Two Theory Driven Approaches Toward a Single Goal: Retaining Students in STEM

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The National Science Foundation funds scholarships in Science, Technology, Engineering, and Math (S-STEM) to address critical workforce needs in the United States. The primary goal of the NSF S-STEM program is to enable low-income students with strong academic ability to pursue careers in in-demand STEM fields [1]. In addition to financial support for the students; funded projects adapt, implement, and evaluate evidence-based activities that effectively support student success in STEM programs. Two distinct theory-driven NSF S-STEM projects are underway at the Rochester Institute of Technology. The first project, titled ENGAgE: *ENhancing Growth-mindset Academic Experiences* to support graduation of undergraduate students in computing, was awarded in 2020. Using Theories of Intelligence and evidence-based growth mindset interventions, this project aims to combine curricular enhancements with mentoring to increase student retention and graduation in the College of Computing. A growth mindset asserts that abilities can be enhanced through persistence and dedicated effort by viewing challenges as a stepping stone to success, and contrasts with a fixed mindset that asserts we are born with innate and unmalleable abilities [2]. The second NSF S-STEM project at RIT, awarded in 2019, is Next Gen-ET: *Graduating the Next Generation of Engineering Technology Professionals by Promoting Competence, Group Identity, and Autonomy*. The guiding principle of this project is to promote competence and develop relatedness and autonomy in Engineering Technology students through the implementation of support networks and pedagogical reform. As posited by Self-Determination Theory, when these three basic psychological needs are met, individuals will be intrinsically motivated to support their own personal growth and well-being [3]. This paper describes two theory-driven strategies being implemented toward a single shared goal of retaining students in STEM programs. These programs are of interest as the evidence-based pedagogical approaches align with best practices for supporting diverse student groups in STEM. In particular, they provide two distinct means that can be adapted to other STEM programs striving to retain minoritized students.

Introduction

The United States is in the midst of a shortage of science, technology, engineering, and mathematics (STEM) workers, and that shortage is projected to grow in the near future [4]. Research indicates that the underrepresentation of minoritized groups in STEM programs, including women and economically disadvantaged students, is contributing to the shortage of STEM workforce [4, 5]. While there has been significant effort to increase the enrollment of underrepresented students in the STEM disciplines, these efforts have not made a significant impact [6]. Many factors contribute to the barriers for students and the resulting failure to increase participation. These factors include a lack of primary and secondary education preparation, financial support, institutional racism, psychosocial factors, such as identity and academic efficacy, and a lack of diverse faculty and mentors [6].

The goal of the National Science Foundation Scholarships in Science, Technology, Engineering, and Math (S-STEM) program is to produce well-educated employees for the technical workforce in the United States. This S-STEM program supports programs whose goals are to provide educational opportunities for low-income, academically talented students; increase retention of these students, and improve student support programs [1]. Students supported by S-STEM programs must be academically talented, domestic students enrolled in S-STEM eligible associate, baccalaureate, or graduate degree programs. Funding for this program comes from the H1B Visas used to hire foreign talent, thereby using these funds to develop domestic technical talent.

NSF S-STEM projects currently underway at the Rochester Institute of Technology: ENGAgE: *ENhancing Growth-mindset Academic Experiences* to support graduation of undergraduate students in computing was awarded in 2020 and Next Gen-ET: *Graduating the Next Generation of Engineering Technology Professionals by Promoting Competence, Group Identity, and Autonomy* awarded in 2019. This paper will provide an overview of both programs, program rationale, programming, and next steps that will highlight areas that can be adapted for other institutions.

Program Descriptions and Implementation

ENGAgE: *ENhancing Growth-mindset Academic Experiences*

Overview

The ENGAgE project aims to increase the number of academically talented low-income students graduating and entering the workforce with a Bachelor of Science degree in computing. After learning about theories of intelligence and growth and fixed mindset, faculty who serve as instructors and mentors infuse a growth mindset into their curriculum and interactions with students. Specifically, first-year programming and second-year career preparation courses are enhanced with evidence-based growth mindset approaches. Three cohorts of ten students are supported with scholarships, faculty growth-mindset instructional and mentoring interactions, and scholar meetings that focus on metacognition and growth mindset.

The concept of growth mindset, grounded in Dweck's work [2], posits that an individual's intelligence and abilities are malleable and may evolve through persistent, dedicated effort. Alternatively, a fixed mindset supports that intelligence and abilities are fixed at birth and are not malleable. Both mindsets may exist for individuals; for example, an individual could have a fixed mindset that they are not good at something (ex. math, art, programming, etc.) and never will be, no matter how much they try, while simultaneously having a growth mindset around something else, such as a sport, where they understand that continued practice will enhance their skills and abilities. Brock and Hundley [7] extend the work of Dweck [2] to offer strategies to promote a growth mindset in an educational setting including normalizing mistakes, person praise versus process praise, effective feedback, and promoting failure as a stepping stone towards success.

