Workshop on Unified Curriculum and Course Design for Mechatronics and Robotics Engineering

Dr. Gregory C. Lewin, Worcester Polytechnic Institute

Dr. Lewin is an Assistant Teaching Professor and the Associate Head of Robotics Engineering at WPI.

Prof. Rui Li, New York University

Dr. Li earned his master's degree in Chemical Engineering in 2009 from the Imperial College of London and his doctoral degree in 2020 from the University of Georgia, College of Engineering.

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 divers

Dr. James A. Mynderse, Lawrence Technological University

James A. Mynderse, PhD is an Associate Professor in the A. Leon Linton Department of Mechanical, Robotics, and Industrial Engineering at Lawrence Technological University. He serves as director for the BS in Robotics Engineering and MS in Mechatronics and Robotics Engineering programs.

Dr. Vikram Kapila, New York University

Vikram Kapila is a Professor of Mechanical and Aerospace Engineering. He directs a Mechatronics, Controls, and Robotics Laboratory and has held visiting positions with the Air Force Research Laboratories in Dayton, OH. His current research is focused at the convergence of frontier technologies (e.g., robotics, artificial intelligence, augmented/virtual reality, and blockchain) with applications to natural and intuitive human-robot interaction, digital health, and STEM education. Under the Research Experience for Teachers Site, GK-12 Fellows, DR K-12, and ITEST projects, all funded by NSF, and the Central Brooklyn STEM Initiative, funded by six philanthropic foundations, he has conducted significant K-12 education, training, mentoring, and outreach activities to integrate engineering concepts in science classrooms and labs of dozens of New York City public schools. His STEM education research, conducted as a collaborative partnership involving engineering and education faculty, postgraduate and graduate researchers, and K-12 educators, has: (1) created, implemented, and examined over 100 standards-aligned robotics-based science and math lessons and (2) developed, practiced, and examined research-guided pedagogical approaches for science and math learning using robotics. He received NYU Tandon's 2002, 2008, 2011, and 2014 Jacobs Excellence in Education Award, 2002 Jacobs Innovation Grant, 2003 Distinguished Teacher Award, and 2012 Inaugural Distinguished Award for Excellence in the category Inspiration through Leadership. Moreover, he is a recipient of 2014-2015 University Distinguished Teaching Award at NYU. His scholarly activities have included 3 edited books, 11 chapters in edited books, 1 book review, 68 journal articles, and 175 conference papers. He has mentored 6 research associates; 1 B.S., 48 M.S., and 11 Ph.D. students; 66 undergraduate research students and 11 undergraduate senior design project teams; over 500 K-12 teachers and 130 high school student researchers; and 18 undergraduate GK-12 Fellows and 59 graduate GK-12 Fellows.

Prof. Michael A. Gennert, Worcester Polytechnic Institute

Michael A. Gennert is Professor Emeritus of Robotics Engineering, CS, and ECE at Worcester Polytechnic Institute, where he led the WPI Humanoid Robotics Laboratory and was Founding Director of the Robotics Engineering Program. He has worked at the University of Massachusetts Medical Center, University of California Riverside, and PAR Technology Corp.

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Abstract

With the increasing demand for cross-disciplinary technical and professional skill sets in the engineering workforce, Mechatronics and Robotics Engineering (MRE) is quickly emerging as its own engineering discipline. However, developing and implementing MRE courses and curricula is challenging for many potential MRE educators because there are no standardized course structures, curricula, hardware and software platforms, or course materials.

To address these challenges, a multi-institutional, multidisciplinary team conducted several workshops starting in 2018 to provide support for curriculum development in MRE and to create a vibrant community of college instructors interested in MRE. Ranging from a half-day to two days, the workshops provided guidance and perspectives from leaders in MRE education. Based on participant feedback from these workshops and our goal for greater impact, we planned and delivered a more intensive three-day, virtual, yet hands-on workshop in the Spring of 2022.

The objectives of the workshop were to: 1) prepare current and future MRE educators to create and teach courses, 2) familiarize MRE educators with advances in undergraduate MRE education, 3) help unify and standardize MRE curricula and courses, 4) pave the way toward accreditation for MRE degree programs, 5) generate enthusiasm and a sense of community among MRE educators, and 6) promote diversity and inclusion within the MRE community. Notably, this workshop differed from previous ones by embedding a significant hands-on experiential learning component, which provided sample laboratory assignments and projects that could form the foundations of introductory and advanced courses in MRE. Remote assistance was provided by workshop leaders and student assistants. Participants actively engaged in many activities, including doing “homework” every evening.

A post-workshop survey revealed that participants overwhelmingly felt that the workshop met their expectations and that they were better prepared to teach mechatronics. Participants also noted that they felt better connected to the MRE community. Finally, participants suggested areas for future training and skill development, which could be incorporated into the development of future workshops.

Introduction

The growing field of Mechatronics and Robotics Engineering (MRE) spans a broad set of engineering and computing disciplines. Drawing deeply from mechanics, electronics, control theory, computational sciences, as well as other disciplines, MRE programs are well-suited to help engineering students develop the skills needed to function on multidisciplinary teams. Despite the growth in the number of MRE programs, including undergraduate majors and minors, graduate degrees, and certificates, there are no standards to define MRE.

