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Diversity and Inclusion in Mechatronics and Robotics Engineering Education

Dr. Christopher Pannier, University of Michigan-Dearborn

Christopher Pannier is an assistant professor in Mechanical Engineering at the University of Michigan-Dearborn. His research is in the application of control theory to additive and other advanced manufacturing processes to improve performance, reliability, and sustainability. He received a PhD in Mechanical Engineering from the University of Michigan, Ann Arbor and a BS in Nuclear Engineering from Texas A&M University.

Dr. Carlotta A Berry, Rose-Hulman Institute of Technology

Dr. Carlotta A. Berry is a professor in the department of Electrical and Computer Engineering at Rose-Hulman Institute of Technology. She is the director of the multidisciplinary minor in robotics and co-director of the Rose building undergraduate diversity scholarship and professional development program. She has been the President of the Technical Editor Board for the ASEE Computers in Education Journal since 2012. She is a member of ASEE, IEEE, NSBE, and Eta Kappa Nu.

Dr. Melissa Morris, Embry-Riddle Aeronautical University

Melissa is an assistant professor at Embry-Riddle Aeronautical University in the Department of Engineering and Technology of the College of Aeronautics. She is specialized in mechatronics and robotics and also has a deep interest in promoting STEAM education rounded with professional skills and ethics. She earned her PhD in Mechanical Engineering from Florida International University, MS in Mechanical Engineering with Bionengineering from Florida Atlantic University, and a BS in Electrical Engineering from Florida Atlantic University. She has industry experience with the Ford Motor Company of Europe and the Sensormatic Corporation. She also has experience at the Technion - Israel Institute of Technology, Florida Polytechnic University, and automotive and robotic companies in the Detroit area.

Dr. Xiaopeng Zhao, University of Tennessee, Knoxville

Dr. Xiaopeng Zhao is a professor of mechanical, aerospace, and biomedical engineering at the University of Tennessee, Knoxville. He received BS and MS degrees in engineering mechanics in 1996 and 1999 respectively from Tsinghua University, China. He received Ph.D. in engineering science and mechanics in 2004 from Virginia Tech. He worked as a postdoctoral research associate in biomedical engineering at Duke University in 2005-2007. Dr. Zhao joined the Department of Mechanical, Aerospace, and Biomedical Engineering at the University of Tennessee, Knoxville in 2007 and has become a full professor since 2019.

Dr. Zhao's research interest is focused on computational neuroscience and brain-computer interface. Dr. Zhao is a recipient of National Science Foundation CAREER award. His group has developed award-winning algorithms for physiological signal analysis and enhancement. Dr. Zhao has developed EEG-based diagnosis methods for detection of early Alzheimer's disease and traumatic brain injury. He has also designed and developed EEG-based brain computer interface platforms for neurorehabilitation and neurofeedback.

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Introduction

Mechatronics is described as "a philosophy in engineering technology in which there is a coordinated, and concurrently developed, integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes" [1]. Robotics expands upon mechatronics with emphases on perception, action, and interaction of robots. As a discipline at the intersection of traditional engineering disciplines, "mechatronics and robotics engineering" (MRE) is fast-growing and future-minded but suffers similar diversity and inclusion challenges as engineering broadly. This paper explores these challenges and identifies unique opportunities inherent to MRE to 1) increase the participation of women and underrepresented minorities (URM) in MRE, and 2) use MRE to increase the participation of women and URM in science, technology, engineering, and mathematics (STEM) broadly. This paper resulted from the Fourth Future of Mechatronics and Robotics Education (FoMRE) Workshop held September 27-28, 2019 at Lawrence Technological University in Southfield, Michigan. This workshop was the final in a series of National Science Foundation (NSF)-supported academic and industrial workshops in a project that aims to define and promote the concept of MRE as a distinct engineering discipline, build a community of MRE educators, and promote diversity and inclusivity within the MRE community [2]. The project leaders write:

> "Our vision is that MRE will become one of the most impactful disciplines of engineering; attracting diverse and innovative students, graduating professional engineers who will design, develop, and implement transformative autonomous technologies, and improving health and welfare sectors while extending human reach to previously inaccessible realms large and small, near and far." [2]

This paper advances the discussions on diversity and inclusion (D&I) in MRE at the 4th FoMRE workshop with a literature review, workshop findings, and findings from an online survey to the MRE community in the United States. The scope is limited to participation of women and URM at the college level (two-year and four-year degree programs), a level at which little is found in the academic literature specific to diversity and inclusion in MRE.