Rationale

Many studies have suggested that when students were encouraged to embrace a growth mindset, this has a positive effect on student learning demonstrating a reduced vulnerability to stereotype threat [8]. However, work specifically grounded in computing education around growth and fixed mindset has been limited and with mixed results, some with no correlation between mindset (fixed or growth) and course grades [9] or little impact from interventions [10]. Further, student growth-mindset interventions were commonly very narrowly focused [10] or non-existent [9]. On the instructional side, Canning, et al [11] demonstrated that faculty mindset is significant in positively impacting the student learning environment. Their study revealed a racial achievement gap twice as large for students in courses taught by professors with a more fixed mindset than courses taught by professors with a more growth mindset. Thus, the ENGAgE project embraces a holistic approach toward interventions that include both faculty *and* student understanding and development of growth mindset.

Programming

Three ENGAgE project components have been developed to foster a holistic growth mindset approach with students: (a) faculty mentoring, (b) computer programming and career preparation course augmentations, and (c) regular scholar meetings. Prior to implementing each of these, faculty learned about their own mindset as well as how to foster a student growth mindset by participating in the Growth Mindset Faculty Community of Practice (GM-FCoP). The GM-FCoP was designed using an active learning approach, alongside the key tenets of communities of practice whereby members with varying levels of knowledge and expertise gathered regularly to encourage and support each other as they developed knowledge and collaboratively generated shared resources [12]. By infusing a growth mindset throughout every aspect of the project, students experience the notion that mistakes, hurdles, and “bumps in the road” are to be expected and the faculty work to support students in continuing to move forward rather than seeing the hurdles as insurmountable roadblocks.

Faculty mentors meet individually with scholars every two weeks to make connections between academics and career plans; advise on personal issues, including finding academic resources on campus; managing personal relationships; and help to develop an understanding of university systems. Mentors do all this with an approach that deepens growth mindset connections. The mentors also meet as a group every three weeks to share advice on challenging situations that arise and to deepen their own growth mindset understandings on a continuing basis.

Existing curriculum in Programming I, Programming II, and Cooperative education (co-op)/career preparation courses have been augmented with a growth mindset. It is important to note that a new curriculum has not been developed nor has the curricular content been changed. For example, in programming classes, error messages are normalized to be understood as helpful in debugging code rather than being viewed as an indication of programmer failure. In the career preparation course, panelists visiting the classroom to discuss career paths are encouraged to share their stories of challenges and how they were able to overcome them and move forward toward success. Augmenting programming courses are important because these courses prove to be challenging for many computing students and successful completion is important in retention efforts for students to persist as computing majors. Career preparation courses are also important as students are required to complete co-op for graduation and often face challenges in searching for and obtaining a position.

The scholars also meet every two weeks to learn about growth mindset metacognition tenets. Meetings start with an ice breaker, such as local area trivia or a game, so that scholars can get to know one another. An active learning exercise on growth mindset follows, where students are asked to share their thoughts and experiences. For example, students have acted out scenarios with a fixed mindset and then reworked the scenarios with a growth mindset to understand the differing approaches, with a discussion following. First year experiences focused on general college and class interactions while second year exercises will focus on career preparation and more advanced planning and task management using a growth mindset.

Next Steps

Data collected from members of the Growth Mindset Faculty Community of Practice (interviews and mindset surveys), ENGAgE scholars (demographic, mindset surveys, focus groups, and academic performance), and non-scholars (demographic, mindset surveys, and academic performance) during Year 1 is in the process of being analyzed with initial findings reported [12-14]. Data will continue to be collected from scholars as they enter their second year of college and begin to consider computing career opportunities as they take a cooperative education (co-op) preparation course and seek their first co-op job. Year 2 of the project also welcomed the second cohort of scholars and data collection, analysis, and dissemination of findings will continue as additional cohorts enter the project.