Indeed, there have been many educational efforts around MRE, but they have not been well-integrated or widely adopted [1]. The problem partly stems from the lack of a clear definition of

Mechatronics and Robotics [2,3], in particular, and is likely compounded by the fact that many Robotics and Mechatronics programs are "housed" in different academic departments at their respective institutions [4]. Consequently, we continue to re-invent MRE modules, courses, and curricula instead of adopting and improving existing content. With the rapid increase in demand for robotics and automation engineers, failure to define MRE through standardized curricula and accreditation criteria risks missed career opportunities for individuals and missed economic opportunities for industry. By defining a common set of knowledge and skills for MRE programs and courses, students and employers will understand the abilities a graduate should possess and students will develop the technical foundation and professional skills that are critical to fulfill the research and development needs for advanced mechatronic and robotic systems [5,6].

The authors believe MRE has matured to the point where it is a distinct and identifiable engineering discipline. Indeed, several universities have developed programs in mechatronics and robotics, and several have recognized MRE as a discipline by creating Mechatronics and Robotics Engineering Departments.

To help MRE move forward as a discipline, the authors delivered an intensive, three-day workshop on MRE curriculum in the Spring of 2022 with the following objectives:

1. Prepare current and future MRE educators to effectively design and teach courses in this discipline
2. Familiarize MRE educators with the most recent technological and pedagogical advances in undergraduate MRE education
3. Help unify and standardize MRE curricula and courses
4. Pave the way toward a standardized accreditation process for MRE degree programs
5. Generate enthusiasm and a sense of community among current and future MRE educators
6. Promote diversity and inclusion within the MRE community

This paper presents the general format and outcomes of the workshop, and draws on the analysis of participant surveys to assess the success with respect to the stated objectives. Attention is given to the extent to which the workshop realized goals for attendee demographics, changes in participant attitudes, and development of the MRE community.

Background and Motivation

Academic interest in MRE has grown considerably from individual courses, minors, and concentrations in CS, ECE, and ME departments to well-developed curricula that define distinct academic programs. A recent survey of the state of robotics education is available in [7]. Although the programs presented there share some common features, they have generally risen independently in the absence of a cohesive community in MRE.

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 human health and welfare. Indeed, mechatronics was identified by Technology Review as one of the top 10

emerging technologies with potential to change the world [7]. Therefore, the authors' long-term goals are to:

- Develop a diverse, inclusive community of MRE educators, students, and practitioners
- Collaboratively define the MRE knowledgebase
- Achieve recognition of MRE as a distinct engineering discipline
- Accelerate adoption of MRE courses and curricula

Previously, the Future of Mechatronics and Robotics Education (FoMRE) group organized several workshops to bring together educators and professionals to create a coherent definition of MRE, create a broader sense of community, promote the adoption of teaching materials, and improve the quality of undergraduate MRE education [8]. In addition, by engaging important stakeholders from both industry and academia, a clearer picture of the objectives of MRE programs could be defined [1,2].

The first three workshops were half-day events that included several moderated breakout sessions to facilitate discussions on topics of interest in MRE education. The fourth workshop spanned two days, which enabled a deeper investigation of pertinent topics. One outcome of the fourth workshop was a set of action items and creation of working groups, which have persisted beyond the workshop (including the group encompassing the current authors).

Overall, reactions to all four workshops were very similar: participants felt that the workshops achieved the goals of increasing the knowledge and confidence in teaching MRE and building a community of educators that they could belong to. Major findings included the need to develop a general consensus for standardizing MRE curricula and offerings, as well as preparing faculty to teach courses in MRE and foster a diverse and inclusive community, particularly with respect to gender and historically underrepresented groups [8].

One challenge in the prior workshops was the limited time allocated to them. Participants asked for more direction during interactive sessions to enhance their effectiveness and to spend more time on MRE curricula and training for delivering MRE courses. They also commented on the need for ongoing mentoring and improved diversity. As a result, the authors proposed and delivered a more intensive, three-day workshop with the following expected outcomes:

- Increase the number and breadth (public, private, Historically Black Colleges and Universities, Hispanic-Serving Institutions) of colleges and universities that can offer MRE education,
- Strengthen the MRE offerings at colleges and universities that already teach MRE,
- Prepare faculty to teach mechatronics and robotics courses and projects through hands-on activities,
- Empower faculty to lead MRE curriculum initiatives at their institutions,
- Provide access to course materials through an MRE website, and
- Foster a diverse, inclusive community of MRE educators.

The workshop drew from the combined knowledge of project team members, whose accumulated experience delivering MRE courses and projects amounts to several decades and thousands of students.