The level of women and URM participation in MRE at the college level influences the level of their participation in industry after they graduate. It is widely believed that a diversity of insights and experiences on an engineering design team creates better ideas and better results. Furthermore, a design team benefits greatly from experiences related to those of its product's end users. While a diversity of insights and experiences is difficult to quantify and analyze, demographic diversity is simple to quantify and correlates with diverse insights and experiences. A further argument is often made regarding the importance of equity in participation, including fairness, opportunity, and achievement by people from different groups. Equity in participation becomes especially pertinent to this paper in discussions of role models and feedback loops for participation. It is common to see the concepts "diversity" and "inclusion" discussed with the addition of "equity," in the triplet "diversity, equity, and inclusion." While this paper touches on equity issues, it does not explore them in depth. The title and scope of this paper follows from the 4th FoMRE workshop session titled "Diversity & Inclusion", and the authors encourage further investigation of educational equity in MRE in future work.

In 2018, women earned 21.9% of the bachelor's degrees awarded in engineering and URM earned between 19.1% and 23.3% of the bachelor's degrees awarded in engineering that year [3]. This is despite women making up 52% of the population and URM making up 28% of the noninstitutionalized resident population of the United States ages 18 to 64 (2017 data) [4]. Therefore, there is a 30-percentage-point gap between women's share of engineering bachelor's degrees and of the US population and a corresponding 5- to 9-percentage-point gap for URM, demonstrating large opportunities for increased representation and diversity in engineering education and the workforce. Further note the size of these gaps relative to each group's share of the US population. A gap of 30 percentage points for women is more than half of the 52-percentage-point share of the US population and a gap of 5 to 9 percentage points for URM is about a quarter of the 28-percentage-point share of the US population, as shown in Figure 1. Note that the definition of URM in the US for this work is Hispanics, African Americans, Native Americans, and people of mixed race that includes at least one of the preceding groups.

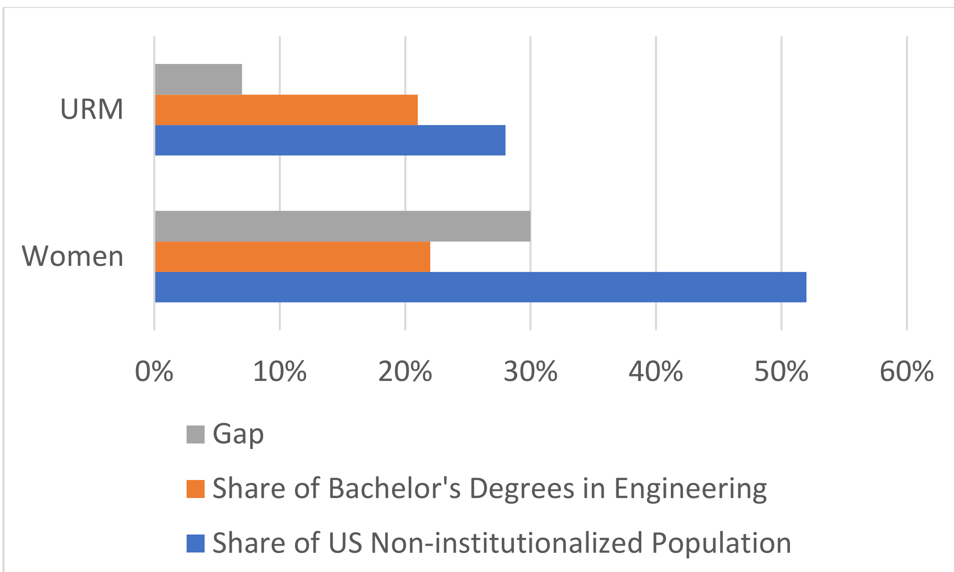

Figure 1 A bar chart of the percentage point shares of URM and women in engineering degrees and population and the percentage point gap between the two.

Also note that there have been improvements in the representation of women in engineering over recent years. Data shows that women earning degrees in engineering increased from 17.7% to 19.9% between 2012 and 2017 [5]. However, the rise has been small given the major efforts to close the gap. This paper seeks more fruitful efforts toward creating a more diverse and inclusive workforce in engineering, particularly in MRE through educational interventions. The paper presents literature, workshop, and survey findings regarding the current status and ideas for improvements. This lays the foundation for future work to understand and improve the participation of women and URM in MRE through educational interventions. This paper is organized into a literature review, methods and findings of the workshop session, methods and findings of the online survey, a discussion of the findings, and a conclusion.

