Push and Pull: Exploring the Engineering Retention Problem for Underrepresented Groups and Gauging Interest in Interdisciplinary Integration into Undergraduate Curriculum

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Abstract

Underrepresented minorities (URMs) leave the engineering field at a rate significantly higher than average. Researchers conclude that low self-efficacy, lack of support, and hostile and benevolent discrimination are contributing causes. We contend that URMs' lack of retention in engineering is due to a push by these causes, as well as a pull towards fields that more closely align with their identity. To explore further, a Qualtrics survey instrument was developed to understand the experiences of people who have fully or partially left the engineering field. We surveyed 47 URM and 38 non-URM participants at various stages of their careers, and found that when URMs leave the engineering field for a non-engineering career, they not only face less bias and discrimination, but also feel as if they are more positively impacting the world. We suggest some methods for retaining URMs in engineering by leveraging interdisciplinary studies to offer better identity coherence by incorporating complex, impactful problem solving into their fields. All participants, especially URMs, expressed interest in the following methods of introducing interdisciplinary aspects to engineering: (1) promoting interdisciplinary internships and intracollegiate research, (2) a revised first-year curriculum to introduce meaningful interdisciplinary-based projects, and (3) facilitation of accelerated bachelor's/master's degree programs across different disciplines.

Introduction

In the present day, exclusion from higher education is present on the basis of many demographic factors. Black, Latino/a, and Native American students are underrepresented across all majors [1]. Women are slightly overrepresented in higher education overall, but severely underrepresented in engineering and computer science fields [2]. LGBTQ+ individuals are also underrepresented across all majors [3], but this disparity is even stronger in science, technology, engineering, and mathematics (STEM) fields [4]. This lack of diversity has negative implications for the engineering field, which is characterized by teamwork and collaboration [5]. Teams with high gender and ethnic diversity have a more complex collective knowledge base [6], resulting in improved ability to solve today's complex problems. Ensuring that everyone is represented in the engineering field also promotes social justice by interrupting patterns of unjust social inequality [7]. Finally, diversifying the workforce now will result in an expanded talent pool, and ultimately better long-term scientific and economic growth for the world [8].

Despite recent efforts to combat the lack of diversity in engineering, it has remained an issue. The National Society of Black Engineers (NSBE) reports that only 29.7% of Black students who enter engineering graduate with an engineering degree within six years [9]. Comparatively, the average retention rate in engineering across all races is approximately 50% [10], [11]. Similarly, despite comprising 31% percent of the population, fewer than 20% of engineering degrees are awarded to minority students [11]. Moreover, even after obtaining bachelor's degrees in engineering, URMs flee the field at staggering rates, perpetuating the lack of diversity in the

field [12]. The National Center for Education Statistics reports that Black, Hispanic and Native American people make up 21% of science and engineering bachelor's degree recipients – yet, this population only makes up 11% of science and engineering employment [13].

Improving the retention of URMs in engineering has been the focus of many research efforts [14]. Since poor academic performance is a large cause for high attrition, one method of improving retention is to better prepare students for coursework through summer bridge programs [15], engineering support centers [16], and supplemental instruction [17]. These programs not only allow minority students to overcome academic hurdles, but they also improve their sense of belonging by creating communities, which leads to higher success in completing their stem degree. Nevertheless, these efforts are largely limited by a lack of institutional funding. Moreover, these programs are mostly driven by student commitment, thus placing the burden on students, which is problematic for an already disadvantaged population. Mentoring has also been shown to improve the technical, professional, and soft skills necessary to succeed in an engineering field [18]–[20]. Mentoring aids in the transition to university, which reduces first year attrition. However, it has been shown that women in engineering may struggle to access mentoring networks because of reinforced masculine discourses [21]. The lack of diversity in engineering also limits the number of available mentors, often leaving large mentor to mentee ratios, which can lower the efficacy of the mentoring. Mentors are rarely compensated, which further increases tokenism and the unpaid labor load of URMs [22]. Another common effort is offering scholarships to URMs, which promote the access to education [23]. These scholarships, however, initially lower the barrier to higher education but do not support the continued success of URMs. In addition, these scholarships are only awarded to select URM students, thus the solution is not wholistic in retaining URMs. Hence, we seek to find alternative methods to improve URM retention that can be offered to everyone at an institution level.