Approach

To meet the curricular objectives, the planned workshop included sessions focused on:

- Curriculum Design from a top-down approach, including establishing a vision and program objectives, developing courses and projects under resource constraints, and assessing effectiveness,
- Introductory MRE Courses, including hands-on activities where participants could work on exercises in teams,
- Intermediate and Advanced MRE Courses, including presentations of curricular design from established MRE programs,
- Hardware, including examples of common hardware that can be adopted in MRE courses,
- Software, including environments and languages and the value of simulation and visualization, and
- Tours of robotics facilities, as well as a nearby robot corporation.

To address the objectives centered on diversity and inclusiveness, the organizers put a focus on recruitment and included break-out discussions centered on those themes. There are numerous studies regarding the "leaky pipeline" with respect to the dearth of women, minoritized, and marginalized populations in engineering (see [9], for example, for a review). Some of the barriers to diversity in STEM include a lack of champions and diverse role models, a lack of resources to build programs to target underrepresented groups, and a limited knowledge base for nascent programs. By growing the MRE community, it may be possible to close the diversity gap in STEM by increasing the number of academics and practitioners who teach, mentor, and serve as role models to the robotics and mechatronics engineers of tomorrow.

The current workshop aspired to address these needs by recruiting diverse facilitators and participants, providing free or low cost workshop materials, and sharing knowledge and best practices to help foster knowledge in a broader MRE community. The workshop announcement was posted to a number of online venues, including several directed at women and other historically underrepresented groups: ASEE Women in Engineering, Black In Engineering, Black In Robotics, African American PhDs in Computer Science, and African American Roboticists. As indicated by the workshop participant demographics (see below), these efforts were proven to be very successful in recruiting a diverse population of academics, more so than the earlier workshops sponsored by the authors.

The workshop was originally planned as an in-person event to be held at Worcester Polytechnic Institute (WPI), which was chosen because of its extensive experience in robotics education, as well as connections with local robotics companies.

Pivot due to COVID

Because of restrictions from the COVID-19 pandemic, the workshop could not be conducted as planned. Instead, the project team reconceptualized the workshop to enhance its impact -- while still meeting the original objectives -- by replacing the in-person concept with a virtual workshop that made use of remote learning methodologies that had been refined during the COVID-19 pandemic. By re-allocating the budget line items for travel, food, and lodging to other categories, the workshop was able to supply over 200 hardware kits, which were used in hands-on activities. Two classes of faculty participants received hardware:

1. 20 faculty participants each received a set of 10 robot kits suitable for teaching an entire introductory and/or follow-on robotics class with up to 24 students (with spares). Faculty who had plans for using the materials or developing courses were given priority for the full sets.
2. 10 faculty participants each received a single robot kit, which allowed them to experiment with materials and allowed the workshop organizers to broaden participation to several more institutions, even if the participants could not yet commit to offering a class.

The hardware kits were based on Pololu's Romi platform [10] and included a differential drive chassis, a control board, several sensors for line following and distance measurement, and a servo motor to drive a lifter arm. One 3d-printed lifter arm was provided to each participant, and design files were provided so that they could produce more, as needed. A complete list of hardware components can be found at [11].

The workshop schedule was also revised to allow more unscheduled/free time for participants to work through lab exercises to build and program their own robots. Materials were delivered to the participants well in advance of the workshop, and participants were given instructions for assembly and of the robots and installation of software tools before the start of the workshop.

The workshop was held using Zoom, a popular remote meeting platform. With the elimination of group meals and a company tour, and the schedule was adjusted to allow more time for hands-on activities. Sessions for curriculum design, hardware and software considerations, and open discussion were retained. The Complete schedule is shown in Table 1.

Table 1. Workshop schedule.

<table>
<tr><th></th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>11:00</td><td>Introductions</td><td>Welcome back</td><td>Welcome back</td></tr>
<tr><td>:15</td><td>Overview</td><td>Intro Act. 4 Summary & Reflection</td><td>Adv. Activity 2 Summary & Reflection</td></tr>
<tr><td>:30</td><td>M&R Intro Activity 1</td><td>M&R Intro Activity 5</td><td rowspan="2">Hardware Discussion</td></tr>
<tr><td>:45</td><td rowspan="3">Hands-on: Intro Activity 1</td><td rowspan="3">Hands-on: Intro Activity 5</td></tr>
<tr><td>12:00</td><td rowspan="3">Software Discussion</td></tr>
<tr><td>:15</td></tr>
<tr><td>:30</td><td>Summary & Reflection</td><td>Summary & Reflection</td></tr>
<tr><td>:45</td><td>M&R Intro Activity 2</td><td rowspan="2">Curriculum Discussion 2</td><td rowspan="2">Breakout Groups 1</td></tr>
<tr><td>1:00</td><td rowspan="3">Hands-on: Intro Activity 2</td></tr>
<tr><td>:15</td><td rowspan="2">Capstone Project Discussion</td><td>BG1 Report-Out</td></tr>
<tr><td>:30</td><td>Breakout Groups 2</td></tr>
<tr><td>:45</td></tr>
</table>

