Workshops for Building the Mechatronics and Robotics Engineering Education Community

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Abstract:
Intelligent Autonomous Systems, including Intelligent Manufacturing & Automation and Industry 4.0, have immense potential to improve human health, safety, and welfare. Engineering these systems requires an interdisciplinary knowledge of mechanical, electrical, computer, software, and systems engineering throughout the design and development process. Mechatronics and Robotics Engineering (MRE) is emerging as a discipline that can provide the broad inter-disciplinary technical and professional skill sets that are critical to fulfill the research and development needs for these advanced systems. Despite experiencing tremendous, dynamic growth, MRE lacks a settled-on and agreed-upon body-of-knowledge, leading to unmet needs for standardized curricula, courses, laboratory platforms, and accreditation criteria, resulting in missed career opportunities for individuals and missed economic opportunities for industry. There have been many educational efforts around MRE, including courses, minors, and degree programs, but they have not been well integrated or widely adopted, especially in USA. To enable MRE to coalesce as a distinct and identifiable engineering field, the authors conducted four workshops on the Future of Mechatronics and Robotics Engineering (FoMRE) education at the bachelor's degree level.

The overall goal of the workshops was to improve the quality of undergraduate MRE education and to ease the adoption of teaching materials to prepare graduates with a blend of theoretical knowledge and practical hands-on skills. To realize this goal, the specific objectives were to generate enthusiasm and a sense of community among current and future MRE educators, promote diversity and inclusivity within the MRE community, identify thought leaders, and seek feedback from the community to serve as a foundation for future activities. The workshops were intended to benefit a wide range of participants including educators currently teaching or developing programs in MRE, PhD students seeking academic careers in MRE, and industry professionals desiring to shape the future workforce. Workshop activities included short presentations on sample MRE programs, breakout sessions on specific topics, and open discussion sessions. As a result of these workshops, the MRE educational community has been enlarged and engaged, with members actively contributing to the scholarship of teaching and learning.

This paper presents the workshops' formats, outcomes, results of participant surveys, and their analyses. A major outcome was identifying concept, skill, and experience inventories organized around the dimensions of foundational/practical/applications and student preparation/MRE knowledgebase. Particular attention is given to the extent to which the workshops realized the project goals, including attendee demographics, changes in participant attitudes, and development of the MRE community. The paper concludes with a summary of lessons learned and a call for future activities to shape the field.

1. Introduction

Intelligent Autonomous Systems, including Intelligent Manufacturing & Automation and Industry 4.0, have immense potential to improve human health, safety, and welfare. Engineering these systems requires an interdisciplinary knowledge of mechanical, electrical, computer, software, and systems engineering throughout the design and development process. Mechatronics and Robotics Engineering (MRE) is emerging as a discipline that can provide the broad inter-disciplinary technical and professional skill sets that are required to fulfill the research and development needs for these advanced systems. As early as 2003, mechatronics was identified by Technology Review as one of the top 10 emerging technologies with potential to change the world [1].

However, despite experiencing tremendous, dynamic growth, MRE has not yet settled on an agreed-upon body-of-knowledge, leading to unmet needs for standardized curricula, courses, laboratory platforms, and accreditation criteria, resulting in missed career opportunities for individuals and missed economic opportunities for industry. To enable MRE to coalesce as a distinct and identifiable engineering field, the authors have conducted four workshops on the future of MRE education at the bachelor's degree level with support from the National Science Foundation and industrial partners.

The overall goal of the workshops was to improve the quality of MRE education and to ease the adoption of teaching materials to prepare undergraduate students with a blend of theoretical knowledge and practical hands-on learning. To realize this goal, the specific objectives were to generate enthusiasm and a sense of community among current and future MRE educators, promote diversity and inclusivity within the MRE community, identify thought leaders, and seek feedback from the community to serve as a foundation for future activities. The MRE workshops were intended to benefit a wide range of participants including educators currently teaching or developing programs in MRE, PhD students seeking academic careers in MRE, and industry professionals desiring to shape the future workforce. Workshop activities included short presentations on sample MRE programs, breakout sessions on specific topics, and open discussion sessions.