The lack of retention in engineering may be partially explained by people's initial reasons for entering the field. Although many students are motivated by genuine interest in engineering fields, it is common for students to lack an understanding of what an engineering career involves [24], or to be motivated by earning potential, job availability, and parental pressure [25], [26]. The strong prevalence of extrinsically-motivating factors in engineering students may be tied to low retention. URMs in engineering face additional unique struggles, such as discrimination, prejudice, and bias, as well as a lack of role models and mentors [27]. Black and Latina women engineering students report feeling undermined by accusations of being an "affirmative-action baby" – causing them to question whether they are academically qualified [1]. Harmful stereotypes associate LGBTQ+ individuals with a lack of technical competence. Therefore, LGBTQ+ students find themselves attempting to "pass" as straight or working harder to "prove" themselves to their peers, resulting in a hostile environment [28], which can even lead to negative impacts on students' mental and physical health [29]. As a result, Estrada et al. [30] found that URM students do not integrate into the scientific community at the same rate as non-URM students. When URMs do integrate into the scientific community, such as by forming study groups, participating in undergraduate research, and getting involved in clubs or organizations, their likelihood of completing an engineering degree increases [9], [31]. URMs

who leave engineering fields cite a lack of sense of belonging or engineering identity, further demonstrating the importance of becoming integrated into the field [32]–[35].

Beyond factors such as these that push URMs away from engineering, research has indicated that URMs may be pulled towards other careers, particularly by an interest in altruistic and socially-relevant work, which can be difficult to fulfill in a STEM field [36]. Garibay et al. [37] found that URMs value "working for social change" in their career more than majority students. Similarly, Gibbs and Griffin [38] evaluated recent PhD graduates interested in pursuing academia and concluded that URMs were more likely to feel driven by a desire to help their community or serve as a role model. Moreover, they found that URMs were also more likely to eventually leave academia in order to pursue careers that aligned with their social identities that had larger impact on their communities. Thoman et al. [39] also concluded that URM undergraduates studying STEM value altruistic work more than majority students. Thus, we contend that URMs' lack of retention in engineering is a combination of push and pull factors: a push away from technical engineering fields with which they experience discrimination and poor sense of belonging, and a pull towards more altruistic fields with the appeal of more socially impactful work.

Hypothesis

Interdisciplinary studies can be defined as the co-learning between different fields to realize advancements in uncharted problems [40]. Despite the historical lack of respect afforded to arts and humanities by the engineering field [41], the integration of engineering and non-engineering fields is more critical than ever in order to solve today's complex problems [40], [42], [43]. For example, human-computer interaction (HCI) research merges the studies of computer science, psychology, and design to improve user experiences with technology. The benefits of interdisciplinary studies in engineering education have been well-reviewed. Most report that interdisciplinary study improves communication skills and allows for diverse perspectives, thereby establishing higher levels of critical thinking [40], [42]. We hypothesize that interdisciplinary studies can also be used to improve URM's retention in engineering. As reported above, URMs often feel both a lack of belonging and a desire to pursue altruistic work, which may contribute to them leaving engineering. We hypothesize that URMs in engineering experience both a push away from engineering and pull towards other fields in a way that is unique to URMs. If this hypothesis is supported by data, we believe that this push-pull effect may be attenuated by exploring interdisciplinary studies at the intersection of engineering and other fields, which may offer better identity coherence and allow the pursuit of more fulfilling careers. In this report, we will evaluate URMs' and non-URMs' engineering and non-engineering identity to understand its influence on attrition. Then, we will gauge URMs' level of interest in interdisciplinary studies through a variety of proposed solutions. Future work should involve the implementation and evaluation of the effectiveness of these solutions.