Graduating the Next Generation of Engineering Technology Professionals by Promoting Competence, Group Identity, and Autonomy (Next Gen-ET)

Overview

Grounded in the framework of Self-Determination Theory [3], the *Graduating the Next Generation of Engineering Technology Professionals by Promoting Competence, Group Identity, and Autonomy* project is a comprehensive program developed to increase enrollment of economically disadvantaged, academically talented students in Engineering Technology disciplines. The targeted students recruited for this program are students from groups traditionally underrepresented in Engineering Technology including women, African Americans, Latin Americans, Native Americans (AALANA), First Generation (FG), and Deaf and Hard of Hearing (D/HH). Over its five-year duration, the program will provide scholarships to 36 undergraduate students who are pursuing bachelor's degrees in any of the following programs in the College of Engineering Technology at RIT: Civil, Computer, Electrical, Mechanical, Mechatronics, or Robotics & Manufacturing Engineering Technology. While the overall goal of this project is to increase STEM degree completion among low-income, high-achieving undergraduates with demonstrated financial need, targeted recruitment of students traditionally underrepresented in Engineering Technology has the potential to increase diversity in the Engineering workforce. The enrollment of AALANA, FG, and D/HH students in Engineering Technology programs at RIT exceeds national levels and is, in some cases, more than double that of engineering programs at RIT. As such, this program supports the NSF goal of broadening participation in STEM fields. In addition to supporting students, this program aims to advance the understanding of best practices to address the social and environmental factors that have historically contributed to the low retention of underrepresented students in Engineering Technology programs.

Self-Determination Theory (SDT) is based on the premise that an individual will be intrinsically motivated to support their own personal growth and well-being when the three basic psychological needs of competence, relatedness, and autonomy are met [3]. Competence refers to a sense of effectiveness and mastery, and is innately related to self-confidence. Relatedness denotes a sense of familiarity and connection, and is satisfied by forming meaningful bonds with and feeling significant to others. Finally, autonomy refers to the experience of volition and psychological freedom. When an individual feels isolated, pressured, and/or conflicted or that they have failed, their psychological needs will be unmet and they may become frustrated and thus demotivated [15]. In addition to the role SDT plays in intrinsic motivation, there exists a body of literature supporting its role in persistence [3] and achievement in education [16].

Rationale

There has been a long-held belief in engineering education that all students can be successful if they just work hard enough. This has allowed generations of engineering educators to attribute attrition and/or low achievement to student deficit and has led to the belief that engineering diversity can be increased if more students are encouraged to work harder so they can “make it through” [17]. However, a growing number of researchers have identified the inequitable culture in engineering education as the cause of its lack of diversity. They have called into question the pervasive practices that have led to the identification of engineers as masculine, white, middle-class, and heterosexual [18]. The long-standing culture in engineering education has been characterized by its discourse [19], hard work and challenge [20] and competitive, rather than collaborative, approach [21]. Additionally, it has been found that there is an engineering way of thinking and an engineering way of doing, along with the aforementioned engineering identity [19, 22]. All of these factors combine to create what many term an unwelcoming environment in engineering education for women and minorities.