2. Background and Motivation

Academic interest in Mechatronics and Robotics has grown considerably from individual courses, minors, and concentrations in CS, ECE, and ME departments to well-developed curricula that define distinct academic programs. An excellent recent survey of the state of robotics education is available in [2]. Although these programs share some common features, they have generally risen independently in the absence of a cohesive community of Mechatronics and Robotics educators. To initiate a conversation with other educators on mechatronics education, one of the authors (VK) organized a Mechatronics Education Innovation Workshop in November 2016 at New York University with financial support from the National Science Foundation and industrial partners [3]. Based on NYU's experience in building a Mechatronics and Robotics program, this workshop initiated a dialog on mechatronics education with other educators in the field. The workshop was attended by more than 70 academic and industrial professionals from around the world. The main conversation topics included: required skillsets for MRE graduates, the role of industry in shaping MRE education, the key components of MRE programs, and how to best balance theory and practice. The fruitful discussions and interactions during the workshop sparked the idea to create an online community where MRE educators can exchange ideas, share curricula and best practices, and continue the conversation.

To this end, in March 2017, two of the authors (NL, VK), with support from Quanser, Inc. launched the Mechatronics Education Community [4], whose website provides an overview of community activities along with a Forum where instructors can connect with colleagues for opinions, feedback, and suggestions. The community also provides a space for sharing useful resources, such as curricula from institutions around the world highlighting undergraduate and graduate mechatronics programs and courses. This repository, which also includes documents describing student project ideas, mechatronics laboratories, whitepapers, workshop materials, and mechatronics education research, has become a rich library useful for anyone interested in building a new mechatronics or robotics program or improving an existing one.

To date, the online community has attracted more than 200 educators and professionals from around the globe. Following the growth in membership and aiming to further engage the community, the Mechatronics Education Community launched a Mechatronics Education Innovation webinar series in September 2017 [5]. The main goal of the webinars is to connect the community to other MRE programs. Despite numerous success stories in implementing MRE programs, there remains a lack of cohesion and unity among MRE educators. Furthermore, considering rapid technological advancements and the changing needs of industry, it is essential to recognize the need for expanding the MRE community and starting a conversation to shape the future of MRE education. The webinar series, the online community, and feedback from our members motivated us to launch a broader effort guided by a vision of the future of MRE.

2.1. Vision and Goals
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.

To reach our vision, our long-term goals are to:

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

3. Approach

To meet these goals, we organized a series of four workshops on the future of MRE education with support from the National Science Foundation and Quanser, Inc. The workshops aimed to achieve the following outcomes:

- Standardize components such as frameworks, curricula, course outlines, experiments, assignments
- Share broad successes of MRE community with college and university faculty to support goal of adoption
- Involve a broad range of colleges and universities
- Partner with professional societies to help create and support champions
- Prepare faculty to teach mechatronics and robotics through hands-on activities
- Foster a diverse, inclusive community of students and educators

To maximize the number of potential attendees, to reach diverse audiences, and to reduce costs, the workshops were conducted in conjunction with existing conferences when possible. The first of these workshops was held at the Dynamic Systems and Control Conference (DSCC), in Atlanta, GA, Sep. 30-Oct. 3, 2018 [6]. DSCC, organized by the American Society of Mechanical Engineers, which typically draws Mechanical Engineering researchers, especially those interested in Control Systems, including Mechatronics. Results of this first workshop are described in [7]. Lessons learned from the evaluation of this first workshop were used to inform revisions in the content and format of subsequent workshops. The second workshop was held at the Robotics Summit and Expo, June 5-6th, 2019 in Boston, MA [8]. With a focus on commercial design and development, tShe Robotics Summit drew primarily industrial professionals with some academic participants. The third workshop was held at the American Society for Engineering Education (ASEE) Annual Conference and Exposition, in Tampa, FL, June 15-19, 2019 [9]. The ASEE Annual Conference brings together professionals in all disciplines of engineering education to enhance curricula and pedagogy. The fourth and final workshop was held at Lawrence Technological University in Southfield, Michigan, September 28-29, 2019. This workshop differed from the first three in that it was a stand-alone event, in contrast to the conference affiliations of the other workshops, allowing more time to consider the topics in greater depth.