Methodology

Data was collected using an IRB-approved Qualtrics survey instrument, distributed online. First, participants filled out demographic information, including their age, gender, race/ethnicity, sexual orientation, and level of education. Next, they listed the initial engineering field and

secondary non-engineering field that they pursued education or a career in, then provided information about the point in their career in which they made the transition to their secondary field. Participants then reported the factors that led them to choose each of the two fields. This section was multiple choice rather than free-response, in order to reduce the study time, increase response rates, and expedite data analysis. Choices were developed based on findings from various works investigating career choice reasons [44]–[46], and can be seen as the y-axis labels in Figure 1. Similarly, they reported the factors that led them to leave their engineering field. The same factors were available for them to choose from, with the addition of "experienced discrimination." Finally, participants responded to questions describing their identity as a member of each of the two fields. They used a 1-5 anchored Likert scale to assess their level of agreement with statements, such as "I have felt unwelcome in the field," and "My work positively impacts the world," which are designed to investigate push and pull factors, respectively. The identity questions were based on existing self-efficacy [47] and engineering identity frameworks [48], and a full list of the statements can be found in Table 1. Because engineering identity and self-efficacy are closely tied to retention rate [32]–[35], these results allowed us to quantify the influence of push-pull factors on URMs' retention or attrition.

The subject recruitment site Prolific [49] was used to distribute the Qualtrics survey to participants who had previous employment in an engineering sector, but were currently employed in a different field. Participants were paid $1 for completing the survey, which took an average of 5 minutes to complete. Consent was obtained from all participants, and the study was conducted under the guidance of the Institutional Review Board at the Georgia Institute of Technology. Overall, 112 participants completed the survey. However, 27 responses were found to not meet the survey criteria, meaning that the participant had not fully or partially transitioned from an engineering field to a non-engineering field. Of the 85 remaining responses, 52 were men and 33 were women. When asked to describe their sexual orientation, 68 participants identified as straight or heterosexual, 8 identified as gay or lesbian, and 7 identified as bisexual. While the majority of participants (51) were White, 19 were Asian, 4 were Black or African-American, 5 were Hispanic or Latino, and 5 identified as more than one race. Because people in engineering fields are marginalized based on gender identity and sexual orientation, this paper expanded the National Science Foundation's definition of URMs in engineering [13] to include non-heterosexual, non-Asian or White, non-men. Using this definition, there were 47 URM and 38 non-URM participants in total. All participants, 27 of which were first-generation college students, had either completed or were currently enrolled in tertiary education. Of the participants who had completed a degree, 37 held bachelor's degrees, 21 held master's degrees, and 5 held PhDs. In addition, 22 participants were currently enrolled in school, with 6 pursuing a bachelor's degree, 11 pursuing a master's degree, and 5 pursuing a PhD.

Results and Discussion

Figures 1a and 1b summarize the reasons that participants reported for choosing their career fields. The most common factor leading people to choose engineering was a genuine interest or passion for the field, followed closely by high earning potential and job availability. Interestingly, a *lack* of interest or passion was also the most common reason that participants reported for leaving engineering, in addition to a lack of sense of belonging and the academic

rigor of the field. Current trends show that despite understanding the importance of engineering, few people understand what engineers actually do [24]. This may lead to an initial interest in engineering that is lost after actually becoming involved. URMs also reported that discrimination and a lack of belonging was a significant factor in their decision to leave engineering, as shown in Figure 1c, which was expected due to the previously-discussed push factors. The genuine interest or passion once again played the top role in participants' choice of their secondary non-engineering field. However, participants were less motivated by earnings and job availability than they were when choosing an engineering field, instead reporting that their desire to have an impact on society and "make a difference" was a key factor in their choices, with URMs placing higher emphasis on these factors.

To analyze the results of the Likert scale identity questions, two-way ANOVA testing was performed in RStudio. Because identical sets of questions were asked about both the engineering and non-engineering field, ANOVA could be used to understand and directly compare the participants' identity and experience in each field. Table 1 shows the results of the ANOVA testing. The two independent variables under investigation were the engineering vs non-engineering field responses (labeled as "Field") and the responses from URM vs non-URM (labeled as "URM Status"), as well as the influence of the two variables ("Field" and "URM Status") on each other (labeled as "Interaction"), while the dependent variable was the participants' response to each statement on the 1-5 Likert scale, with 1 indicating low agreement and 5 indicating high agreement.