Literature Review

In order to provide justification for this work and identify what others have done with respect to diversity and inclusion in MRE education, the authors performed a literature review. There is a plethora of information about the need for diversity and inclusion but unfortunately, there was a dearth of information at the college level (2- and 4- year degree programs). However, it was possible to find many great resources at the K-12 level that address using robotics and mechatronics to increase diversity and inclusion in STEM. For example, the FIRST Robotics programs were the most prevalent and have been shown to prepare students for greater success in the STEM classroom and workforce [6]. Brandeis University Center for Youth and Communities did a five year longitudinal study of the FIRST program and found that young women in high school and college who participated in these programs have made significant gains in STEM areas such as interest, career, activity, knowledge, and identity compared with peers not in the program [6]. These young women are also more likely to major in engineering or computer science or take more courses in these areas. Peixoto et al. examined techniques to use robotics for inclusion and integration of students in engineering as well [7, 8]. Peixoto et al. surmised that robotics is ideal for diversity, inclusion, and integration of students because it is a tool for developing STEM pedagogy. The STEM pedagogy is developed because robotics promotes innovation, guided discovery, inductive learning, and constructivism. Engagement with robotics also improves student motivation and competencies such as communication, teamwork, leadership, problem solving, resilience, and entrepreneurship [7,8].

The question of why diversity and inclusion in MRE education is important has been asked for many years, and two of the leading women in social robotics, Maja Mataric and Cynthia Breazeal, answered this question in an interview with the Wall Street Journal in 2016 [9]. Mataric and Breazal stated that the key to drawing in women innovators is to show them how the work they do will impact the world. They stated that it is important to engage developers of all genders and ethnicities because innovation is a personal, experience-driven pursuit. Breazeal stated that people work on things that have a deep significance to them, so if developers come from a diversity of backgrounds and sensibilities, their innovations will have a greater impact on the world. Nichols states that the culture of robotics changed between 2008 and 2018, and due to the rapid change in technology, it will continue to change [10]. However, in the past, due to the expense, technical challenges and programming language complexity, roboticists were very specialized, and the workforce reflected the very limited persistent stereotype of an engineer. This stereotype was that the majority of people who work in robotics, engineering, and computer science are white males. Due to these challenges, women and minorities became severely underrepresented in robotics. Recently, the prevalence of free and open-source software and hardware designs and low-cost makerspaces has made robotics more accessible to broader populations. This broader community of roboticists and developers has challenged the stereotypes. The increased access to hardware and software resources creates a vision for the future that makes MRE more accessible and therefore more diverse. Greenemeier states that robotics has long had diversity issues due to "too much diversity among the robots and not enough diversity among the engineers designing them" [11]. One consequence of the low diversity is that artificial intelligence algorithms including those on robots tend to reflect the inherent gender and racial biases of the developer.

One university that used robotics in order to inspire women to participate in computer science was Spelman College [12]. Spelman is a historically black liberal arts college for women in Atlanta, GA. Spelman addressed the lack of African American women in computer science by using autonomous robotics to raise awareness and interest. In 2005, the Spelbots became the first all-women African American team to participate in RoboCup. Williams and O'Banner conjecture that the right resources, which include robotics curricula and appealing robots, will inspire women and African American students to pursue robotics education. Therefore, Spelman offered workshops to students and faculty. In fact, due to the success of the Spelbots, robotics training was expanded to other historically black colleges and universities (HBCU) and Carnegie Research I institutions through the NSF ARTSI (Advancing Robotics Technology for Societal Impact) project [13]. The goal of the ARTSI alliance was to increase the number of students from underrepresented groups that pursue advanced training in computer science. The mission of this program was to give research and education opportunities to students from non-traditional backgrounds by studying robotics in an area that is applicable to society. One way to benefit society was to conduct outreach to raise awareness about African American achievements in robotics. In this way, the alliance could recruit more diverse students into the STEM pipeline. This program seeks to increase the pipeline by building confidence and skills and ultimately preparing students for graduate work in robotics or computer science. Boonthum-Denecke et al. also propose that although robotics is interdisciplinary, it should be taught differently to computer science versus mechanical or electrical engineers. One difference is whether the course is taught in simulation or with physical hardware. The results of the ARTSI alliance was that 300 HBCU students were served, there were 51 research experiences for undergraduates (REU) internships, 23 HBCU faculty were trained, and workshops were held for 1,450 K-12 students. There were also 10 students who went on to graduate studies.

Methods: Workshop Session

The Fourth FoMRE Workshop was held September 27-28, 2019, a Friday afternoon and Saturday morning, at Lawrence Technological University in Southfield, Michigan. The 43 attendees included 11 professionals from industry, 31 faculty or instructor attendees from 28 US colleges and universities, and one attendee from a US community college. The "Diversity & Inclusion" breakout session was held on Friday afternoon for 45 minutes. Discussions were held in 3 to 5 breakout table groups with mixed industry and academia representation, each group summarized its discussion on poster-sized sticky notes and a representative from each table presented the table's findings to the whole body at the end of the session. The posters were photographed for all tables and notes were taken during the discussions. The authors of this paper do not have notes from every table group.