2:00		R&M Advanced Activity 1	
:15	Summary & Reflection	Hands-on: Adv. Activity 1	BG2 Report-Out
:30	Break		Break
:45			
3:00	Curriculum Discussion 1		Roadmap & MRE Community
:15		Summary & Reflection	
:30	M&R Intro Activity 3	Break	Open Discussion
:45	Hands-on: Intro Activity 3		
4:00		R&M Advanced Activity 2	
:15		Hands-on: Adv. Activity 2	Survey
:30			Thank you and Farewell
:45	Summary & Reflection		
5:00	M&R Intro Activity 4		

The hands-on sessions were broadly divided into two levels: a project suitable for an introductory course and a project for an advanced course. The former centered on a "delivery robot" project that was born out of the COVID-19 pandemic and successfully adopted at WPI. For the project, students program and optimize a robot that gathers "bags" to be delivered via a grid of "streets" made with black tape on a white surface (see "Project Overview" in [11]). A variety of challenges are introduced, including delivery platforms of different heights and rewards for delivering more weight in a specified time, which encourages the students to consider trade-offs in the configuration of their robots. Workshop participants were presented with lab handouts and code libraries used in the project, as well as a number of "skeleton codes" to help them complete activities in the time allotted.

The advanced project, drawn from course material at Rose-Hulman Institute of Technology focused on navigating a 4-by-4 grid-based "maze" that can be reconfigured to motivate basic exploration and mapping. Robots start at one corner of the maze and visit each of the grid cells, indicating the location of walls on a map. A complete set of provided materials, as well as links to videos from the workshop, can be found at [11].

Workshop coordinators and student helpers were made available in "breakout rooms" to help troubleshoot and give participants more personalized assistance. Given the complexity of the challenges and the variety of skill levels of the participants, there was no expectation that everyone completed the activities – some participants completed several of the challenges, while others worked through some of the material, gathering ideas for how they could customize one of the projects for a class.

The effectiveness of the workshop was assessed through surveys and informal feedback. Survey questions were designed to assess the objectives laid out above.

Evaluation

Pre-workshop and a post-workshop surveys were developed to collect essential information for evaluating the learning outcomes of the workshop. Overall, 23 individuals participated in the

pre-survey, and 19 participated in the post-survey. For the post-survey, 17 of the respondents were current faculty, one was an instructor, and one a future faculty member. The survey was approved by the IRB at WPI.

Before the workshop, participants were asked about their expectations. As shown in Figure 1, about half the participants indicated a desire to learn how to teach new topics, while curricular improvements and expanding their networks were also notable. In the post-survey, 84% of the participants noted that their expectations were met.

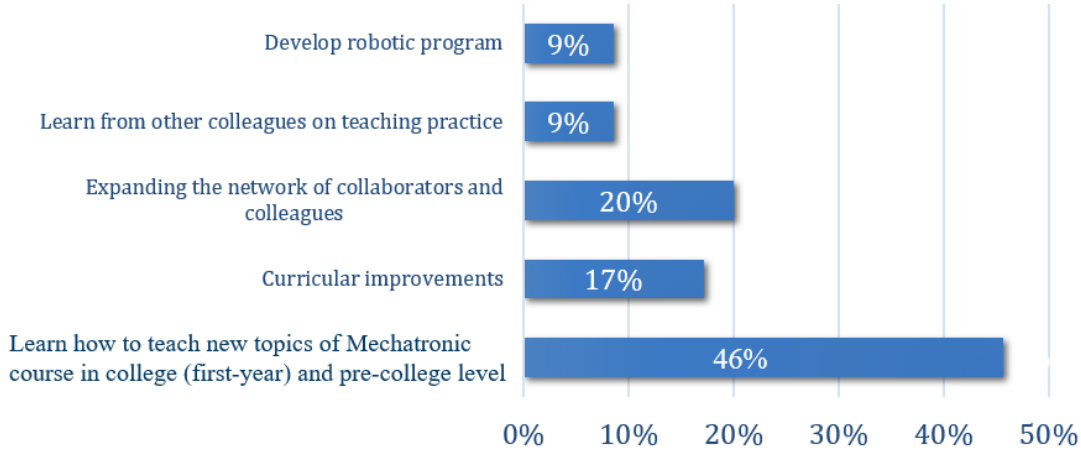


Figure 1. Pre-workshop responses to the prompt, "What do you expect to gain from the mechatronics and robotics engineering workshop?"

Participants were also asked to rate how important the different types of sessions were to them, where the definition of "importance" was left to each participant and could be based, for example, on their own professional development, knowledge of their students' abilities, or in-demand skills in the workplace. As shown in Figure 2, the vast majority of participants rated each activity "important" or "very important." Notably, the hands-on portions (Intro and Advanced Course Labs) were perceived as the most important by the participants.