As shown by the significance of the Field variable in Table 1, all participants reported a higher sense of belonging ($p < 0.001$), identity fit ($p < 0.001$), self-confidence ($p < 0.001$), and fulfillment ($p = < 0.001$) in their secondary non-engineering field compared to their initial engineering field. Additionally, participants were more likely to have a mentor ($p < 0.001$), perform well academically ($p = 0.012$), and participate in related extracurricular activities ($p = 0.003$) in their secondary field. These trends, which were present across all participants, were an expected finding of the study: participants who left the engineering field and currently work in a different field are likely to feel negatively about engineering and more positively about the new field.

Comparing URMs and non-URMs directly allows us to focus on the hypothesis of this paper. To focus on the URMs, we looked for significant results among the URM Status and Interaction variables in Table 1. URMs were more likely than non-URMs to experience discrimination ($p < 0.001$), bias ($p < 0.001$), low self-confidence ($p = 0.003$), and feel unwelcome ($p < 0.001$) in any career field. However, when URMs switched from an engineering field to a non-engineering field, each of these four negative sentiments lessened significantly ($p = 0.014$, $p = 0.030$, $p < 0.001$, $p < 0.001$, respectively). In addition, interaction effects showed that URMs felt that they could make more of a positive impact on the world in their secondary field compared to their engineering field ($p < 0.001$), while this trend was not significant for non-URMs. This finding is extremely important as it proves the presence of a push *and* pull effect on URMs in engineering – not only are they pushed away from engineering by discrimination and bias, but they are also pulled towards non-engineering fields by a desire to positively impact the world that may be

difficult to reconcile with STEM work, as posited by McGee and Bentley [36]. The discovery that this effect is only significant among URMs is also notable.