Findings: Workshop Session

Here, we make a high-level summary of the discussions in diversity and inclusion at the workshop. The workshop attendees expressed beliefs that promoting diversity and inclusion is a responsibility of MRE educators. The participants of the workshop recognized that diversity is important to industrial workforces and recommended the engineering industry recruit a diverse workforce. The participants recommend developing training programs to increase the awareness of the need for diversity and inclusion (D&I) at corporate management levels.

The marketing of MRE programs was discussed with regards to promoting D&I in MRE education. The FoMRE workshop included a presentation by Dr. Tom Lee from the MRE educational hardware company Quanser about reimagining the educational concept of a makerspace—where students learn by building systems from granular, often hobbyist components to achieve elementary functions—into what he calls a *systerspace* (pronounced "sister space")—where students learn by integrating and synthesizing systems for higher-level and industrially relevant functions including supervisory control, multi-agent networks, and automated driving. The term *systerspace* indicates a welcoming environment for women, but has yet to gain traction. Likewise, the near parity of women and men in environmental and biomedical engineering enrollment was noted at the workshop, prompting suggestions to market MRE programs in a biomedical context, for example emphasizing applications such as robotic surgery, in course and degree program names.

Outreach programs that promote diversity and inclusion can take different forms and formats. A list of examples discussed in the session includes bridge programs for students from under-resourced high schools to college, leadership training and scholarship programs like the Posse Foundation's Posse program, minority engineering programs in college, K-12 engineering summer camps, REUs, robotics competitions, and Engineers Without Borders college groups. Session participants noted that successful role models are important to help individuals from underrepresented groups break the barrier and boundaries.

Participants described challenges in developing and maintaining effective engineering D&I programs, including a lack of programs that target first-generation Americans and first-generation college students.

Participants made a few recommendations for future D&I programs and activities. Recommendations included adding engineering applications that address humanitarian issues to engineering curricula, such as ensuring safety and living conditions of global workers and preserving the ecological environment. A focus on equality of opportunity and inclusion was recommended for future D&I efforts, including clear and accessible student support resources. Participants also recommend a younger start for outreach to recruit girls and URM into STEM. For girls, the recommendation is to start in middle school. These young student D&I programs need to have a theme and keep it fun. These programs should engage parents, teachers, and communities to ensure long term program sustainability and impact. College-run outreach efforts to K-12 can "cold call" potential schools to start outreach program relationships. Participants also recommended exposing high school and college students to industry experiences so they can see themselves in engineering roles. In sum, the workshop identified existing D&I programs, challenges, and recommendations for future programs to address the challenges.

Methods: Online Survey

Due to the limited literature about findings at the college level, and to expand upon the workshop discussions, an online survey was conducted on D&I in MRE education. The survey was distributed via an e-mail link to email lists in nationwide engineering professional society divisions, along with links to three other surveys from other workshop-induced papers. No incentive was given for participation, other than to help further knowledge in this topic. The survey questions are presented in the Appendix. Open ended response textboxes were used instead of Likert scales due to the expectation of a relatively low number of responses.

One point that had to be clarified was who was considered an under-represented minority (URM) in STEM. The scope of this study was limited to traditionally under-represented groups within engineering in the US, easily trackable by demographic data. The biennial NSF digest “Women, Minorities, and Persons with Disabilities in Science and Engineering” gives a definition of URM. The report states:

> “Women, persons with disabilities, and underrepresented minority groups—blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives—are underrepresented in science and engineering (S&E). That is, their representation in S&E education and S&E employment is smaller than their representation in the U.S. population” [4].

Persons with disabilities are not included in the scope of this study. The survey instructions given were, “For the purposes of this study, we consider underrepresented minorities (URM) to be blacks or African Americans, Hispanics or Latinos, American Indians or Alaska Natives, and any mixed race that includes at least one of the preceding groups.”

The survey begins by identifying the respondent’s nation and type of institution. This was asked for demographic reasons. MRE programs within the US and Canada were the focus of the survey, but no responses were from instructors in Canada. Responses from other countries were not solicited, so only responses from the US were evaluated. The participants were also asked whether their academic institution is a public or private institution.

The next part of the survey collected demographic information about specific classes or extracurricular activities that the survey respondents teach or facilitate. Participants were asked to discuss specifics about each course and/or extracurricular activity from the past year, one at a time. For each of these activities a series of questions were then asked. Questions first focused on type of degree program (2 or 4 year), the grade level(s) included, and the survey participant’s role. Questions then shifted to the total number of students and the estimated numbers of women and URM. Answers requested a number with a plus or minus uncertainty range. Responses are expected to be based on instructor estimation and assumption of whether a student is a member of an underrepresented group, not necessarily based on precise records.

After completing information for each activity, participants proceeded to the third section of the survey. Here they were asked about their efforts and ideas for improving D&I. These optional open-ended questions were used to allow participants to freely give their ideas and opinions. These questions asked about what their institution did to attract and retain women and underrepresented minorities, what resources would help attract and retain these groups, and why. Participants were also asked about aspects of MRE that they think attract women and URM, how mechatronics and robotics could diversify STEM education, and a final open ended question allowing for any additional comments that could be helpful to the goals of the survey.