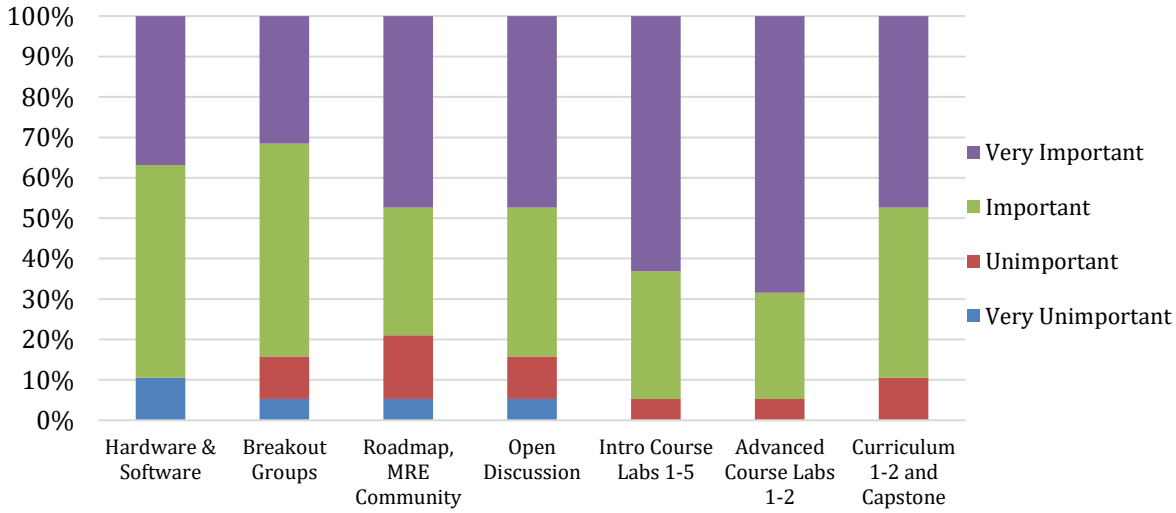
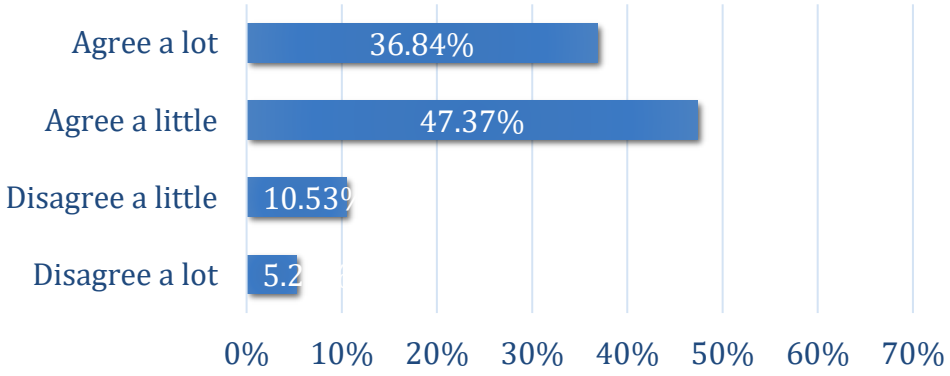
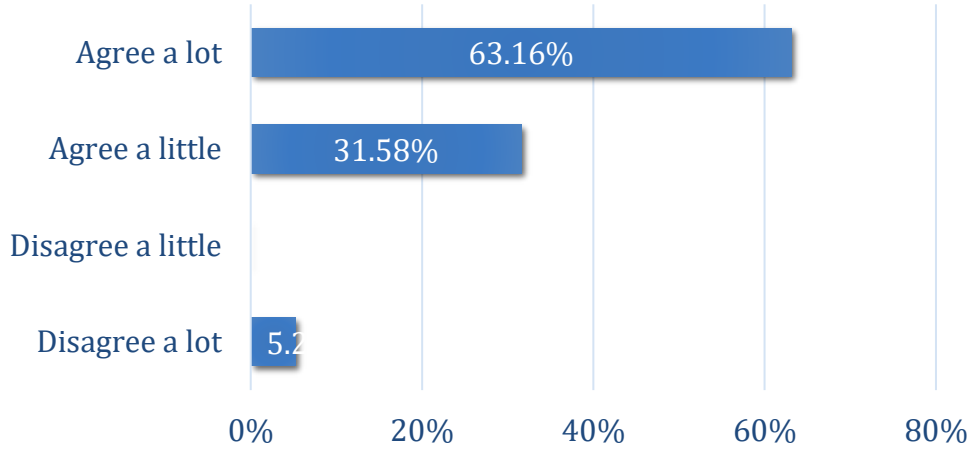


Figure 2: Participants' responses to the prompt, "How important were the [category] sessions to you?"