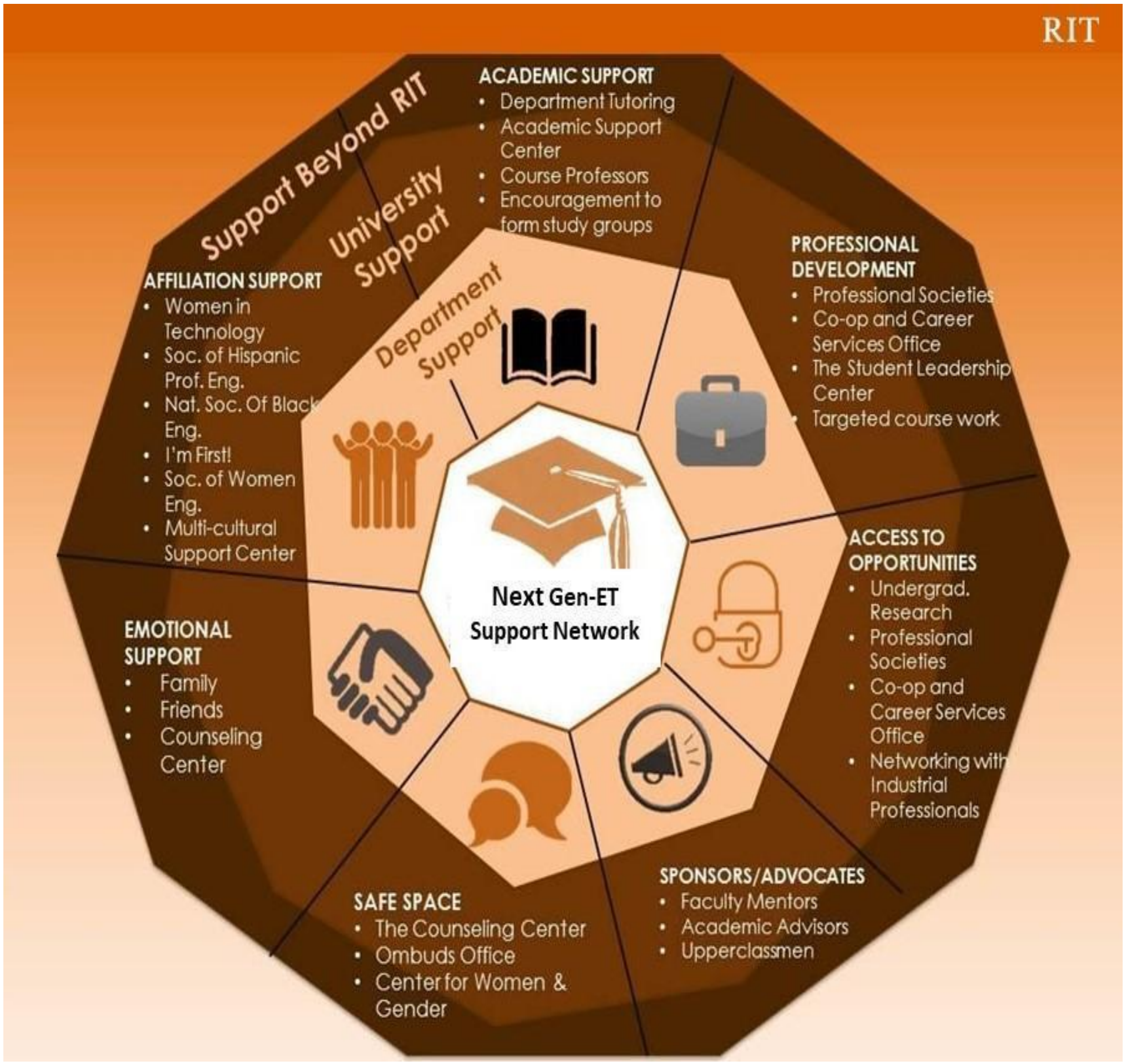
Studies have found that in order to counter these factors, actions in two separate areas, academic support and a supportive engineering community that provides a sense of belonging [23, 24] are needed. As such, a program based on SDT can help to mitigate the unwelcoming environment and increase persistence of engineering students. As such, comprehensive programming in the *Graduating the Next Generation of Engineering Technology Professionals by Promoting Competence, Group Identity, and Autonomy* project is two-fold. It is designed to not only develop relatedness, competence, and autonomy in the scholars but also to include faculty and help them to adopt pedagogy that is accessible to a wider range of learners with varied learning styles.

Programming

Programming in the *Graduating the Next Generation of Engineering Technology Professionals by Promoting Competence, Group Identity, and Autonomy* project falls into two categories. The majority of the effort is in support of promoting Self Determination in the scholars. We have developed a generalized student support network (SSN), as shown in Figure 1. This network includes project specific, department specific, university-wide, and external resources that are available to foster competence, relatedness, and autonomy in the scholars. As every scholar's needs are different, they are each assigned a faculty mentor and a peer mentor with whom they collaborate to create a personalized SSN and Individualized Development Plan, which are updated each semester based on the scholar's current needs. A mentoring protocol was developed to assist faculty with effective mentoring to promote competence, relatedness, and autonomy [25].

In addition to faculty and peer mentors, the project promotes relatedness through several other means. Each scholar participates in a one-credit seminar during their first semester. The goals of the seminar are to engage students in campus life, assist students in developing academic and personal success strategies, provide professional development, build an understanding of the field of engineering, and promote awareness and utilization of campus resources. In terms of relatedness, the seminar helps to create a community of scholars and provides a forum for connections to be made. Several times throughout the semester, students from the other cohorts

Figure 1: The NextGen ET Scholar Support Network



are invited to the seminar to further the community building process. Additionally, students are personally invited and encouraged to attend activities sponsored by the college's Director of Women in Technology, Community Engagement, and Student Diversity Initiatives, along with being introduced to and encouraged to join professional societies and groups related to their academic major and/or demographic representation.

Competence is enhanced by helping the scholars to develop a stronger understanding of their chosen engineering discipline. The program includes field trips to local companies engaged in engineering, where the scholars can see engineering in action and interface with professionals in their field. It also includes panel discussions with engineers from underrepresented populations. To further scholars' confidence in their knowledge of their field, they are required to complete one outreach project per year, which can include a STEM fair, assisting with a campus tour, or presentation to a high school technology class.

Programming to promote relatedness and competence also helps to nurture voice and agency to develop autonomy. In preparing scholars for outreach and professional interactions, one component of the professional development portion of the seminar is communication skills. Scholars are introduced to skills to communicate confidently with majority groups in their major, their professors, and potential employers. Prior to the university-wide career fair, scholars meet with a representative from the RIT's Cooperative education (co-op) and Career Center to learn how best to prepare and promote themselves.