The third section of the survey received text responses from 17 respondents, with mostly single-sentence responses, some non-responses (empty text boxes), and a few paragraph-long responses. These respondents reported demographics on 25 classes in 4-year degree programs, 4 graduate classes, one extracurricular activity, and no classes in 2-year degree programs. Demographics for the 25 classes in four-year degree programs are shown in Table 1, including median, mean, minimum, and maximum across the 25 classes for each of total enrollment, female percentage of enrollment, and URM percentage of enrollment. Note that the median, minimum, and maximum numbers do not necessarily correspond to the same class or activity across the three columns. Also, note that the demographic data is not expected to be representative of a larger population because of the small sample size and self-selection in survey opt in. The minimum and maximum data show a large range of women and URM representation. The respondent breakdown by institution type was 10 public (or state-assisted) institutions and 7 private institutions.

Table 1 Demographics of the 25 MRE undergraduate classes in 4-year degree programs

	Total Enrollment	Female Percentage	URM Percentage
Median	30	13%	13%
Mean	48	17%	20%
Minimum	10	0%	0%
Maximum	100	100%	67%

The survey was analyzed using qualitative text analysis [14] to answer the following **guiding research questions** for this study:

> What do college-level MRE instructors perceive as challenges, successes, and opportunities for attracting and retaining female and URM students in college-level MRE education programs?

What attributes of MRE education encourage diversity and inclusion within MRE education and STEM education broadly?

Findings: Online Survey

The responses to the survey's third section were analyzed to find underlying themes and summarize the respondent's perspectives and ideas and present any contrasting perspectives within the survey data. Five themes emerged, ordered from most frequent to least: 1) the instructor perspective, 2) social context to MRE, 3) specific attributes of MRE, 4) pre-college interventions, and 5) in-college interventions.

Opinions and statements listed in this section were given by the respondents and the examples are diverse. They are meant to convey an array of ideas to facilitate further discussion in D&I in MRE and do not necessarily represent the authors' personal views or recommendations.

Theme: Instructor Perspective on D&I in MRE Education

As instructors themselves, almost all respondents commented on the instructor's perspective, instructor interventions, or instructor challenges. Instructor evaluation of the status of increasing D&I in MRE education was often uncertain, meaning that respondents said they either did not know or were not convinced of the effectiveness of their individual efforts or their institution's efforts at increasing the representation of women and URM in the MRE classes and degree programs. Some respondents did have evaluations that were certain; one cited 40% women enrollment and another cited 25% women enrollment as signs of success. Other respondents cited the entry of mentee women or underrepresented minority students into graduate studies as an indicator of success. The reported instructor interventions included giving equal attention to all students and creating female-majority project teams. The female-majority project team is important because, as one respondent wrote, "As a woman myself, I have been very aware that female students often do not feel comfortable speaking up in class, or are 'talked over' by the male students." In addition to showing the importance of each student's comfort in the academic environment, this quote also shows a common perception that comes up in D&I discussions: a perception of male students talking over female students. Such statements can be polarizing and set one group against another, even if unintentionally. The authors do not support attempts to advance D&I using polarization. Additionally, other reported instructor interventions included instructor participation in STEM outreach programs to female and URM students, instructors encouraging female and URM students to further their studies, participate in extracurricular activities, and use office hours, and instructors giving feedback to female and URM students.

The survey captured some mixed or even dissenting views held by instructors on the importance of outreach and diversity. One respondent wrote about their perception of other instructors, stating "Enthusiasm for outreach and K-12 education in academia seems mixed," and "[some professors] view [outreach] as a waste of time that detracts from research." The survey captured some contrasting actions and dissenting views. To the question "As a class instructor, what, if anything, did you do to attract and retain female students and URM students in the class(es) and degree program(s)?", 10 the 17 respondents described efforts they made, and the other 7 indicated that they did not make particular efforts. On the question "How do you think mechatronics and robotics engineering education can be used to diversify STEM (science, technology, engineering, and mathematics) education?", one of these four who reported that they did not make particular efforts further dissented "Diversity is not very important. People should just do what they're interested in / good at regardless of gender or race." This was a minority view held by one of the 17 respondents. The theme of the instructor's perspective was the most common theme among the respondents, but several other themes emerged with high frequency including the importance of MRE's social context.