At the conclusion of each workshop, participants completed an online survey intended to assess their expectations of, and experiences in, the workshop, as well as their plans for implementing MRE in their respective institutions. The final workshop produced another outcome – a set of draft inventories and commitments by the working groups to refine and publish their findings [10-14].

4. Workshop Descriptions

Each of the first three workshops followed the same general pattern, covering a half-day of three to four hours. The workshop started with brief introductions from the organizers about their background, expertise, and involvement in MRE education. The presentations were followed by two breakout / report-out sessions with a break in between. The sessions were intended to provide an opportunity for workshop participants to discuss important topics related to MRE education. At the beginning of each breakout session, participants were asked to divide into smaller groups based on their topic of choice. Each topic was moderated by one of the organizers.

Figure 1: Workshop 3 Interactive Session.

At all workshops, the interactive breakout / report-out sessions, which generated lively, enthusiastic, and frank discussions, were the most popular part of the workshops (Figure 1).

Each workshop concluded with a summary by the organizers of what was covered and learned. The schedule for workshop 3, shown below, was typical of all workshops in the series, although the topics covered by the parallel sessions varied slightly among the workshops:

1. Introduction and Overview
2. Interactive parallel sessions I
    a. Mechatronic education knowledge base
    b. Robotics education knowledge base
    c. Project-based learning in Mechatronics and Robotics
    d. Advanced and open-source platforms for Mechatronics and Robotics
3. Report out I
4. Interactive parallel sessions II
    a. Reducing barriers to adoption
    b. Accreditation
    c. Preparation to teach Mechatronics and Robotics Engineering
    d. Community-building
5. Report out II
6. Summary

The stand-alone final workshop covered two half-days, totaling eight hours. This enabled a deeper investigation of topics, and the production of more substantive products. As noted in the schedule below, each interactive session included the production of an inventory or action plan that captured the consensus of each group. The final interactive session was further tasked to operate as a set of Working Groups. This gave more structure to the session and led to the formation of working groups that have persisted past the workshops themselves. As with the other workshops, ample break time, plus reception and meals, allowed informal conversations and community-building. The fourth and final workshop format was:

Day 1

1. Introduction and Overview
2. Interactive parallel sessions I
   a. Student Prep – Foundational
   b. Student Prep – Practical: HW/SW
   c. Student Prep – Applied: projects

   Outcomes: Documented Inventories

   Gallery Walk
3. Interactive parallel sessions II
   a. Diversity and Inclusion (D&I)
   b. Industry Engagement

   Outcomes: D&I/Engagement Plans
4. Open Discussion/Next Steps
5. Summary

Day 2

1. Keynote Industry Presentation
2. Interactive parallel sessions III
   a. MRE Knowledge – Foundational
   b. MRE Knowledge – Practical

   Outcomes: Documented Inventories
3. Parallel sessions IV: Working Groups
   a. Textbooks
   b. Hardware and Software Platforms
   c. Adoption
   d. Project-Based Learning

   Outcomes: Action Items
4. Open Discussion/Next Steps
5. Industry Tour (optional)

4.1. Evaluation

The project included frequent formative evaluation activities. At the conclusion of each workshop, participants were asked to complete a short anonymous online survey comprised of both 4-point Likert-scale prompts and short answer prompts. The survey link was distributed at the conclusion of each workshop and participants were encouraged to complete the survey using a personal device prior to leaving the workshop. Most participants completed the survey immediately.

The survey was developed by one of the authors (MJ) in the role of project evaluator in consultation with the workshop organizers. Data analysis was performed by the evaluator and reported to the workshop organizers for both continuous improvement and overall project assessment.

5. Outcomes

5.1. Methodology

First, frequencies were calculated for each of the survey items to determine perceptions of the workshop as well as growth in MRE knowledge and confidence. Second, qualitative methodologies were utilized to analyze the narrative responses. This analysis relied upon the qualitative methodology of open coding; that is, a strategy that divides the narrative data into discrete units of analysis (quotes) reflective of the major themes that are embedded in the words of study participants [15]. The coding scheme represented emergent themes and variables of interest, including challenges and strengths of the workshops. Themes are presented below with illustrative quotes drawn from the participant responses (in italics), staying true to the language of the participants.