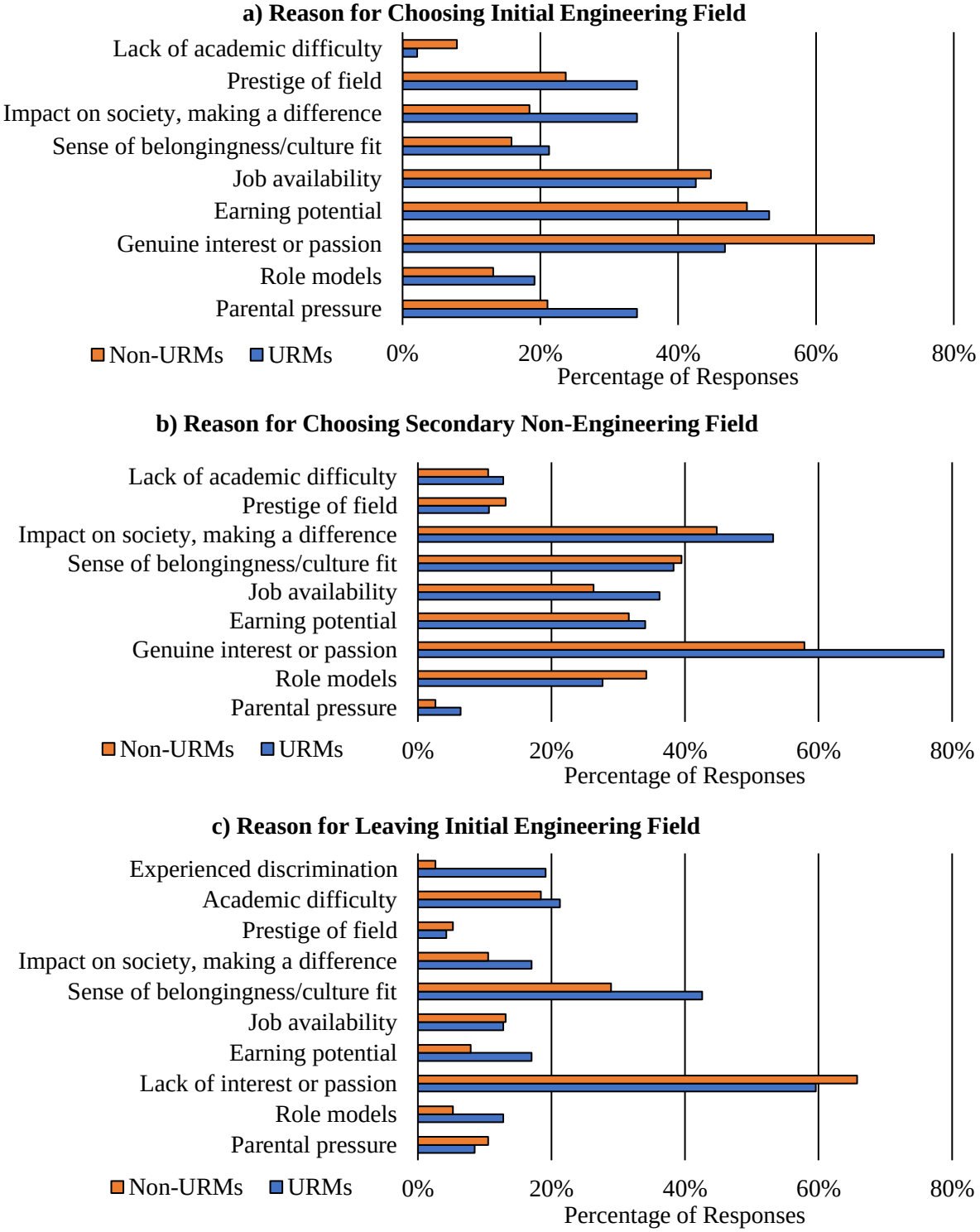

Figure 1. Reasons given by participants for (a) choosing their initial engineering field, (b) choosing their secondary non-engineering field, and (c) leaving their initial engineering field

*Table 1. Results of two-way ANOVA testing on career field and URM status (a significance level of $\alpha = 0.05$ was used and denoted by *, while † denotes factors that were explored further in post-hoc t-testing)*

In the field, I…	Variable	Test Statistic	Significance
Have a sense of belonging	Field	39.473	< 0.001*
	URM Status	0.041	0.839
	Interaction	2.210	0.139
Have a mentor	Field	19.320	< 0.001*
	URM Status	0.098	0.754
	Interaction	1.518	0.220
Social network with others in field	Field	2.277	0.133
	URM Status	2.157	0.144
	Interaction	0.153	0.696
Experience discrimination from others in the field	Field	2.559	0.112
	URM Status	20.996	< 0.001*
	Interaction	4.888	0.028*
Have a positive impact on the world	Field	23.097	< 0.001*
	URM Status	0.381	0.538
	Interaction	3.318	0.070†
Have felt unwelcome in the field	Field	19.350	< 0.001*
	URM Status	18.210	< 0.001*
	Interaction	10.580	0.001*
Experience bias	Field	1.715	0.192
	URM Status	18.870	< 0.001*
	Interaction	3.257	0.073†
Lack self-confidence	Field	36.296	< 0.001*
	URM Status	8.843	0.003*
	Interaction	0.974	0.325
Feel that my identity fits in the field	Field	39.374	< 0.001*
	URM Status	1.475	0.226
	Interaction	1.651	0.201
Get a sense of fulfillment from work	Field	44.877	< 0.001*
	URM Status	0.295	0.588
	Interaction	0.806	0.371
Perform well academically	Field	6.426	0.012*
	URM Status	2.821	0.095
	Interaction	0.014	0.908
Participate in extracurriculars	Field	9.080	0.003*
	URM Status	0.592	0.443
	Interaction	0.103	0.749

Proposed Solutions

The purpose of the survey was to gain an understanding of why people, especially URMs, leave engineering to pursue other fields by comparing their engineering identity with their new field identity. Results showed that all participants felt their identity aligned more closely with their non-engineering field. In particular, URMs transition to non-engineering fields to escape bias and discrimination, as well as to fulfill a desire to positively impact the world. According to our survey results, the majority of URMs (55%) left engineering during their undergraduate degree, which is why our solutions focus on improving the undergraduate experience. All students, not just those at risk of leaving engineering, can benefit from learning from interdisciplinary studies since it addresses complex problem solving [40], [42], [43]. In fact, over one-third of scientific publications are classified as interdisciplinary, truly emphasizing its relevance to all engineers [42]. Moreover, we believe that incorporating interdisciplinary elements early in undergraduate engineering curricula will lead to a higher sense of belonging for URMs in the engineering field, as well as the ability to benefit the world through more complex problem-solving. We have developed several recommendations for integration of interdisciplinary studies into engineering programs, detailed below. In order to compare URM and non-URM interest in the recommendations, we surveyed the previous survey participants' interest in the solutions from a scale of 1 (extremely disinterested) to 5 (extremely interested).