Theme: Social Context to MRE

The theme of the social context of engineering and technology was identified in the literature review and at the workshop. More than half of survey respondents also indicated the importance of teaching with social context, meaning teaching engineering concepts with discussion of their applications and social implications. For example, multi-axis robotic arms can be taught with the application of robotic surgery and the social implication of improved healthcare. The responses highlighted positive mechatronic and robotic applications and social contexts, unlike the negative implication of biased AI algorithms discussed in the literature review. Identified applications included automation in medicine, manufacturing, textile manufacturing, gardening, farming, services, and the arts, with goals of improving quality of life generally. Interestingly, no survey responses mentioned the concept of automation eliminating jobs, which has potentially negative societal impacts. Specific applications were identified to be more attractive to or more familiar to female and URM students. Possibly reflective of stereotypes, the most frequently mentioned application was biomedical applications; respondents indicated that biomedical applications would be useful to attract women into the MRE field. Local social impact was also identified, and one respondent wrote, "[As a class instructor, I assigned] projects that involved clear service to the community and helped others; Women in particular were eager to participate." In sum, teaching with the social context of MRE in college curriculum was identified as a priority.

Theme: Specific Attributes of MRE

The survey asked about "aspects of mechatronics and robotics engineering that make the field attractive to female students or URM students" and elicited responses on the theme of specific attributes of MRE that relate to diversity and inclusion. Identified attributes included multidisciplinary, collaborative, exciting/futuristic, tactile, visual/relatable, and safe/clean. As MRE is a multidisciplinary field, one respondent wrote that it has "a niche for nearly everyone," but a theme of personalization in MRE education arose that suggested MRE should be taught differently to different engineering majors, even to the level of tailoring support to individual student needs. Collaboration was discussed in terms of college student design teams in classes and extracurricular activities. The excitement of MRE was captured in the responses, "Young students LOVE robots," "many students find this field very exciting and futuristic", and "to excite students into STEM." Several respondents wrote about MRE concepts and applications as tactile, hands-on, visual, and relatable, emphasizing the use of physical robots and real-life concept examples in teaching and outreach. One respondent further commented that the perceived safety and cleanliness of these applications relative to applications in traditional engineering fields may make MRE relatively attractive to women. In contrast, one respondent wrote that MRE attributes including logic, math, design, building, testing, CAD, and problem-solving are, "the same things that attract white men to MRE." Respondents also noted that hands-on MRE lab equipment has a financial cost that must be considered—to the student at the college level and to the K-12 outreach programs—and that the quality of the equipment is important to student perceptions of the institution's support to the student. Lastly, respondents emphasized that tactile MRE examples can be used to teach and excite about broader STEM principles and concepts both before and in college.

Theme: Pre-college Interventions

A specific theme of pre-college intervention emerged from the survey responses. More than half of respondents mentioned pre-college interventions or college preparation issues among female and URM students, and several respondents highlighted a need for middle school and earlier programs, as opposed to starting in high school. In agreement with the literature, K-12 robotics team competitions were cited as a common and successful pre-college intervention. Specific programs cited included the FIRST Robotics Competition for high school students, the FIRST LEGO League for elementary and middle school students, the VEX Robotics Competition for elementary through college students, the Botball Educational Robotics Program competitions for middle and high school students, the SeaPerch Program builds and competitions for elementary through high school students, and university-run summer programs specifically for female and URM high school students. The concept of a "pipeline" of students from K-12 into college was mentioned and "plugging leaks in the pipeline" for female and URM students who "start to lose interest in STEM subjects" in middle and high school. While college recruitment of female and

URM students was emphasized in several responses, one respondent wrote, “Focusing on admitting more female and URM students to college STEM degree programs is too late if many of the target students lost interest in STEM years before that.” Interestingly, one of the suggested faculty interventions is for faculty and their research students to conduct K-12 outreach activities. A respondent wrote that small, infrequent time commitments of this type by many faculty members can “make a huge difference.” Alternatively, the issue of college preparation was brought up in survey responses. “In general, minorities seem less likely to have had Calculus in high school,” wrote one respondent, who then suggested “Remedial math options that do not hinder progress through the program.” Several other respondents indicated a need for improved pre-college STEM prep for some URM students in math, programming, engineering, robotics, and technology. One suggestion is “More … support for K-12 teachers to teach STEM topics” in addition to more robotics collaboration and competition programs. Aligned with college preparation is student awareness of higher education and potential STEM careers. “The level of awareness must be increased before [incoming college students] choose the school or the major,” wrote one respondent. In sum, respondents identified a challenge of maintaining STEM excitement, preparation, and awareness for female and URM students through the end of high school, with some existing and proposed pre-college curriculum, teacher, and outreach interventions.

Theme: In-college Interventions

Regarding in-college interventions, one frequent theme was role modeling and mentoring. Those respondents who mentioned this theme voiced support for an increased representation of women and URM in the body of instructors and among the faculty and program leadership. It was even suggested that the representation of female and URM students among prospective student tour group guides is important. Respondents also mentioned peer mentoring and role modeling through female and URM engineering student organizations, as well as faculty-student mentoring programs. Additionally, targeted scholarships and financial aid for female and URM students was mentioned with a similar frequency to role modeling and mentoring. Respondents were aware of these individual and institutional efforts at role modeling, mentoring, and targeted financial aid, but had mixed opinions about their efficacy to date.

