Mentoring STEM Students by STEM Faculty: A Literature and Expert Panel Review

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Abstract.
Introduction: What We Did and the Approach We Used: In this study, we conducted a thorough review literature on the importance and effectiveness of mentoring STEM students by faculty, including those aspects of mentoring that promote mentoring failures versus mentoring successes, and reported on insights generated by a panel of experts who develop mentoring programs and train STEM faculty in mentoring.

Why We Did This Study (Why is It Important): We conducted this review in order to provide a more comprehensive picture of what constitutes effective mentoring for these students, in particularly in light of research that shows the influence of mentoring on their academic self-efficacy and outcome expectations and the specificity of their career goals.

What is the Approach We Used and Why: The focus was on reviewing emerging research from the past decade, especially given the shifting educational and vocational landscape encountered by STEM students.

How This Article Adds to the Literature: This study adds to the literature by focusing on the needs and mentoring strategies for STEM students compared to much of the literature that focuses more broadly on college students in general; and by delineating components that would be salient for inclusion in a best practices model for mentoring STEM students by faculty.

1 Mentoring STEM College Students: What Faculty Mentors Need to Know

The educational and vocational landscape encountered by STEM students is shifting due to changes in educational delivery methods, the questioning of the return on investment for completing one's STEM degree, and the uncertainty of obtaining one's desired career in STEM. Faculty mentoring for STEM students can make that critical difference between whether they successfully complete their STEM degree and work in a STEM field or whether they go on into a different type of degree program or career. Mentoring from faculty has a unique place in helping students prepare for their careers from the beginning of their college experience well into their initial employment in a STEM

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occupation. Mentoring from faculty can consist of guidance and support of students from one's academic discipline, one's academic community, or even from a different university. Some professional associations, such as the IEEE Mentoring Program [1], American Indian Science and Engineering Society's [2] Full Circle Mentorship Program and the Society of Women Engineers [3] Big Sis/Little Sis Mentoring Program, offer faculty mentoring for STEM students, indicating a recognition among the STEM professions that mentoring can be a critical activity in promoting the success of STEM students, especially students who need career guidance and/or who are underrepresented in STEM professions.

Research has also shown that mentoring from faculty can be incredibly important, especially for students who are navigating their college education and career preparation in this post-pandemic world. Complex challenges, including adjusting to college and academic life, complex career decision-making, and engaging effectively in the learning and mastery of one's discipline in online and hybrid learning environments mean that faculty must go above and beyond their traditional sharing of disciplinary knowledge and classroom-based instruction [4]. This current need for quality faculty mentoring provides additional challenges for faculty who for the most part are not trained in the art and science of mentoring [5], nor who do not necessarily have the support and recognition they need from their administration for engaging in the mentoring of students in STEM.

These realities mean that while mentoring can make the difference between student success and failure in both the educational and career development domains [5] [6], there is a gap between faculty mentors' knowledge and abilities to provide effective mentoring, and the mentoring needs of students in STEM disciplines. Thus, in this article, we will focus on 1) reviewing the available literature on the importance and effectiveness of mentoring STEM students by faculty, including those aspects of mentoring that promote mentoring failures versus mentoring successes, and 2) report on insights generated by a panel of experts who develop mentoring programs and train STEM faculty in mentoring.

2 The Importance and Effectiveness of Mentoring

Effective mentoring can bring many positive benefits, while ineffective mentoring can adversely impact STEM students, increasing their stress, and contributing to low retention in many STEM fields [7]. Recent research has demonstrated the critical nature of providing effective mentoring for STEM students. For example, Turner et al. [8] found that effective mentoring can enhance students' academic self-efficacy (i.e., students' self-confidence that they can successfully complete academic tasks), outcome expectations (i.e., students' expectations that the outcomes of their choice to enter a STEM career will help them reach their career and life goals [9]), and the specificity of their career goals (with greater goal specificity related to a greater motivation to succeed in STEM [10]). In this cross-sectional study using a multi-group Structural Equation Model (SEM) among a U.S. sample of approximately 25% each of African American, Asian American, White, and Latinx students ($n = 189$ STEM students and $n = 222$ non-STEM students), these researchers found that STEM students' academic self-efficacy was strongly predicted by emotional support, including faculty mentoring support, at $\beta = .50$ ($p = .000$). The predictive strength of mentoring on the academic self-efficacy of

STEM students was almost twice as high as it was for non-STEM students ($\beta = .29$, $p < .05$), and was superseded as a predictor of academic self-efficacy only by the STEM students' grade point averages ($\beta = .64$, $p = .000$). Thus, the result of this study provides evidence for the positive gains for STEM students who are mentored by faculty, and suggests that there is a critical need to focus on training and supporting faculty who can mentor them.

In another study [11], research demonstrated a positive relationship between effective mentoring American Indian ($N = 83$) students by faculty, family, and peers, and their college self-efficacy (i.e., self-confidence students have in their abilities to complete specific college-related tasks [12]), self-esteem (i.e., students' positive or negative attitudes toward self [13]), and perceptions of support (i.e., students' beliefs that their needs for support, information, and feedback are being met [11]). In addition, there was a strong negative relationship between mentoring and college non-persistence; and, when compared to student and family mentoring, faculty/staff mentoring had the strongest impact on STEM students' decisions to persist in college and not to drop out before graduation.