While this project aims to increase self-determination in its participants, it also includes programming for faculty, especially those who work with first and second year students. Previous studies have found that the most successful support programs focus on changing industrial structures along with helping students [26]. Faculty in the College of Engineering Technology have received training in the importance of culturally responsive pedagogy and teaching for equity during college-wide retreats. Through encouragement from the project team, many have also participated in workshops put on by RIT's Division of Diversity and Inclusion. Another opportunity for faculty members in the College of Engineering Technology to reform their instruction is through yearly workshops sponsored through RIT's partnership with the Kern Entrepreneurial Engineering Network (KEEN). These workshops are focused on effective pedagogies, curriculum development, assessment, teamwork, and student mentoring and support. This project leverages the KEEN partnership to support the transformation of engineering technology classrooms to better serve a diverse student population. The framework of the KEEN approach to engineering education is developing an Entrepreneurial Mindset [27]. This framework promotes learning outcomes that cultivate curiosity, empower students to make connections, and promote value creation. These "3 C's" directly relate to the relatedness component of SDT.

Next Steps

In the fall of 2022, the program welcomed its third and final cohort of scholars. Each fall and spring semester, data is collected to measure the scholars' perceived competence, autonomy, and relatedness using a modified version of the Basic Psychological Need Satisfaction in General Scale (BPNS-G) [3, 28] adapted for college students in a similar manner to Jenkins-Guarnieri, Vaughn & Wright [29]. We continue to analyze these data to ensure that project programming results in increased self-determination. Three-year results from the first cohort of scholars will be ready for publication in the summer of 2023. For the third year, focus groups will be held in the spring of 2023, the results of which will drive programming for the 2023/2024 school year. Opportunities for faculty workshops through the KEEN network will continue to be offered throughout the academic year and the summer. In addition, a diversity speaker will be brought in for a workshop in the spring of 2023 and a college-wide survey of faculty will be conducted to help determine faculty programming for the remainder of the grant period.

Discussion

Both the ENGAgE and Next Gen-ET programs utilize evidence-based approaches to increase retention and graduation of diverse student groups in STEM. SDT and growth mindset serve as two distinct theories that have been implemented to center on supporting the success for academically gifted but economically challenged undergraduate STEM scholars. Both theories provide a framework under which students interact with each other and with faculty to be part of a supportive community focused on student success. The programming focuses on development of the scholars, the faculty serving as mentors, and faculty serving in instructional roles. Targeted scholar activities for both programs includes developing an understanding of college resources and career development sessions as well as specific tenets that are core to the theories. For example, ENGAgE scholars learn how to reframe experiences as growth minded and practice understanding that challenges are a stepping stone toward success. Next Gen-ET scholars develop agency and confidence while making connections with other scholars and their discipline.

In regards to faculty, both of the programs focus on their interactions with students and instruction rather than singularly placing the burden of academic success on students as has been observed in the past. For example, faculty in the ENGAgE project focus on reframing student challenges as opportunities to learn and move forward in their interactions with students. They impart this through their own choice of words in the classroom and the examples they present where mistakes are normalized rather than presented as anomalous failures. With Nex Gen-ET, faculty also learn about the importance of culturally responsive pedagogy and infusing relatedness in their classes through the KEEN framework that promotes curiosity, connections, and creating value [27]. Faculty mentors meet regularly with scholars to make connections between academics and career plans, understand available academic resources on campus, and serve as role models as a professional in their chosen fields. Faculty mentors intentionally use these meetings to develop a growth mindset in ENGAgE, sharing their own career hurdles and how they were managed. With the Next Gen-ET program, guided conversations promote relatedness, competence, and autonomy.

While each of the programs uses a unique theory to support student success in STEM programs, the approaches can be generalized to other domains. For example, faculty mentors and instructors can learn about and apply a growth mindset in their interactions with students in any domain - history, government, art, etc. Likewise, faculty can also support the key aspects of relatedness, competence, and autonomy in non-STEM domains. In this sense, students would experience an even more holistic approach toward their education, likely benefiting them to an even further degree as they move on a pathway toward their professional domain.

Conclusion

To meet the growing demands for well-educated technical workers, universities need to not only attract students into STEM disciplines but also to retain and graduate these students to become contributing members of the workforce. Both the ENGAgE and Next Gen-ET programs at RIT integrate evidence-based approaches to increase the retention and graduation of STEM students, particularly underserved students in STEM. The next steps will look at evaluating the effectiveness of current programming with the intention of continuous improvement and understanding student success.

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