Discussion

The workshop and survey had small sample sizes (n=31 and n=17, respectively) among the population of college-level MRE instructors in the US, a population that numbers in the thousands, so the findings must be viewed as exploratory, and may not accurately represent the population. Furthermore, online survey respondents opted into the survey. Additionally, the two samples were not mutually exclusive, so the survey may have served as a vehicle for some workshop attendees to contribute their ideas and expand on the workshop discussions. However, for the purposes of collecting ideas and perceptions, these data proved valuable.

The workshop findings focused on justification for D&I, listing existing D&I-promoting activities, and recommending changes to activities. The presence of industry participants influenced the discussions, particularly about justification for D&I from an industry perspective. Workshop participants also shared about their children’s experiences in the K-12 STEM pipeline or, in some cases, leaking out of that pipeline. The list of D&I-promoting activities was consistent with those found in literature and with the activities mentioned in survey data, although different specific pre-college and in-college MRE activities were named in each. The workshop session recommended college curriculum changes to emphasize the social context of MRE and to start pre-college interventions earlier, highlighting two of the themes that emerged from the survey data.

The five survey themes are discussed in order as follows. First, the instructor's perspectives revealed instructor uncertainty about the effectiveness of their efforts and their institution's efforts to promote diversity, suggesting that other college staff may provide a more complete picture for the study of these research questions. The finding of mixed responses by the respondents about whether they actively promote participation by women and URM indicates a few concerns. First, the finding shows that some instructors do not make a special effort to increase participation of these groups, so D&I efforts by instructors are concentrated among a small group of instructors. Second, the finding begs the question of why some instructors do not make a special effort to increase female and URM participation. Possible explanations suggested in the data include 1) differing instructor views on D&I, and 2) faculty time commitments to research. There was a consensus that instructors are responsible for addressing in their pedagogy the interpersonal dynamics that hinder equity in education, such as some men "talking over" women or dominating project teams. Identified interventions include the instructor's assignment of students to teams or the instructor's calling on students during a lecture. The survey findings showed some dissent among instructors, which was not expressed at all in the workshop discussions. One respondent expressed a minority view against efforts to increase participation by women and URM students, instead favoring a social Darwinist approach that ignores equity of opportunity. This viewpoint is present in the public generally but was unexpected in the survey.

Second, incorporating the social context of MRE into curriculum and outreach was advocated. The literature, workshop, and survey agreed that incorporating social context to engineering education would benefit all college students, particularly under-represented students. For MRE education, this context comes easily from the many real-life and near-future applications of automation and robots. The frequent recommendation of using biomedical applications of MRE to provide social context for women suggested a stereotype that women prefer to work in environmental, biological, and medical related areas over other technical areas [3]. While emphasizing and exploring biomedical applications may prove fruitful for increasing women participation, it may also prove useful for increasing participation broadly. Further, the data suggest that the traditional MRE industrial applications of automotive, fossil energy, traditional manufacturing, and defense could be de-emphasized in order to make space for futuristic and inspiring MRE applications in the curriculum, such as vertical farming, services, and the arts.

Third, the research question about using MRE to improve diverse participation was answered with a pedagogy of robots. The visual and tactile activity of building and interacting with robots is engaging for students of all ages and backgrounds, so incorporating it into curricula and outreach would improve STEM outcomes for underrepresented groups. Robotics competitions already do this well as many educational levels from elementary school to college. A variety of robotics competitions could also be used outside of formal education for working-aged people and seniors. The cost of robotics projects was noted as a challenge at the college level and in K-12 outreach programs. The identified K-12 robotics programs vary in their cost and the amount of the build and fundraising work performed by the students. Societal prioritization of funding for robotics hardware activities is warranted for increased D&I in both MRE and STEM generally. Additionally, the multidisciplinary and collaborative nature of MRE is a strength for engaging diverse student populations.

Finally, interventions pre-college and in-college were identified to increase female and URM participation. The well-known pipeline concept of maintaining student interest in STEM from preschool through K-12 to college was supported in the data. Women and URM are believed to leak from the pipeline at higher relative rates than men, non-Hispanic Caucasian Americans and Asian Americans, and perhaps this leakage occurs at younger ages for women and URM, so intervention and continued pipeline support must occur earlier, such as middle—or even elementary—school. Equity was discussed regarding college prep. Students from under resourced high schools, due to socioeconomic circumstances, are less likely to have calculus, engineering, programming, or advanced placement courses in high school, so they begin college engineering programs at a disadvantage in skills and credits. The disadvantage can compound throughout the college years as these disproportionately non-URM students who enter college with more engineering skills and college credits apply their surplus time or tuition savings to participate in resume-building experiences such as undergraduate research. The common in-college interventions of role modeling, mentoring, and financial aid were reported, but novel solutions were not suggested. From this perspective, and short of major change, the increase in participation of women and URM in engineering will follow its slow march forward, perhaps with positive feedback from increases in instructor diversity.