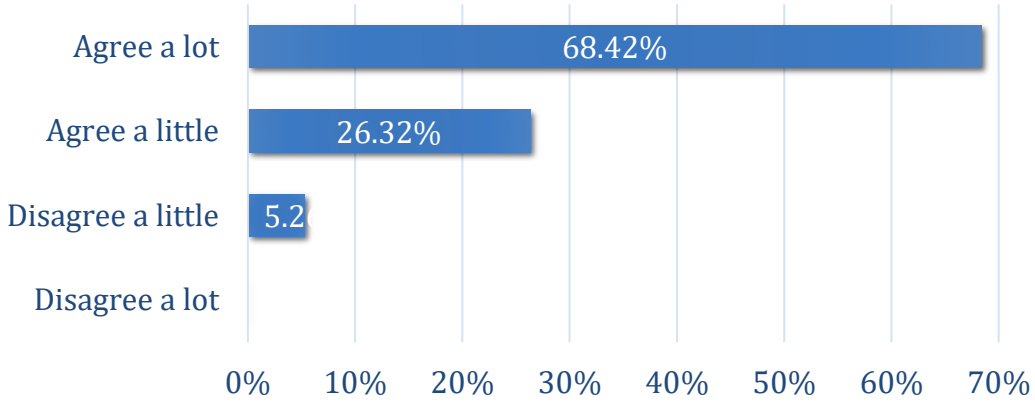
Participants were asked if the workshop better prepared them to teach mechatronics and robotics and if they felt better connected to the broader MRE community. As shown in Figure 3, the majority felt they were better prepared to teach concepts and the vast majority felt better connected to and that they belonged in the MRE community.



(a) Responses to the prompt: "After participating in the workshop, I feel better prepared to teach mechatronics and robotics engineering concepts."



(b) Responses to the prompt: "After participating in the workshop, I feel more connected to other mechatronics and robotics engineering educators."



(c) Responses to the prompt, "After participating in the workshop, I feel like I belong within the mechatronics and robotics engineering community."

Figure 3: Participant responses to prompts relating to preparation and community.

The survey also asked, "*Did participation in the workshop change your plans for integrating or revising mechatronics and robotics engineering education in your institution and/or courses?*" As shown in Figure 4, the vast majority indicated that the workshop helped them develop a new course or integrate content into an existing course.

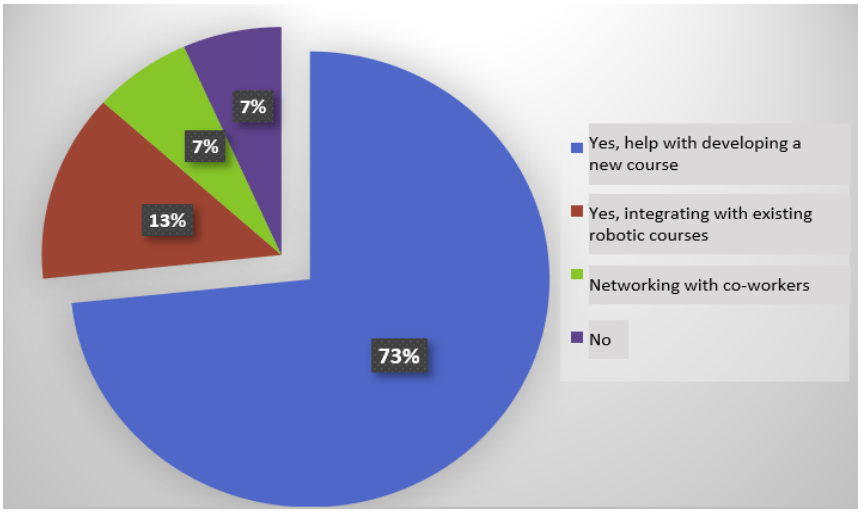


Figure 4: Responses to the prompt, "Did participation in the workshop change your plans for integrating or revising mechatronics and robotics engineering education in your institution?"

Outcomes

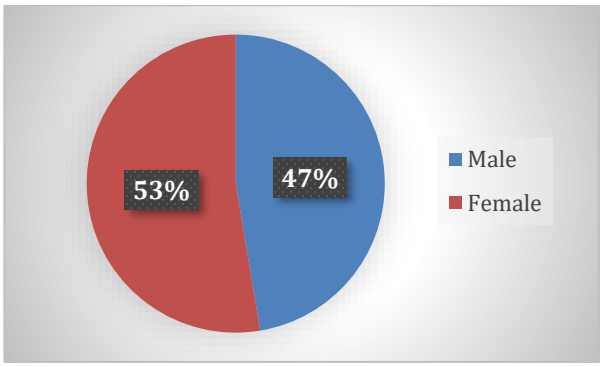
The workshop produced a number of useful findings, as indicated by the select quotes in Table 1.

- Participants asked for more interactive sessions, such as discussion time.
- Many participants encountered difficulties with programming the robots.
- Participants asked for more inclusive training for K-12 educators.

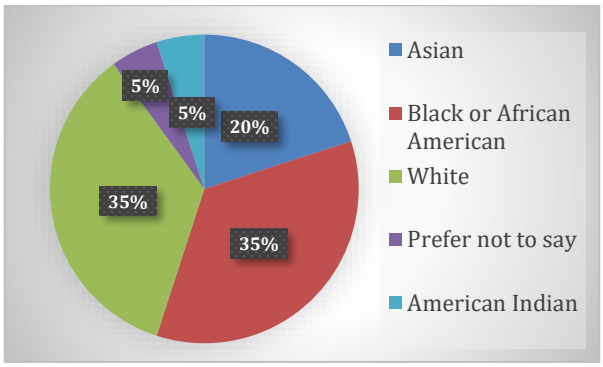
- Participants asked for more specialized training for different levels of learners, including novice and experts in robotics.

