

A systematized literature review of STEM intervention programs for high school students and its effects on student retention

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Abstract

This study describes a systematized literature review on articles relevant to the effectiveness of Science, Technology, Engineering, and Mathematics (STEM) intervention programs at identifying and retaining underrepresented minority students in high school. The review details the methodology of the literature search through relevant databases for journal articles related to STEM programs that support underrepresented high school students interested in STEM. The search resulted in a full-text review of 25 articles that explore programmatic outcomes for pre-college students with the intent to diversify the STEM workforce. Initial findings suggest that the goal of these intervention programs is to provide enriching experiences for these students to encourage interests to pursue a STEM career as well as boost confidence in STEM subjects. Metrics used to target the effectiveness of programs revolved around three criteria: (1) student academic achievement in science and math, (2) matriculation through a STEM major and (3) competency in engineering-oriented skills. Three common recommendations for more robust programs are well-prepared STEM teachers, a college-preparatory, STEM-focused curriculum, and a robust network of student support systems.

Introduction

A significant gap exists in our ability to expose, prepare, and retain underrepresented minority students in engineering. My research vision is to characterize unique factors that contribute to the success of underrepresented minority students as they navigate their career pathway as engineers. In doing so, I can actualize the cultural wealth that students from diverse

backgrounds and experiences bring to STEM disciplines. There are several STEM intervention programs nationwide that have attempted to broaden participation in engineering through mentorship, afterschool and summer exposure programs, skill-development camps, etc. However, there have been varying perspectives on how to properly equip underrepresented minority students to persist and thrive throughout their engineering career pathway. To help organize these different methods, I am synthesizing the literature to create a catalog of programmatic strategies that STEM interventions can offer to enrich the experiences of underrepresented minorities interested in STEM. This research is important because it has significant implications for developing effective methods to train and nurture talents of youth in becoming confident in their STEM identities and necessitating success in becoming a professional engineer to diversify the STEM workforce further.

Literature Review

Industrialists, educators, and scientists reached a consensus regarding the low scientific literacy of the United States (National Science Foundation, 1996), a persistent problem as evidenced by the 6% representation of African Americans, Latinos, and Native Americans in the total STEM workforce despite consisting of one-fourth of the U.S. population (2014). As the world becomes increasingly technological, the U.S. has begun to seek new approaches for broadening participation in STEM beyond the white, male labor supply (Gonzalez & Kuenzi, 2012). Increasing participation in STEM careers by engaging underrepresented youth in K-12 serves as a means of meeting the national demand for a competitive STEM workforce (Byars-Winston, 2014). Outreach programs may provide youth from traditionally underrepresented backgrounds with an accessible, out-of-school curriculum to establish an early awareness of STEM careers (Genalo, Bruning, Adams, 2000). Increasing the number of diverse professionals

in the STEM workforce begins with exposing, preparing, and educating students at an early age. Minority students experience disenchantment with STEM at a young age for several reasons. Factors ascribed to underrepresentation include intimidating climate in science classes, poor quality of instruction, little (or no) career counseling, and perceived lack of relevance to daily life (Seymour and Hewitt, 1994; Simpson, 2003). Students from low socioeconomic status (SES) background, a high percentage of whom are minorities, have limited resources and access to high-technological equipment (DeCastro-Ambrosetti & Cho, 2002). Due to these and other factors, the nation has shown a steady decline in STEM affinity and STEM career trajectories among high school graduates and college students (Council of State Governments, 2010). The National Science Foundation Committee on Equal Opportunity in Science and Engineering determined in 2007 that K-12 programs were key to increasing the number of students seeking STEM careers.

In this paper, I explore the methods and outcomes of Pre-college engineering programs that target underrepresented minority students in high school. Based on my personal experience with intervention programs I've seen how STEM interventions shared a common goal of promoting STEM to spark the interest of and equip students to persist in STEM majors and careers. The type of interventions I have observed vary widely from afterschool programs to STEM high schools. In addition to organizational structure, the length of time in which students participated in programmatic activities also ranged between a few hours to 3 years. Despite program length and structure, student feedback mostly indicated positive outcomes, including higher interests in STEM, developing support systems, and gained confidence in STEM-oriented skills and abilities. College and career preparation incorporated in program activities consistently aligned with student's matriculation into STEM majors.

The wide range of exploratory activities, support systems, and curricula contributes to the effectiveness of recruiting students into the STEM pipeline. Due to the high variability in STEM programs, this literature review aims to assess the practical methods of educating and retaining minority students interested in engineering careers.