Conclusion

Increasing diversity and inclusion in MRE is an important goal, and many educational interventions to achieve this have been tried or proposed. This small study captures several ideas along broad themes as well as challenges that have hindered progress in the past. The most promising new ideas are in curriculum reform to incorporate social context into engineering education and in expanding STEM outreach by colleges to elementary and middle schools. Encouragement and continued funding of existing efforts at the college level, such as robotics summer research experiences for women and MRE undergraduates, are also important to help students understand the context of what they learn in the MRE curriculum and encourage them to consider graduate studies in MRE. Furthermore, MRE was found to have several attributes that make it well-suited for promoting diverse participation. The many tactile and futuristic robot systems make for engaging K-12 projects and the meaningful applications and right-sized scale of MRE projects are engaging to students at the college level. The traditional roadblocks of limited outreach and educational program funding, socioeconomic equity issues, tenure-track faculty time obligations, and a lack of role models and mentors were identified. Also, the silence in the literature for diversity, equity, and inclusion in MRE at the college and graduate levels beckons further study and larger surveys. Additionally, an examination of D&I regarding student abilities and ages was not explored in this study and should be conducted in the future. Likewise, D&I in MRE was not explored in the context of online learning. The recent emphasis on online learning in response to COVID-19 related campus closures makes this a pertinent issue for the near future.

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Appendix

The survey questions answered by participants are presented below.

Respondent demographics section:

- In which country is your college/university/institution located? [USA, Canada, Other]
- Please indicate the type of your institution: [Public, Private, Other]
- How many classes or educational activities would you like to report?

For each activity:

- What is the approximate name of the class or extracurricular activity? Do not include the name of your institution, the course number, or any personally identifiable information
- Was this class or activity part of a: [2 year degree program, 4 year degree program, other]
- What was the intended grade level of this class or extracurricular activity? (Select as many answers as apply) [First year of college/university, Second (sophomore) year of college/university, Third (junior) year of college/university, Fourth (senior) year of college/university, Not applicable, other]
- What was your role in this class or extracurricular activity during this time period? (Select as many answers as apply) [instructor or co-instructor of record, teaching assistant or grader, adviser or mentor, other]

- At the end of your involvement with this class or extracurricular activity during calendar year 2019, approximately how many students were in this class or extracurricular activity, and what is your estimate of the uncertainty in that number? (for example, answer "25 +/- 2" or "25 plus or minus 2").

- At the end of your involvement with this class or extracurricular activity during calendar year 2019, approximately how many female students were in this class or extracurricular activity, and what is your estimate of the uncertainty in that number? (for example, answer "10 +/- 3" or "10 plus or minus 3").

- At the end of your involvement with this class or extracurricular activity during calendar year 2019, approximately how many URM students were in this class or extracurricular activity, and what is your estimate of the uncertainty in that number? (for example, answer "10 +/- 3" or "10 plus or minus 3").

For the purposes of this study, we consider underrepresented minorities (URM) to be blacks or African Americans, Hispanics or Latinos, American Indians or Alaska Natives, and any mixed race that includes at least one of the preceding groups.

Likewise, we consider fully represented or over-represented racial/ethnic groups to be non-Hispanic whites, Asians, Middle-Easterners, or North Africans and any mixed race that does not include an above-mentioned underrepresented group.

Concluding section:

- As a class instructor, what, if anything, did you do to attract and retain female students and URM students in the class(es) and degree program(s)? Please include observations on how well these efforts worked, if you are able.

Recall that for the purposes of this study, we consider URM to be blacks or African Americans, Hispanics or Latinos, American Indians or Alaska Natives, and any mixed race that includes at least one of the preceding groups.

- Optional - what, if anything, did your institution do to attract and retain female students and URM students in the class(es) and degree program(s)? Please include observations on how well these efforts worked, if you are able. Please do not include the name of your institution or any personally identifiable information.

- What new resources or initiatives would help attract and retain female students and URM students in the class(es) and degree program(s)? Why so you think so?

- Are there aspects of mechatronics and robotics engineering that make the field attractive to female students or URM students? If so, what?

- How do you think mechatronics and robotics engineering education can be used to diversify STEM (science, technology, engineering, and mathematics) education?

- Please provide any additional comments about this survey or general comments that you think may be helpful to the goals of learning about and improving diversity and inclusion in mechatronics and robotics engineering: