM undergraduates. Path analysis is a useful regression-based method for examining direct and indirect effects of independent (exogenous) variables on dependent (endogenous) variables; as such, it is very useful for testing theory and empirically-based hypotheses. Path analysis can provide sufficient evidence for building causal models as well. A causal model posits that an endogenous variable is explained by exogenous variables, which are assumed to be determined by factors outside the hypothesized model.

Path coefficients were calculated for all direct effects using an estimate of standardized beta; indirect effects were calculated by multiplying the direct effect coefficients between the variables in a given path. To determine whether certain paths could be deleted, a conservative threshold for statistical significance ($p < 0.05$) was used.

Several indicators were used to judge the goodness of fit of the model. These included chi-square (_2), the Goodness of Fit Index (GFI), the Adjusted Goodness of Fit Index (AGFI), the Root Mean Square Residual (RMR), and the type-2 Normed Fit Index (NFI). Assessment of the goodness of fit of the model was also guided by a careful examination of standardized residuals, Q-plots of standardized residuals (not shown here), modification indices, and individual parameter estimates as recommended by others.

Results

Path analysis results indicate that engagement with faculty members on research (i.e., SURE participation) had a positive direct effect (_=0.176, p<0.01) on science/technology learning. Age and type of STEM major also exerted positive direct effects (_=0.034, p<0.01 and _=0.309, p<0.01, respectively) on science/technology learning. Older students and those majoring in hard sciences (i.e., physical/biological/mathematical sciences or engineering) reported higher gains than their counterparts (i.e., younger students and those majoring in soft sciences [i.e., social/behavioral sciences]).

Race and transfer status had only positive, yet modest, indirect effects on learning through engagement with faculty in research; indirect effects were 0.010 (p<0.01) and 0.003 (p<0.01), respectively. Sex and advanced degree aspirations had both direct and indirect effects on learning, although sex influenced engagement and learning negatively, while degree aspirations influenced both outcomes positively. For instance, sex had a negative direct effect (_= -0.059, p<0.01) on science/technology learning and a negative indirect effect (_= -0.014) on science/technology learning through engagement with faculty in research. Advanced degree aspirations, on the other hand, had a positive direct effect (_=0.108, p<0.01) on science/technology learning and a positive indirect effect (_=0.016) on science/technology learning through engagement with faculty in research. The latter results indicate that students who aspired to earn a graduate degree participated in SUREs more than students who had no graduate degree aspirations; and, those aspiring to earn a graduate degree learned more about science/technology. While the final model was statistically significant in explaining variance in science/technology learning, F(10, 2014)=137.85, p<0.001, R=0.396, R2 =0.156; the residual variance, or error, term (e=0.92) suggests that a significant amount of variability in science/technology learning can be explained by variables not included in the model. In total, the direct effects outlined in the model explain 16% of the variance in science/technology learning. Figure 1 presents the parsimonious model.

Discussion

The purpose of the study was to measure the direct and indirect effects of SURE participation on perceived science/technology learning among STEM undergraduates who responded to the national administration of the College Student Experiences Questionnaire. Path analysis results suggest several major conclusions that will be discussed in light of the existing research. Implications for policy, practice, and future research are highlighted as well.