Scope and Research Question

Scope

This research topic examines how enrichment programs prepare underrepresented minority students in high school for careers in engineering. The population was limited to underrepresented minorities in high school. In this literature review, students outside of the United States were not considered as part of the populace because underrepresentation in engineering is consistent within a national context. Although engineering programs are the primary intervention of interest, discussions of STEM programs were also included to allow for articles that do not separate engineering from science, technology, and mathematics. The programs' approaches to fostering interests in engineering careers and retaining student participants in STEM were studied.

Research Question

Although this research project fits within a larger goal of understanding how to prepare underrepresented minority students to be engineering professionals, the research question for this project is concerned with how high school intervention programs contribute to underrepresented minority student success in STEM. The research question is:

What does the literature say about how STEM intervention programs prepare and retain underrepresented minority high school students for engineering careers within the US?

Methods

Search Procedure

The systematized literature review began in Fall 2018 with an evaluation of selected databases using a relatively unaffected search string to query articles that adequately address the research question. Three databases were selected to discover literature: Education Source, ERIC, and Scopus. Education Source and ERIC, both hosted by EBSCOhost, are education-related databases that provide journal articles in STEM education programs for high school students. These databases produced results of programs assessing the retention of underrepresented students in the STEM pipeline. Scopus is the largest abstract and citation database of peer-reviewed research literature and supports research needs in several subjects including scientific, technical, and social science. Scopus was selected due to the expansive coverage of engineering-related articles, particularly exploring engineering programs for high school students.

A four-part string was used to garner the relevant search results, as seen in Table 1. The first part of the search string had keywords or subjects that included “engineer,” “STEM” or any form of “tech.” The second part of the search string included “secondary,” “high school,” and all alphanumeric variations of high school grade levels 9-12 (i.e., ninth or 9th, tenth or 10th...). The third part of the search string included all forms of “program,” “center,” and “network” to capture program types. The final part of the search string included keywords or subjects “underrepresented” and “minority” for the type of students supported in these STEM intervention programs.

Table 1. Complete search strings and results of database query

Search String	Database	Additional Search Limitations	Results
AB (engineer* OR STEM OR tech*)	Education Source	Education, Engineering Education	28
AND AB (secondary OR high school OR ninth OR tenth OR eleventh OR twelfth OR 9th OR 10th OR 11th OR 12th)	ERIC	Engineering Education STEM Education, high school students	28
AND AB (program* OR center* OR network*)			
AND AB (underrepresented OR minority)			
OR SU (engineer* OR STEM OR tech*)			
AND SU (secondary OR high school OR ninth OR tenth OR eleventh OR twelfth OR 9th OR 10th OR 11th OR 12th)			
AND SU (program* OR center* OR network*)			
AND SU (underrepresented OR minority)			
OR TI (engineer* OR STEM OR tech*)			
AND TI (secondary OR high school OR ninth OR tenth OR eleventh OR twelfth OR 9th OR 10th OR 11th OR 12th)			
AND TI (program* OR center* OR network*)			
AND TI (underrepresented OR minority)			
(engineer* OR STEM) AND (secondary OR high school OR ninth OR tenth OR eleventh OR twelfth OR 9th OR 10th OR 11th OR 12th) AND (program* OR center* OR network*) AND (underrepresented OR minority)	Scopus	Subject: Engineering	41

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were utilized to refine search results directed toward the research question. The first inclusion criteria restricted results to peer-reviewed journal articles through a filtering menu. All other criteria were filtered by subject, language, or manual evaluation at the title and abstract level. If necessary, a second round of sorting was conducted to

assess whether full text adhered to the remaining conditions. Table 2 contains a summary of these criteria.

In addition to document type, all articles not written in English were excluded. Documents were also removed if they were not published in the United States. Items that discussed students outside of high school were also omitted. Articles that focused on promoting STEM or engineering as a career were included. Articles that did not explore methods of retaining underrepresented minorities in STEM were excluded.

Table 2. Considered and non-considered factors in eliminating database search results

Exclusion Criteria	Not Considered
<ul style="list-style-type: none">• Not a Peer-Reviewed Scholarly Journal Article• Not published in United States• Not written in English Language• Does not discuss underrepresented minority high school students• Does not actively promote STEM or engineering careers• Does not explore retention of underrepresented students in engineering career pathway	<ul style="list-style-type: none">• Age of article• Type of intervention program (i.e., summer program, after-school, etc.)