Moreover, effective mentoring can contribute to students' social capital (i.e., access to opportunities, resources, and information [14]). In another study [15], which used a Grounded Theory case study approach, participants were drawn from a long-term, comprehensive science support program at a medical university in the Midwest; 11 Latinx high school and college students, 3 staff members, 12 graduate student mentors, and 13 faculty mentors participated in one-to-one, in-depth qualitative interviews in which they described how mentors promoted their mentees' social capital through bonding with their mentees and bridging their mentees to new educational and career opportunities. Results showed that mentees' interests in and exploration into STEM science careers was increased, their perspectives about these career paths were broadened, and their professional development was enhanced. Results from this study suggests that having effective, competent mentors, including faculty mentors, for STEM students, especially STEM students of color, can increase students in the STEM education to career pipeline.

Other empirical studies have shown that effective mentoring from faculty can promote women students' sense of belonging and their interests in STEM [16] and have a positive impact on underrepresented students' STEM identity [17]. Mentoring can foster mastery and independent critical thinking, as well as agency and leadership among diverse students [18]. Mentoring can increase STEM students from underrepresented groups perceived academic skills and competencies [19]; and, mentoring may be key in addressing current participation and persistence gaps in STEM.

Research has also shown that there are distinct characteristics between mentoring failures and successes when mentoring STEM students. For example, researchers have found that mentors in general receive little to no training in mentoring students, and therefore are often forced to model their mentoring style on experiences with their own mentors [20] [21]. In addition, according to [22], mentoring failure can come from two sources. These are distancing/manipulative behavior by the mentor and poor dyadic fit between the mentor and mentee. Poor dyadic fit consists of such issues as mismatched expectations between the mentor and mentee, misalignment of mentors' expertise and the goals of the mentor/mentee relationship, and misalignment of time needed versus time

available. Distancing/manipulative behavior consists of abuse of the mentor's power in the relationship, lack of awareness of the mentee's culture or values, lack of proper crediting of the mentee's work by the mentor, and conflict, competition, lack of boundaries, or overdependence between the mentor and the mentee.

On the other hand, mentoring successes can come from.

- Mentors' practicing self-awareness of personal and positional power in the mentoring relationship [23]
- Mentors' willingness and opportunity to actively engage in mentorship training, learn mentorship skills, and engage in sound mentorship practices [24]
- Mentors' provision of opportunities to interact with faculty in meaningful ways outside of the classroom [25], and thereby acknowledging that their mentee as a STEM group member and a growing professional member in the world of STEM [26]
- Mentors showing care and fostering relationships and personal connections with their mentees [27] [28] via the practice of relationship skills [29], such as providing emotional support, establishing trust [30], and giving and receiving constructive feedback [31].
- Mentors providing support to STEM students early in the students' college-going experience [32]; and along with that helping their students establish a network of connections with their cohort and other peers, support personnel in the academy, and resources that they can turn to for help in setting and reaching academic and career goals [32]
- Mentors maintaining flexibility in mentoring, keeping in mind that different students have different mentoring needs [33]
- Mentors practicing cultural awareness and the awareness of cultural differences with STEM students [24], cultural affirmation that acknowledges community wealth and the ways students overcome institutional barriers [18], and cultural humility by which faculty learn from students what their priorities are within their own contexts while continuing to recognize their own biases in the mentoring relationship [34].

3 Additional Expert Data

In a foundational study of what types of training mentors of STEM students would need to enhance their effectiveness, a panel of experts were convened by the lead author of this article to discuss what they believed were the most essential issues that could lead to the development and testing of a best practices model of mentoring training. This panel included one faculty from Chemistry and one from Mechanical Engineering who had collaborated to develop a peer mentoring program for underrepresented undergraduate STEM students and also had contributed to the development of faculty mentoring training programs at their respective universities. The panel also included one Robotics faculty member who had developed a Women in Computing mentoring program for graduate and undergraduate computer science students; and, the panel included one Educational Psychology faculty member who conducted research and training on faculty mentorship for both STEM and non-STEM students. The panel was asked to share insights and to identify and discuss issues in a non-structured format as they together considered faculty preparation and support.

Panel insights included providing faculty with empirically based, best practices training, rather than anecdotally-based instruction on developing the mentor-mentee relationship, and helping mentors develop a very clear understanding of what mentoring is, and what the goals of mentoring are. The panel also discussed helping mentors understand their role expectations as mentors, as well as the supports they provided in their students' lives, such as offering encouragement, feedback, mastery learning experiences, and role-modeling to their STEM student mentees. The panel discussed helping mentors gain content knowledge and skills that they could use to help their mentees develop their own careers, in areas such as how to network with other STEM professionals given that a large majority of jobs are procured through these types of informal channels [35]; and they discussed providing mentors with tools to build closer and more supportive relationships with their mentees, while still maintaining professional boundaries. Finally, the panel discussed supporting mentors in their training and in their mentoring practice through such mechanisms as merit reviews, and ongoing mentoring of mentors, as well as recognizing and celebrating their mentoring accomplishments through mentoring awards.

4 Conclusion

The mentoring of STEM students can be a powerful support for them as they strive to reach their educational and career goals. Indeed, the mentoring of STEM students may be more critical for them than for students in other disciplines [8]. Yet, while the effectiveness of mentoring has been established for STEM college students, there is little systematic and ongoing mentoring training for faculty mentors, even though many faculty members lack a basic understanding of mentoring, or a clear conceptualization of how they can mentor students in ways that are most effective. Thus, in this article, we have examined relevant literature regarding the effectiveness of mentoring, as well as those mentoring characteristics and actions that could contribute to both mentoring failures and mentoring successes. In addition, we have provided additional expert data designed to lead to the development and subsequent testing of a best practices model in mentoring for STEM students. We hope that this article will promote additional research on mentoring that is specific to STEM students, and that best practices and empirically supported mentoring models will be systematically utilized to prepare competent mentors for them.

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