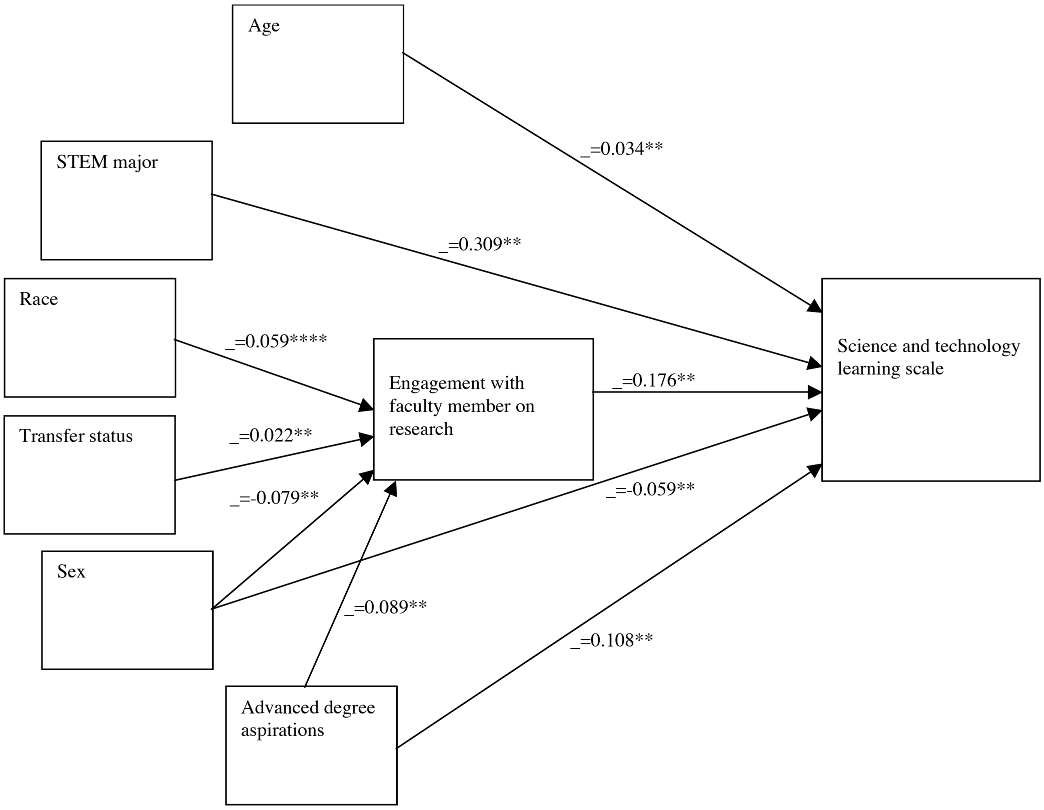
It is clear that STEM undergraduates who participate in SUREs with faculty members learn about science, technology, and the consequences of both. These findings are consistent with prior research about the efficacy of SUREs. Interestingly, however, age and type of STEM major had positive direct effects on perceived learning as well. In other words, the older the student, the greater the perceived learning gain; similarly, if a student was majoring in a “hard” science or engineering, s/he reported greater learning gains. These results, in part, raise questions about whether and how “soft” science majors learn about science/technology. That “soft” science majors must learn about science, technology, and their consequences is without question, especially since those majoring in social/behavioral sciences conduct experiments, use advanced technologies, and, at times, expose subjects to risky experiments and interventions. Knowing more about science, the evolution of technology, and the consequences of both ensures that such majors are conscious of the benefits and potential dangers of science, thereby making them more socially responsible. Echoing Rene Descartes, educators are reminded that: “The greatest minds are capable of the greatest vices as well as of the greatest virtues.” Learning about science, technology, and the consequences of both is likely to condition great minds to virtuous acts; findings presented here suggest the need for more learning opportunities among social/behavioral science majors.

Another finding that warrants discussion suggests that sex had a negative direct effect on science/technology learning, as well as a negative indirect effect on learning through engagement in SUREs. In other words, men learned more than women about science/technology and they also learned more than women about science through participating in SUREs. One possible explanation is that opportunities to learn science/technology (e.g., courses, labs, internships) are organized in ways that resonate with the preferred learning styles of men (i.e., they’re predisposed to learning that way) or, alternatively, opportunities to learn are inequitable between men and women (e.g., women are overtly or covertly discouraged from taking classes, participating in labs). Given national interest in broadening participation among women in STEM fields, the results of this analysis raise concerns about gender equity issues in terms of learning outcomes, but also point to areas over which we have some degree of control through policy or programmatic efforts. Deans, faculty members, and SURE program coordinators should consider these results when implementing new or enhancing existing programs so as to increase learning opportunities for women in STEM.

Aspiring to earn a graduate degree had a positive direct effect on science/technology learning, as well as a positive indirect effect on learning through engagement with faculty in research. The former may be explained, in part, as a consequence of academic effort—that is, the amount of time and energy students who aspire to graduate school are willing to invest in learning about topics that seem critical to their future success. The latter, however, may be explained as a sort of self-selection phenomenon. In other words, it seems reasonable to assume that STEM undergraduates who aspire to attend graduate school, widely known for its emphasis on research and specialized scientific training, may elect to work with faculty members on a research project as either a way to (a) socialize themselves to graduate school and/or a research career or (b) increase their chances of being admitted to graduate school.

Lastly, an examination of the overall pattern of findings provides empirical support for the proposed model, which explains 16% of the variance in perceived learning gains about science/technology. Still, goodness of fit indices indicate that a significant amount of the variability in learning can be accounted for by variables not included in the path model. Future research should build upon the omnibus model presented in this analysis by testing new paths and adding theoretically-based exogenous variables. As one of very few studies that examine the direct and indirect effects of selected variables on science/technology learning, the present study breaks new ground on what’s known about SUREs and offers a number of implications for future policy, practice, and research, many which are highlighted above.

