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NSF HBCU-UP Implementation Program: Enhancing STEM Education for Underrepresented Students through Course-Based Undergraduate Research at HBCUs

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Abstract: This paper presents the development and implementation of a transformative engineering curriculum at Tennessee State University (TSU), designed to improve retention and graduation rates among underrepresented students in Science, Technology, Engineering, and Mathematics (STEM). Central to this initiative are Course-Based Undergraduate Research Experiences (CUREs), which aim to enhance student engagement, develop visual-spatial skills, and promote learning outcomes. These efforts are crucial, especially at Historically Black Colleges and Universities (HBCUs) like TSU, which play a vital role in providing underrepresented students with authentic research opportunities. Over two semesters, the CURE program yielded significant findings, including increased student interest in STEM, shifts in degree aspirations, and positive changes in self-concept and relationship with science. Quantitative assessments and qualitative evaluations through surveys and interviews will further explore the impact of CUREs on students' academic success, empowerment, and self-efficacy. The study highlights the potential of such initiatives to bridge gaps in research exposure, foster academic and professional growth, and build confidence among underrepresented students. Further research will explore the long-term effects of CURE participation on academic trajectories and career decisions in STEM fields.

Keywords: Curriculum-Based Undergraduate Research Experience (CURE); STEM Education; Historically Black Colleges and Universities (HBCUs)

Introduction

STEM (Science, Technology, Engineering, and Mathematics) education plays a critical role in driving innovation, fostering economic growth, and enhancing global competitiveness in the United States. Academic institutions nationwide are pivotal in preparing the next generation of scientists, engineers, and technologists. However, the persistent underrepresentation of minority students in STEM disciplines poses a significant challenge, underscoring the urgent need for inclusive educational strategies that promote diversity (Yan et al., 2024). Historically Black Colleges and Universities (HBCUs) are uniquely positioned to address this disparity by offering equitable access to quality STEM education for underrepresented minority (URM) students, particularly African Americans.

HBCUs have been central to diversifying the STEM workforce, producing a substantial proportion of Black professionals in science, technology, engineering, and mathematics fields. Despite their significant contributions, HBCUs face challenges such as limited funding and resource constraints, which can negatively impact educational quality and student support services. These systemic barriers, combined with insufficient pre-college STEM preparation, limited access to mentorship and research opportunities, and the need for culturally responsive support systems, create substantial obstacles to the academic success and retention of minority students in STEM fields.

The Curriculum-Based Undergraduate Research Experience (CURE) has emerged as an effective intervention to enhance retention, engagement, and graduation rates among STEM students. CURE programs integrate authentic research experiences directly into the curriculum, enabling students to engage in real-world scientific inquiry as part of their coursework. This approach not only deepens students' understanding of scientific concepts but also cultivates a sense of belonging and confidence in their research abilities. By participating in CURE, students develop critical thinking skills, gain exposure to scientific processes, and foster a stronger interest in STEM careers. Research indicates that CURE programs can significantly narrow achievement gaps by providing URM students with equitable access to research opportunities, mentorship, and collaborative learning environments (Yan et al., 2020). As such, CURE represents a vital strategy for supporting URM students in academically rigorous settings.

Literature review

The significance of STEM education in shaping innovation and economic development cannot be overstated. Historically Black Colleges and Universities (HBCUs) play a pivotal role in advancing diversity in these fields, producing a notable percentage of African American professionals in science, technology, engineering, and mathematics (Davis, 2023). However, despite their critical contributions, HBCUs often encounter systemic obstacles such as limited resources and funding constraints (Escobar et al., 2023), which hinder their capacity to fully address the unique challenges faced by underrepresented minority (URM) students.

Retention and graduation gaps among URM students in STEM disciplines remain a pressing concern. Many of these disparities are linked to barriers such as inadequate pre-college preparation, limited mentorship opportunities, and the absence of culturally responsive teaching approaches (Kricorian et al., 2020). By addressing these systemic challenges, HBCUs have the potential to significantly enhance the participation and success of URM students in STEM, thereby enriching the overall talent pool (Yan et al., 2018).

CURE fosters essential skills such as critical analysis, collaborative problem-solving, and independent thinking. Students gain confidence as they work on meaningful projects, developing a stronger connection to their disciplines and a clearer sense of purpose in their academic and professional journeys (Hansen et al., 2024). Faculty also benefit from the implementation of CURE by aligning teaching with their research interests, creating a mutually beneficial academic environment.