First, we recommend the introduction of interdisciplinary projects that address relevant social issues into undergraduate engineering curricula. Incorporating the National Academy of Engineering's Grand Challenges [50] or the United Nations' Sustainable Development Goals [51] as part of class projects would allow engineering students to participate in more impactful problem-solving. As shown in Figure 2, this proposal was viewed favorably by the participants in this study. It is also supported by suggestions from McGee and Bentley [36] to emphasize how engineering can serve humanity in order to make engineering careers more desirable for URMs.

Next, we recommend that universities establish research opportunities between colleges in order to support interdisciplinary research into fields such as human-computer interaction or design cognition. These research opportunities would help retain URMs by bridging engineering studies with fields they feel a strong pull towards. Participation in undergraduate research, especially research of an altruistic nature, has been purported to contribute to a sense of STEM identity, and thereby retention, in URMs [39], [52]. In addition to providing opportunities to socialize with other like-minded students, this would provide students with the opportunity to receive mentorship from faculty members, which is tied to higher engineering persistence [32]. As indicated in Figure 2, all participants expressed interest in interdisciplinary research.

Similarly, we suggest that universities join forces with industry partners to offer and effectively market interdisciplinary internships, especially towards URMs. Internships have been shown to increase retention and graduation rates for engineering students [53], particularly URMs [54], making them a promising setting for interdisciplinary collaborations. For example, Indeed has listings for internships in interdisciplinary engineering fields such as Framework and Behavior for Human AI Training, Energy Economist, Intellectual Property, and more. Introducing or leveraging existing co-operative education programs focused on these areas would allow students to explore different fields in and outside of the classroom. These opportunities could be

closely tied to engineering, such as the above listings, or loosely tied, such as social science research, which can later aid in pursuing careers such as HCI. Both options allow students to explore the use of their degree and find a higher sense of belonging that encourages retention within engineering. As shown in Figure 2, survey participants expressed interest in these opportunities, with URMs expressing significantly higher interest than non-URMs ($p < 0.001$).

Likewise, both populations also showed interest in our fourth proposed solution, accelerated interdisciplinary Bachelor's and Master's degrees, with URMs again expressing significantly higher interest than non-URMs ($p = 0.003$). Although all engineering students would benefit from these proposed programs, we feel that they are especially promising for increasing retention of URMs.