5.2. Participant demographics

Sixty-six participants completed a survey from one of the four workshops on MRE Education. The majority of these participants were white, male, and current faculty.

- 74% Male (87% of the sample reporting)
- 68% White; 19% Asian; 12% Black or Latin(x); 2% Other (97% of the sample reporting)

Professional role (97% of the sample reporting):

- Current faculty (78%)
- Students and/or future faculty (14%)
- Industry professionals (8%)

Mechatronics/Robotics teaching experience: The participants reported 1-25 years of experience (70% of the sample reporting):

- 21% More than 10 years;
- 30% 6- 10 years;
- 28% 1-5 years;
- 21% No experience.

For those with no formal MRE teaching experience, some were from 'industry' and had experience conducting formal trainings, others had worked as mentors on research projects, and some others collaborated with MRE students.

5.3. Summary of Formative Evaluation

Eight of the survey questions asked participants to agree or disagree with a statement about the workshop. These questions were scored on a 4-point Likert scale (Disagree a lot=1, Disagree a little=2, Agree a little=3, Agree a lot=4). Workshop 2 had too few survey responses to yield meaningful results, so it is combined with Workshop 3 which took place two weeks later.

Question	W 1 Mean	W 2&3 Mean	W 4 Mean	Overall Mean
1. I knew a lot about mechatronics/robotics engineering (MRE) education prior to participating in the workshop.	2.8	3.1	2.9	3.0
2. After participating in the workshop, my confidence as a MRE educator has increased.	3.2	3.1	3.5	3.3
3 After participating in the workshop, my knowledge of MRE education has increased.	3.4	3.3	3.7	3.5
4. After participating in the workshop, I feel better prepared to teach MRE concepts.	3.1	2.9	3.1	3.0
5. Even if I try very hard, I will not teach MRE as well as I teach other subjects.	1.3	1.7	1.8	1.6

6. I found the activities/discussions during the workshop difficult.	1.7	1.5	1.6	1.6
7. A community of MRE educators was successfully built at the workshop.	3.5	3.2	3.6	3.4
8. I feel like I belong within the MRE community.	3.5	3.4	3.6	3.5

Overall, participants responses from all four workshops were very similar. Evidently, workshop 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 would belong to.

5.4. Reasons for participation: To share experiences and resources

The majority of participants reported having MRE courses and/or MRE lab resources at their respective institutions. Course topics varied widely but most included robotics and/or mechatronics content. Participants reported that they attended the workshops to share experiences and resources with the hopes of further developing MRE courses or programs. One participant explained:

> *My goal is to teach at the undergrad/graduate level. While my background is in MRE, I feel like this multidisciplinary subject has particularly challenging aspects in terms of curriculum generation and presentation. I feel like many of the current courses fall short. I am intensely interested in learning about ways to prepare to teach MRE, as well as to get more involved in the MRE community.*

Participants reported that their students are interested in this growing field and that they hoped their respective institutions would respond. One participant stated:

> *I believe mechatronics is an extremely important area for the future and is exciting and interesting as a draw for students.*

Whether they had plans to start a new robotics major, were trying to incorporate MRE content into their engineering courses, or had established MRE departments, participants wanted to network with others and learn more about the "*best practices and industry standards and relevant/cutting edge topics*," as well as the "*expectations for MRE education and programs*."

5.5. A community of educators was built

Almost all of the participants (94%) agreed that a community of MRE educators was successfully developed at the workshop, with just about half of the sample strongly agreeing that this MRE community was successfully built. And 97% agreed that they experienced a sense of belonging to the MRE community. One participant stated:

While I learned many opportunities and challenges in teaching MRE disciplines, the most valuable thing I came back with is the sense of belonging to the MRE community. I learned what experts are doing and what they are facing and, more importantly, what they think are best approaches to solve many of these challenges.