The criteria used to evaluate the results of the search process were suitable to attain literature that discussed the effectiveness of STEM intervention programs in attracting and retaining underrepresented students in STEM. Figure 1 illustrates the PRISMA flowchart. From the 84 non-duplicated documents pulled in the search process, a total of 27 were included in the review. The first round of abstract-level evaluation removed 57 articles (based on the exclusion criteria in Table 2). The subsequent round of full-text evaluation removed an additional 2 articles. The remaining articles covered 13 years of literature from 13 journals.

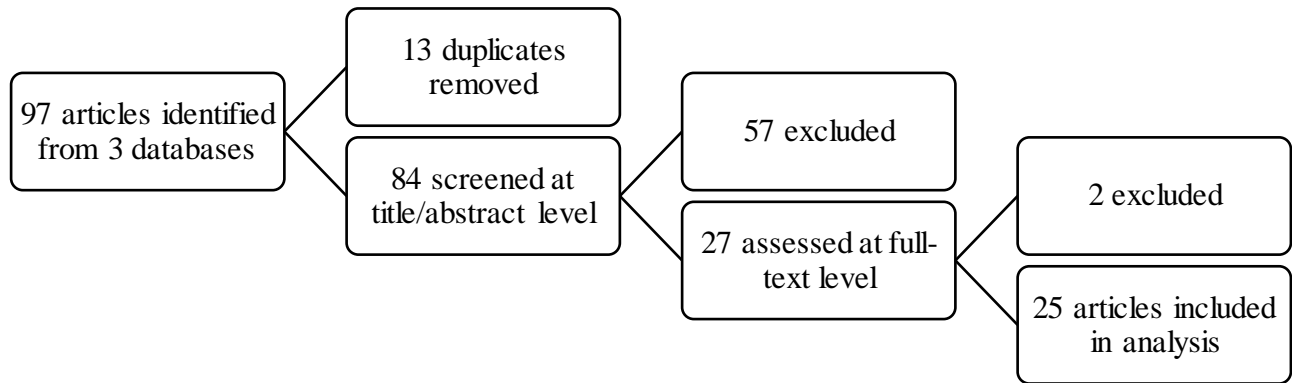


Figure 1: Adaptation of the PRISMA flowchart for described search process (Moher et al., 2009)

Analysis

The analysis was conducted using a general content analysis which exposed common threads across multiple articles. A thematic analytic process was performed for the systematized literature review, adapted from Thomas and Harden's (2008) recommendations on qualitative content analysis. A first pass across the entirety of the full-text articles resulted in notetaking about points of interest, sections considered to be highly relevant, and connections between the readings. A second pass was conducted using the NVivo software to collect and code themes that consistently appeared in the introductions, results, and discussions of each text. The themes below emerged from the second reading of the select passages.

Results

The results below come from an analysis of 25 articles collected in a systematized search. Four themes emerged from an analysis of these articles. First, articles discussed the critical components aimed to develop the experiences and engagements of students within the program. Second, articles generally identified approaches in which educational content was delivered with limited emphasis on its direct contribution to the student experience. Third, articles typically

emphasized the importance that informal and formal support systems contributed to students' confidence and persistence in STEM. Finally, articles generally discussed assessing student outcomes by measure of the improvements of student interest in STEM and confidence in STEM-oriented skills through pre- and post-surveys or tracking matriculation into STEM majors and careers. The narrow research conducted into student experiences in enrichment programs brought forth opportunities to explore effective methods of operating a STEM program.

Theme 1: Programmatic Components

Many of the articles analyzed included the programmatic components developed for student engagement, although the number and types of elements differed. These differences allowed for variability in timespan and depth in which students were able to explore content, build relationships, and develop STEM-oriented competencies. Programs incorporated one or more of the following components: onboarding process, STEM-focused curriculum, research apprenticeship, internship, mentorship, hands-on STEM activities/projects, oral and poster presentations, STEM workshops, and college/career preparation. The common components for the intervention programs included recruiting and onboarding, type of intervention, length, and accommodations and incentives.