Participant demographics

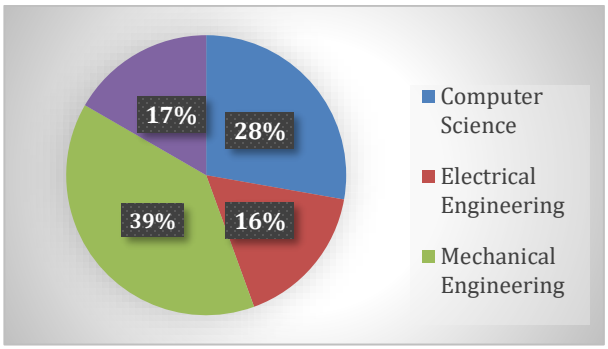
Demographic data for the workshop is shown in Figure 5. Notably, the gender and ethnic diversity represented by the participants is significantly greater than seen in typical student or faculty populations [12].



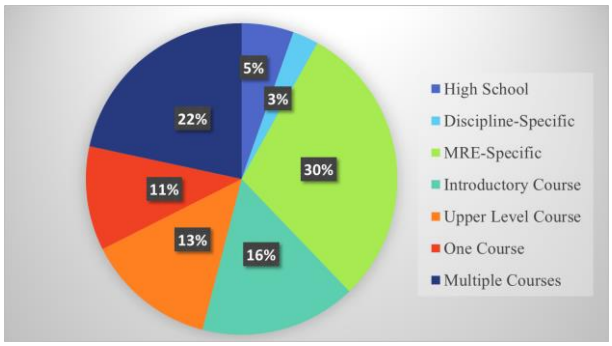
(a) Gender



(b) Ethnicity



(c) Professional role



(d) Mechatronics/Robotics teaching experience

Figure 5: Demographic data of participants (as indicated in the post-workshop survey).

Findings with select quotes

Table 2 summarizes popular phrases in the open response feedback and a selected quote in response to each question. Though open response, we attempted to group similar phrases into common themes, and the number of those responses are noted. We selected quotes that reflect both positive experiences and suggestions for improvement.

Table 2: Post-workshop survey questions and selected phrases and quotes.

Questions	Popular phrases	Selected quotes

What recommendations do you have for helping everyone feel like they belong within the mechatronics and robotics engineering community?	"Hold more workshops with networking session" (5); "Stay engaged/use forums for engagement" (5)	"Welcoming and inclusive social interactions. Also become aware of skill sets of members in the community including those not historically involved in or represented in the field so you know what to invite people to help with."
What did you enjoy about the workshop?	"Hands-on" (10); "Developedd programming experience" (4); "Curriculum session" (3); "Discussion sessions" (3); "Informative and well-structured workshop" (3)	"Hands on work. Working through labs that students use."
What was challenging about the workshop?	"Programming difficulty" (9); "Preparation/setup" (5); "Debugging online" (4)	"Trying to troubleshoot hardware problems and debug code problems virtually. However, the team was amazing and answered all my questions. The team was extremely knowledgeable and friendly."
What topics did you find to be the most helpful and/or interesting? Why?	"How other develop labs such as WPI" (4); "Improve own program/course" (4); "Hardware discussions" (4); "Curriculum sessions" (4)	"I really enjoyed discussion of MRE curriculum."
Which topics were the least helpful and/or interesting to you? Why?	"Lack of DEI topic" (1); "Learning curve" (1); "More suitable for someone is ready for full curriculum" (1)	"We are not ready for a full curriculum yet, so that was less helpful for me at this stage."
What recommendations do you have for improving the workshop?	"Separating the activities based on different levels of pre-experience" (2); "Pre-shared schedule" (2); "Better structured lab introduction" (2); "Suggest to have hands-on experience from Day One" (2); "Proposed student assignments" (2)	"Put less emphasis on Libraries may be. I know this is fine for freshmen, but probably not for higher lever classes."

What topics would you like to see addressed in future workshops or activities?	"More intro activities for K-12 and first-year students" (3); "Curriculum development" (2)	"How to make these activities more accessible to K-12 and first-year college students. And not just very skilled CE/CS students. My 1st-year class has students from all over STEM and most have never programmed before. Teaching C++ at the level presented in the workshop would be impossible and/or frustrating for my students. I wanted to know how to bring this material down to their level while still keeping it engaging and educational. Also, my engineering freshmen are learning MATLAB in their second semester. So knowing how to transfer these activities to MATLAB would have been immensely useful."
After participating in the workshop, what are your plans for integrating or revising mechatronics and robotics engineering education in your institution and/or courses?	"Getting more Pololu robots" (6); "Review and develop the existing course structure" (3); "Develop a new course with new faculty group" (3)	"I am currently teaching an online robotics course using CoderZ curriculum for 3rd and 4th graders. I will be teaching the same group along with an older group this summer face to face. My goal is to use Romi (Lulu) as a demo with the younger students by making a large-scale replica of some of the courses and have Lulu travel the course and show the students the code."