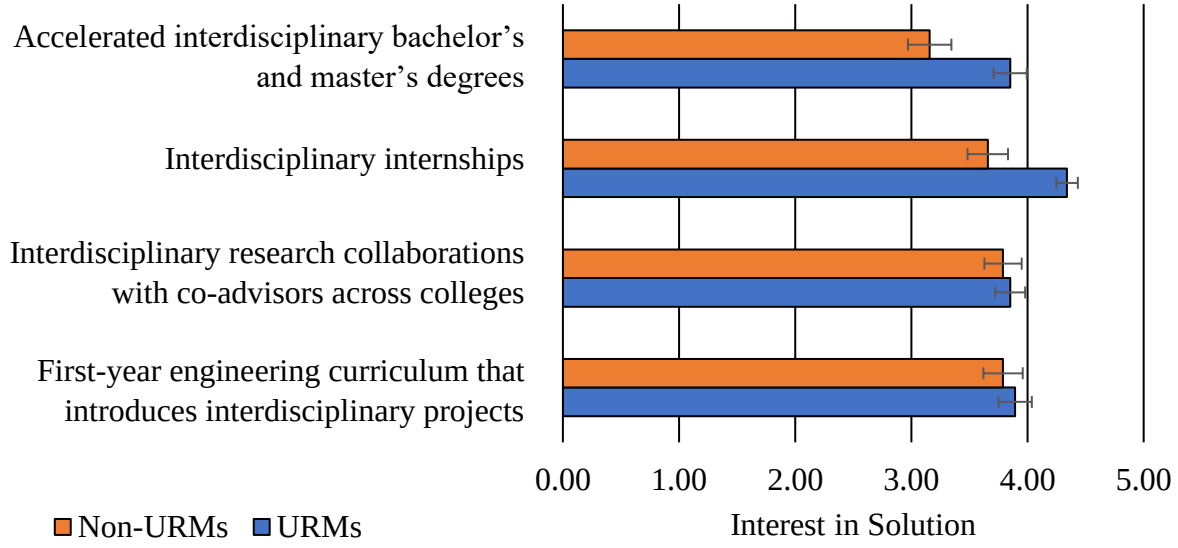

Figure 2. Level of interest in various proposed methods of integrating interdisciplinary work into engineering education. Higher values indicate higher interest. Error bars indicate ±1 SE.

Limitations

Underrepresented minorities were not specifically targeted through the Prolific recruitment filters, due to a desire to reach a sufficient sample size to perform quantitative data analysis. Additionally, one of the goals of this work was to compare the identity and motivations of URMs and non-URMs, so this was an effective method of recruiting people from both groups. Although URMs comprised the majority of the study participants, many of the URMs in this study were included on the basis of gender, with underrepresented racial minorities being, once again, underrepresented. Of the 47 URMs in this survey, 33 were women, 13 were underrepresented racial minorities (not White or Asian), and 15 identified as not heterosexual. Future work should include targeted recruitment of underrepresented racial minorities in order to ensure that their needs are adequately represented in research. In addition, the participants were only recruited from a population of those who originated then left engineering. Because of this, it is possible that participants felt more positively about their non-engineering field, which may influence the

results of the Likert identity test. Future work could include comparing the motivation of URMs who persist in engineering to those who matriculated out.

Although the survey tool used in this study collected data on both push and pull factors, proposed solutions mainly focused on integrating the appealing aspects of pull factors into engineering, rather than reducing factors within engineering that push URMs away. Although this problem is already well-studied, we feel that it is important to reiterate some recommendations. Implicit bias training should be required for anyone involved in engineering, and should particularly focus on microaggressions [1] and other factors that lead to marginalization of URMs. The lack of diversity is a self-fulfilling prophecy from the self-efficacy standpoint: when URMs don't have successful role models to look up to, their self-confidence is negatively impacted, resulting in a lack of retention. In order to provide vicarious experiences for early-career engineers, URMs must not only be present in engineering, they must be visible and successful without being tokenized. There are many other proven techniques and studied interventions for reducing the pushing of URMs out of engineering.

Conclusion

Despite the limitations listed above, this paper presented important findings for the retention of underrepresented minorities in engineering. First, we compared the motivations of majority and URM students for entering and leaving engineering. As we hypothesized, we found that underrepresented minority students leave engineering not only as a result from being pushed away from the field by bias and discrimination, but also due to a pull from other fields where they feel that they will be able to positively impact the world. We suggested that interdisciplinary studies should be utilized to form a partnership between engineering and other fields with greater opportunities to impact the world. Accordingly, we proposed innovations to undergraduate engineering programs to integrate interdisciplinary studies and retain URMs, such as interdisciplinary internships, first-year project-based coursework, research collaborations, and an accelerated interdisciplinary Bachelor's and Master's degree program. Preliminary feedback from survey participants showed that while all participants expressed interest in these opportunities, URMs were especially interested in the interdisciplinary internships and Master's degree. These ideas are promising not only to benefit engineering retention as a whole, but also to begin to close the retention gap for underrepresented minorities in engineering. Our results support our hypothesis, suggesting that interdisciplinary studies are appealing to URMs and may help alleviate the push-pull pressure by bridging engineering with careers they better identify with. These interdisciplinary interventions have not yet been implemented or assessed for actual impact on URM recruitment and retention.

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