Of the 25 articles, 10 included an apprenticeship or internship model for students to participate in throughout the program for professional skill development (Avent, Boyce, Servance, DeStefano, Nerem, & Platt 2018; Burgin, McConnell, & Flowers 2015; Fraleigh-Lohrfink, Schneider, Whittington, & Feinberg, 2013; Finkel, 2017; Harkness, Johnson, Hensley, & Stallworth, 2011; Lynch, Spillane, House, Peters-Burton, Behrend, Ross, & Han, 2017; Martinez, Lindline, Petronis, & Pilotti, 2010; Momoh, 2014; Musavi, Fries, James, & Isherwood, 2018; Tucker-Raymond, Lewis, Moses, & Miner, 2016). These articles also incorporate some

form of mentorship, in addition to 2 other programs (Bystydzienski, Eisenhart, & Bruning, 2015; Phelan, Harding, & Harper, 2015). Articles generally noted the benefits that students expressed by developing a relationship with their assigned mentor.

Recruiting and Onboarding.

Generally, programs recruited students who met several eligibility requirements: strong academic record, family income level, demonstrated interest in math and science, letters of recommendation from school leaders, standardized test scores, answered essay questions, and interview participation. Only one article discussed recruiting students with low performance in STEM because of its aims to prepare students for technical careers through 2-year colleges and trade schools (Bieber et al., 2013).

Program Characteristics.

Program types differed in timeframe in which events and activities occurred. 14 articles mentioned a summer component of the program (Avent et al., 2018; Beiler et al., 2017; Burgin et al., 2015; Bystydzienski et al., 2015; Finkel, 2017; Clark, 2010; Fraleigh-Lohrfink et al., 2013; Harkness et al., 2011; Ilumoka, Milanovic, & Grant, 2017, Lam, Srivatsan, Doverspike, Vesalo, & Mawasha, 2005; Martinez et al., 2012; Momoh, 2014, Musavi et al., 2018; Phelan et al., 2017). Eight articles stated after-school activities were incorporated (Bieber et al., 2005, Bystydzienski et al., 2015; Clark et al., 2015; Finkel, 2017; Ilumoka et al., 2017; Musavi et al., 2018; Puvirajah, Verma, Li, & Martin-Hansen, 2015; West, Vadiee, Sutherland, Kaye, & Baker, 2018). Inclusive STEM high schools posed a unique case in which STEM-focused activities and curriculum were executed throughout the academic year (Lynch et al., 2017; Lynch et al., 2018; Zarske, Yowell, Ringer, Sullivan, & Quiñon, 2012).

Duration.

The length of STEM interventions varied from a couple of hours to multiple years. The shortest outreach program hosted 1.5 to 2.5-hour sessions with students to spark interests in STEM (Scherrer, 2013). Most programs spanned from one to six weeks, particularly in summer programs. Other programs occurred throughout an academic year. The most extended program, aside from four-year high schools, was a three-year intervention program for girls (Bystydzienski et al., 2015).

Accommodations and Incentives.

Accommodations and incentives were important aspects of specific programs due to the socioeconomic status of underrepresented minority students interested in participating in some programs. Proximity was posed as an important consideration as the attendance of some students depended upon ease of transportation/commute to programs (Avent et al., 2018). Stipends and paid internships were necessary for students who may have to contribute to family support. One program reduced their stipend to balance budgets for their grant (Harkness et al., 2011). Free meals and housing throughout programs also helped support disadvantaged students. One article mentions the financial shortcomings of providing residence and meals, changing their program to a day camp and investing more in engineering activities (Bogue et al., 2013). Despite financial limitations, programs have provided accommodations for underrepresented minorities without inhibited the students' experiences. Scholarships through college partnerships were posed as a potential method to boost student enrollment into a STEM program.

Theme 2: Pedagogical Approaches

All articles reviewed mentioned a STEM subject matter where STEM-curriculum and projects were facilitated to the students. Examples of subject areas explored include lasers and fiber optics, interdisciplinary engineering, sustainability, biofuels, and videogame design (Beiler, 2017; Bieber, Marchese, & Engelberg, 2005; Bogue, Shanahan, Marra, & Cady, 2013; Burgin et al., 2015; Clark & Sheridan, 2010). The methods in which programs implemented STEM activities were generally through collaborative, hands-on activities, experiential learning, and project-based learning. However, research apprenticeships mainly used inquiry-based learning to allow students opportunities to engage with the research (Avent et al., 2018; Fraleigh-Lohrfink, 2013; Martinez et al., 2012; Musavi, 2018; Phelan et al., 2017). Well-prepared teachers in Inclusive STEM high schools were able to effectively facilitate STEM learning regardless of instructional practice such as traditional lecture, flipped classroom, lab-based inquiry, or project-based learning (Lynch et al., 2017). In one instance, a studio classroom environment facilitated demonstrations, work sessions, and critiques for video game designing (Finkel, 2017).