Figure 1. Parsimonious path model explaining science and technology learning.



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References

01. Augustine, N. R. (2005). Rising above the gathering storm: Energizing and employing America for a brighter economic future. Retrieved March 19, 2008, from http://www.commerce.senate.gov/pdf/augustine-031506.pdf
02. Hu, S., Kuh, G. D., & Gayles, J. G. (2007). Engaging undergraduate students in research activities: Are research universities doing a better job? Innovative Higher Education, 32, 167-177.
03. Hu, S., Scheuch, K., Schwartz, R., Gayles, J. G., & Li, S. (2008). Reinventing undergraduate education: Engaging college students in research and creative activities. San Francisco: Jossey-Bass.
04. Maton, K. I., Hrabowski III, F. A., & Schmitt, C. L. (2000). African American college students excelling in the sciences: College and postcollege outcomes in the Meyerhoff Scholars Program. Journal of Research in Science Teaching, 37(7), 629-654.
05. Seymour, E., & Hewitt, N. M. (1997). Talking about leaving: Why undergraduates leave the sciences. Boulder, CO: Westview Press.
06. National Science Board. (2006). Science and engineering indicators 2006 (Two volumes). Arlington, VA: National Science Foundation.
07. Packard, B. W. (2005). Mentoring and retention in college science: Reflections on the sophomore year. Journal of College Student Retention, 6(3), 289-300.
08. Hirt, J. B., Strayhorn, T. L., Amelink, C. T., & Bennett, B. R. (2006). The nature of student affairs work at histori-

cally Black colleges and universities. Journal of College Student Development, 47(6), 661-676.
09. Seymour, E. (1992, February). “The Problem Iceberg” in science, mathematics, and engineering education: Student explanations for high attrition rates. Journal of College Science Teaching, 230-238.
10. Hurtado, S., Cabrera, N., Lin, M. H., Arrellano, L., & Espinosa, L. (2009). Diversifying science: Underrepresented student experiences in structured research programs. Research in Higher Education, 50, 189-214.
11. Hu, S., Scheuch, K., Schwartz, R., Gayles, J. G., & Li, S. (2008). Reinventing undergraduate education: Engaging college students in research and creative activities. San Francisco: Jossey-Bass.
12. Strayhorn, T. L. (2009, April). Unraveling the benefits of summer research experiences for economically disadvantaged ethnic minorities: A mixed methods study. Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA.
13. Lopatto, D. (2003). The essential features of undergraduate research. Council of Undergraduate Research Quarterly, 24, 139-142.
14. Lopatto, D. (2004). Survey of undergraduate research experiences (SURE): First findings. Cell Biology Education, 3(4), 270-277.
15. Seymour, R., Hunter, A. B., Laursen, S., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates: First findings from a three-year study. Science Education, 88, 493-594.
16. Seymour, E., & Hewitt, N. M. (1997). Talking about leaving: Why undergraduates leave the sciences. Boulder, CO: Westview Press.
17. Kuh, G. D. (1995). The other curriculum: Out-of-class experiences associated with student learning and personal development. Journal of Higher Education, 66, 123-155.
18. Kuh, G. D., & Hu, S. (2001). The effects of student-faculty interaction in the 1990s. The Review of Higher Education, 24, 309-332.
19. Strayhorn, T. L. (in press). Assessing research self-efficacy among economically disadvantaged undergraduate students of color in mentoring programs at predominantly White institutions. Proceedings of the American Society of Engineering Education.
20. Pace, C. R., & Kuh, G. D. (1998). College student experiences questionnaire (4th ed.). Bloomington, IN: Indiana University.
21. Pascarella, E. T., & Terenzini, P. T. (2005). How college affects students: A third decade of research (Vol. 2). San Francisco: Jossey-Bass.
22. Kuh, G. D., & Hu, S. (2001). The effects of student-faculty interaction in the 1990s. The Review of Higher Education, 24, 309-332.
23. Pedhazur, E. J. (1997). Multiple regression in behavioral research: Prediction and explanation (3rd ed.). New York: Holt, Rinehart, & Winston.
24. Kerlinger, F. N., & Pedhazur, E. J. (1973). Multiple regression in behavioral research. New York: Holt, Rinehart, and Winston.
25. Duncan, O. D. (1966). Path analysis: Sociological examples. The American Journal of Sociology, 72, 1-16.
26. Saddler, T. N. (2008). Socialization to research: A qualitative exploration of the role of collaborative research experiences in preparing doctoral students for faculty careers in education and engineering. Unpublished doctoral dissertation, Virginia Tech, Blacksburg