Methodology

This study examined the integration of CURE methodologies across selected courses during the Fall 2023 and Spring 2024 semesters. Surveys were administered at the beginning and end of each course to assess changes in student perceptions and learning outcomes. Courses included topics such as Computer Engineering Graphics, Foundation Engineering, and Energy Conservation in Buildings. Participants completed voluntary pre- and post-course surveys, which explored their motivations, prior experiences, perceived learning gains, and attitudes toward STEM. Institutional

review board approval ensured ethical compliance, and students retained the option to withdraw at any time. By analyzing pre- and post-survey results, the study captured shifts in engagement, confidence, and interest in STEM careers, providing insights into the effectiveness of CURE within HBCUs.

Statistical analyses were performed using SPSS 27.0. Descriptive statistics summarized key aspects such as students' demographics, motivations for course enrollment, perceived learning gains, and overall course evaluations. Independent samples t-tests evaluated changes in students' attitudes toward STEM disciplines, their educational aspirations, and their confidence in science-related skills before and after participation in the CURE program.

Discussion

This study assessed how the CURE program influenced student engagement, perceptions, and aspirations within STEM fields at Tennessee State University (TSU), a public HBCU. While the program demonstrated potential to enhance STEM education for underrepresented students, the findings also highlighted critical areas requiring refinement to maximize its impact.

Program Strengths and Areas for Growth

The CURE program effectively engaged students in guided and independent research, fostering essential STEM competencies. Participants reported significant learning gains in instructor-led projects and individual research tasks. However, lower ratings for activities requiring collaboration, such as peer critiques, research proposals, and presentations, indicate areas for improvement. Enhancing these components through structured peer-review sessions and group presentations could better prepare students for the collaborative nature of STEM careers, where teamwork and communication are vital skills (Dare et al., 2021).

Influence on Academic Aspirations

While the program maintained students' interest in STEM fields, its impact on their long-term academic aspirations was modest. Some participants reconsidered pursuing doctoral degrees, with a noticeable increase in those undecided about their educational paths. This reconsideration aligns with prior findings that authentic research experiences can reveal the realities of advanced academic work, prompting students to reassess their goals (Chen et al., 2024). To counteract this, CURE programs should include career exploration modules that highlight diverse STEM opportunities, including roles outside of academia, to broaden students' perspectives and reinforce their commitment to STEM careers.

Developing Scientific Mindsets and Self-Efficacy

The program's influence on students' understanding of science revealed a need for more robust communication of scientific principles. Some students adopted deterministic views of research, believing experiments are successful only if they yield expected results. Addressing this misconception requires emphasizing the iterative and exploratory nature of scientific inquiry, along with the value of unexpected outcomes in driving discovery. Incorporating discussions on the

philosophy of science and resilience-building strategies could enhance students' confidence and adaptability in research contexts. Furthermore, students' relatively lower confidence in communication-focused skills, such as drafting research proposals and presenting findings, suggests that these areas need targeted attention (Estrada et al., 2018).

Reassessing STEM Career Intentions

The program's modest influence on students' willingness to pursue STEM majors highlights a potential disconnect between the appeal of research experiences and long-term career commitment. While students valued their exposure to authentic research, the realities of these experiences may have tempered their enthusiasm for traditional STEM paths. Addressing this requires integrating more tailored mentoring and showcasing non-traditional STEM careers, enabling students to connect their skills with broader professional opportunities (Galvez et al., 2024).

Conclusion

This study highlights the transformative potential of CURE programs in fostering academic engagement and enhancing research experiences for underrepresented minority (URM) students in STEM. These programs serve as a bridge to independent learning, empowering students to immerse themselves in authentic research processes. However, the findings reveal critical areas for improvement, particularly in nurturing collaborative abilities and communication skills. Introducing structured activities, such as peer review sessions, scientific presentations, and targeted training in professional competencies, could make these programs more holistic and impactful.

The reassessment of students' academic trajectories observed during the study suggests a need for CURE programs to go beyond research immersion. Integrating career exploration initiatives that link research experiences to a variety of STEM career paths could provide students with a clearer vision of their future opportunities. Tailored mentoring and exposure to diverse professional avenues would also help address the unique challenges URM students face in navigating STEM fields, fostering both confidence and persistence.

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