The instructor role varied by age and level of skill depending on organizational structure. In research apprenticeships, students worked directly with a graduate student or researcher and received additional support from a faculty advisor (Avent et al., 2018). Some programs train college students to teach and tutor high school students in STEM subject areas (Finkel, 2017). A few programs incorporated skilled high school students to provide instruction to their peers (Tucker-Raymond et al., 2016). The role in which instructors served beyond instruction as a source of support and guidance which helped bolster students' confidence.

Theme 3: Formal and Informal Support Systems

Support systems seemed to play a role in creating a sense of belonging, family, and community amongst participants in the program. Given the extended time periods and the close environment in which some programs operate, peers develop relationships with each other, mentors, and teachers. The presence and instruction of supervisors nurture students as their learning. Staff and family also contribute to students' ability to maintain interest in STEM and thrive in rigorous engineering programs.

Academic and Industry Professionals.

In research apprenticeships, faculty advisors served students in a quasi-mentorship role in which the depth of relationships was not fully explored unless surveyed. One article mentioned that participants who regularly contacted their faculty advisor found the relationship important in their laboratory experience (Avent et al., 2018). Industry-mentors, professionals who have been trained in the mentorship role, surprisingly were observed in one article (Ilumoka et al., 2017). Teacher-mentors were regarded as the highest benefit in student motivation toward STEM (Musavi et al. 2018)

Graduate Students and Researchers.

Graduate students and postdoctoral workers served as mentors exclusively in research apprenticeships. These researchers worked directly with apprentices, providing guidance in experiments and laboratory protocols. One article referenced the negative interaction a student experienced working with a researcher, however, upon questioning the student did not attribute the researcher's attitude to racism (Burgin et al. 2015). Such close interactions with students seemed substantial in determining the students' overall reflection of the program.

Peers and Family.

Peers developed relationships throughout group activities, especially in residential camps and daily afterschool programs that operated for an extended period. Programs that intentionally framed the group as a “family” or community help nourish a sense of belonging amongst participants, building confidence to persist in STEM. Students’ families were regarded as highly influential in providing support for students, specifically in keeping students involved in STEM activities and performing well in school.

Theme 4: Common Student Outcomes

The common goals of inclusive STEM intervention programs for high school youth were (1) to spark interest in STEM, (2) to build confidence in STEM-oriented competencies, and (3) to increase the diversity of students enrolling in STEM majors and careers. These programs shared a thread of pre- and post- surveys inquiring about similar student outcomes to determine program effectiveness. These measures centered around the intervention’s ability to funnel students into and successfully persist in the engineering pipeline.

Interest.

Several articles surveyed students regarding their interest in STEM careers at the program’s beginning and conclusion. Several studies generally indicated that the intervention increased the students’ interest in and understanding of STEM careers. The quantitative analysis of survey results limited the depth at which student interest was gauged. This numerical justification did not provide rich descriptions for why students found STEM careers to be engaging or what aspects of the program were most significant in increasing interests.

Confidence and Competence.

Students were generally observed to have improved teamwork abilities, communication skills, math and science literacy, and confidence in understanding the nature of STEM careers. In research apprenticeships, students' sense of agency and feelings of significant contributions led to feelings of belonging in STEM. Little evidence was provided that demonstrated students' aside from anecdotes, grade comparisons, and survey responses. Articles shared minimal detail in how well students understood engineering careers. Montfort, Brown, and Whritenour emphasize that more efforts must be made to change ways students think about engineering so that they may have a better understanding of engineering careers (2013).

Matriculation.

After students graduate from the STEM program, some articles report students who enroll in college, especially STEM majors, the scholarships awarded, the level of degree earned. Phelan suggests that the success of these students was exhibited by their admittance to and academic performance in their partner university (2017). Other studies indicated that exposure to STEM did not significantly affect students entering a STEM career (Bieber et al., 2005; Bystydzienski et al., 2015). Stipanovic and Woo suggest that college and career preparation through counseling helps students persevere, explore, and understand STEM career possibilities to a greater extent, yet this preparation is emphasized in few articles (2017). In these instances, articles noted how professional development activities were useful in scholars' career readiness and exposure to STEM careers.

Discussion

From a systematized review of 25 peer-reviewed journal articles, I found four emergent themes related to how STEM interventions implement programs, execute STEM education, develop support systems, and collect common data points to justify program effectiveness for underrepresented minority students in high school. In this section, I elaborate on the implications of several of these findings as well as discuss the limitations of my analysis.