Conclusions and Lessons Learned

Comparison to stated objectives

Overall, the responses of the participants were very positive, even where there were suggestions for improvement. Participants found value in the exercises, even though time constraints prevented them from fully completing the activities. Discussions of curricula and the future of MRE were vibrant and productive.

The workshop had very high impact with respect to preparing MRE educators (Objective 1). 80% of respondents said they felt better prepared to teach Mechatronics and Robotics Engineering concepts and 86% said that the workshop will help them develop or adjust a course; clearly the workshop helped to inspire attendees to develop content for their own courses. In

addition, nearly half of the attendees expected to gain skills in how to teach new topics, while 84% of the attendees said that those expectations were met.

Though expectations for preparing educators were met, we note that the hands-on activities did not fully accommodate the wide variety of skills and interests of the participants, some of whom came from a high-school setting and others having taught upper level college courses (see Figure 5d). Some attendees struggled with the heavy programming load of the activities, as noted by the comments, while others thought the activities relied too heavily on libraries (which might make them hard to adopt at their institution). Nevertheless, the broader discussions of curriculum development, combined with examples of what activities can look like, helped attendees prepare to create content at their own institutions.

The results also indicate that the workshop had a high impact with familiarizing educators with technological and pedagogical advances (Objective 2). In addition to the positive responses noted above, the vast majority of attendees noted the value of the discussions about curriculum.

The workshop had moderate impact on standardizing curricula and the accreditation process (Objectives 3 and 4). A number of participants stated that they intend to develop activities based on material presented at the workshop. Standardization was also a topic of the curriculum discussions, which, as noted above, were well-received. Though creating a specific set of standards was not an explicit goal, we note that by developing a sense of community (see below) among “up and coming” MRE educators, standardization may become easier as those educators discuss and share curricula and ideas.

Finally, the workshop had high impact with generating enthusiasm among MRE educators and promoting diversity in the community. Both the gender and ethnic diversity were far greater than is seen in typical student and faculty populations. [13] The vast majority of participants indicated that they felt connected to the broader community and that they belonged. The comments indicated that participants appreciated the open aspects of the workshop, but more importantly that they wanted ways to *stay* involved, whether through additional workshops or Internet resources. We note that an MRE forum has been established for sharing the ideas and course materials that will allow potential training participants to be involved at an early stage.

Comparison to long-term goals

The workshop helped the organizers move forward with their long-term goals, as well. Given the demographics of the attendees, the workshop was able to promote a diverse community, though one of the future directions would be to invite more educators from historically black colleges, universities, and Hispanic-serving institutions to participate in panels and online forums, which would better ensure a diverse population as the community continues to grow. Given the positive response towards the activities and curriculum discussions, we believe progress was made towards defining MRE as a community and accelerating adoption of materials and curricula.

Some of the curricular discussions centered around accreditation of MRE and MRE as a distinct discipline. Though achieving that recognition was not an objective of this workshop, the organizers were able to obtain feedback from future educators to help guide us in that goal.

Lessons learned

One of the challenges faced in the workshop (and, frankly, in many courses in MRE) was the range of experience of the participants. It is difficult to create materials to satisfy everyone's expectations for the amount of preparation needed. Having student assistants available in breakout rooms helped streamline activities, as attendees were able to work at whatever level suited them, even if they didn't complete all of the activities. Staffing the breakout rooms with students had an additional benefit that participants could talk to students about their experiences, which may help them avoid future pitfalls. Nevertheless, in the future it may be important to scale activities to varying levels of experience or academic levels as well as clearly enumerate expectations in terms of prior knowledge and provide resources for those who wish to undertake preparatory activities.

Some participants asked for more complete "modules" that they could deliver with little modification. The general theme of the workshop was to demonstrate activities and provide resources, but we did not deliver "packaged" modules that could be taken and used with little modification. Part of the rationale was that an educator needs to work though content to understand the material well enough to customize it to their specific needs. However, providing more complete materials, including assessments and lecture materials, would help standardize curricula. We envision that ongoing discussions will lead to a greater amount of prepared materials.

Finally, in order to improve diversity in content, future workshops could include sessions on ethics, bias or systemic racism in focused topics (such as the effects of bias in artificial intelligence) as well as strategies for addressing and mitigating these factors in technology.

Recommendations and Future Work

We recommend the following actions:

- Continue to offer workshops but perhaps separate by the experience level of the faculty or the target student audience for example novice (K-12), intermediate (first-year college students), advanced (upper level or graduate students).
- Create tracks in the same workshop that are delineated by experience level and target student population.
- Create a repository of learning modules codified by level to place on the Mechatronics Education website.
- Encourage participants to share their course materials with the organizers.
- Encourage participants to facilitate a future workshop to share what they have learned and accomplished due to their prior engagement in MRE activities.
- Determine how to modify the robot platform and/or software to include activities that could be completed with other languages, such as Sketch, Blockly, Python, JAVA, Matlab.
- Give more instruction on how to access GitHub, or find other methods to distribute material to reduce barriers to getting started.

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