Implementation

The first theme that emerged from the articles was the implementation strategies of the programs, which generally recruited students who fit a model according to the purpose of the programs. This theme highlights the variable methods in which programs systematically create a conducive environment for student engagement with STEM through stringent application requirements, daily activities, incentives, and other forms of structure. An argument may be made that underrepresented minorities must overcome underachievement caused by several factors (e.g., inadequate schooling, perceived racism, low expectations for academic success, etc.) to consistently meet the expectations held by prestigious programs (Maton & Hrabowski, 2004, p. 548). The nature of diversity and outreach STEM programs may benefit from removing high academic barriers to reach a broader audience of students. Although financial and personnel resources may be a limiting factor in broadening the participation of engineers, programs may find more significant gains in increasing the number of eligible applicants for a more pronounced effect in survey results. Reports of such assessments and resultant programmatic changes may also provide essential guidance for developing programs.

Education

The second theme that emerged from the articles indicated STEM interventions use of common instructional practices. Learning STEM was generally facilitated using project-based learning, hands-on activities, and inquiry-driven research. Experiential education and collaborative work permeated throughout the articles, demonstrating the importance of students developing 21st Century skills (Partnership for 21st Century Skills, 2009) which best aligned with the “4C’s”; critical thinking; communication; collaboration; and creativity. The self-directed choices that students were able to make when problem-solving provided a deeper sense of agency in solution-seeking. This newfound independence allowed students to feel a sense of accomplishment, especially when their contributions felt significant toward the project. Achievement and confidence of students were critical in determining the likelihood of pursuing STEM careers (Mau, 2003; O’Brien, Kopala, & Martinex-Pons, 1999). In some instances, advanced students were motivated to serve as instructors and tutors in subsequent iterations of programs. Teachers of various levels were generally able to positively influence student ability, especially when offering guidance in a facilitator role. Instructors played a crucial role in encouraging and nurturing students’ perceptions of their abilities in STEM.

Support

The third theme that emerged from the review exposed the significant contribution of support systems in instilling belongingness of underrepresented minority students in STEM. Each program’s infrastructure facilitated bonding between students, mentors, and faculty provided through participation in daily activities and projects. Through these events, peers sustained relationships of support beyond the parameters of the program. My review revealed that industry professionals were used less often as mentors than faculty and peers. If programs

intend to diversify the STEM workforce, it would be advantageous to incorporate industry mentors to broaden career possibilities for participants (Avent et al., 2018). Also, STEM interventions that set a tone for building family and community amongst all participants observed improvements in student perceptions of STEM identity (Burgin et al., 2015).

Success

In my final theme, the shared goal to further diversify the STEM workforce was observed through measures theoretically aligned with the programs' success. Observations of student outcomes revealed a frequent reliance on pre- and post- surveys to gauge student interests, confidence, and persistence in STEM. Interest was generally assessed by short-term programs which occasionally noted that interest does not necessitate enrollment, especially for high school seniors. Longitudinal studies, though uncommonly conducted, indicated varying degrees of success in students matriculating into STEM majors and careers due to the challenges such as intimidating academic climate and lack of support in rigorous engineering colleges (Bystydzienski et al., 2015). These transitions between STEM intervention and college coursework suggest a need for programs to include more comprehensive methods of sustaining underrepresented minority students in the engineering pipeline. Pre-college engineering programs may benefit from a standardized instrument for assessing effectiveness to better understand how to maintain consistent preparation of confident, competent students who aspire to be engineers.

Limitations

As a systematized literature review, the level of depth and rigor attributed to understanding pre-college engineering programs was limited by the explanations within

literature. As such, the scope of the results focused on the aspects that articles considered to be most relevant to the program's successes and failures. As I searched through texts, the commonalities between program decisions did not capture subtle details that may have had a significant impact on student experiences. Additionally, I believe having an opportunity to interview stakeholders (i.e., administrators, students, staff, and faculty) within the program would help provide richer descriptions and potentially remove biases posed within articles.

Conclusion

This systematized literature review investigated how pre-college STEM programs discussed methods and effectiveness in preparing underrepresented minority students in high school. A search that yielded 84 articles from three databases was filtered down to 25 articles that were read and annotated for emergent themes. These themes related to the programmatic components in the articles, the pedagogical approaches for facilitating STEM education, informal and formal support systems that developed students' belongingness within a STEM community, and common student outcomes sought after by programs. These findings not only connect pre-college engineering program choices and impact but also indicate how underrepresented high school students may enter and persist in engineering by participating in strategic programs.

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