Participants expressed high levels of satisfaction with the workshops and almost all of the participants named the opportunity to connect with others as what they most enjoyed about the workshops.

I wanted to get more involved with the MRE community and now I have a good number of connections.
I met people from different disciplines with different backgrounds looking for the same goal, to promote mechatronics and robotics education.
I was happy to have met others who want to steer MRE into the future and to hear about individual successes. It's great to see the work being done to form a community around our common interest!

It is likely that these feelings of belonging to the MRE community will inspire the development of MRE courses and programs because the experience of belonging is known to be a strong motivator and has been found to influence learning and behavior in educational environments [16],[17].

5.6. Gains in knowledge and confidence

The majority of the participants had prior experience as instructors of MRE-related topics (79%), either in college courses or labs, and agreed that they knew a lot about MRE education prior to participating in the workshop (72%). Nonetheless, almost all of the participants agreed that after participating in the workshop their knowledge of MRE education increased (97%), with 52% strongly agreeing. Participants identified the most helpful and/or interesting topics to be those that built a mechatronics knowledgebase and prepared participants to teach MRE. The majority of participants agreed that their confidence as MRE educators increased (92%) and that they were better prepared to teach MRE concepts after participating in the workshop (80%).

Participants attributed these gains in knowledge to the community discussions *"that elicited interesting viewpoints from all participants."*

The discussions allowed the participants to get to know one another more closely and helped people to work together and form useful future collaborations. They also allowed people to flesh out their ideas and to better articulate their viewpoints.

Although participants agreed that they had a greater understanding of "*what constitutes MRE*" and "*what is required to start a program*," they also admitted that these discussions revealed how challenging it is to define MRE.

5.7. The scope of MRE

Many participants wrote about how difficult it is to define the scope of MRE because "*There is still much segmentation due to automation-mechatronics misunderstanding*." Because MRE includes elements of mechanical engineering, electrical engineering and computer science, it was difficult to identify how much of each of these fields would contribute to an MRE course or program. One participant stated,

> *I was able to hear about and compare the various efforts in defining what makes a[n] MRE program. There are slight differences in how broad this program can be. Some of the programs cover industrial automation and PLC's, and others are more focused on mobile or aerial objects. Interesting to see what the division line will be drawn.*

Another stated,

> *One thing that became clear during the workshop is that there are no hard and fast definitions of anything in MRE [...]. I think it will be really important for us to define the boundaries of MRE. This would help guide any forays into accreditation, and could equally provide a framework for program and course design.*

In spite of these challenges, participants agreed that further discussions about these boundaries, ones that include industry professionals, would be essential to the future of MRE.

> *It is critical as educators to work with industry, to anticipate the skills needed by them, and to identify the essential fundamental concepts as well as practical experiences that students need sufficient exposure to in order to be able to be employable.*

Participants were concerned about a lack of financial resources, and dedicated faculty, at their home institutions for building MRE departments and courses. Competition between engineering departments was identified as an area of resistance. However, many planned to incorporate the knowledge gained from the workshop into new or existing undergraduate and graduate courses and some intended to develop an MRE concentration. Participants explained that continuing to learn from other academics and industry professionals would inform curricula development and support their efforts at MRE expansion.

I think MRE will grow into a stand-alone program at most engineering schools in the future. Knowing what others are doing is helpful to make a good case for upper university administration when asking for program support.

6. Conclusions and Lessons Learned

Revisiting the original workshop outcomes, we can evaluate the workshops as follows.

- Standardize components: There was general consensus on the need for standard components and progress was made in identifying them. These are documented in several of the workshop publications [10, 12, 13].
- Share broad successes of MRE: This outcome was achieved.
- Involve a broad range of colleges and universities: This outcome was achieved.
- Partner with professional societies: The organizers reached out to professional societies, and industry was involved through an Advisory Board. Nonetheless, more effort is needed to create true partnerships.
- Prepare faculty to teach MRE: As noted by several attendees at the first workshops, scheduling future workshops for a day or more would better prepare faculty to teach MRE. With the longer final workshop, this outcome was partially achieved.
- Foster a diverse, inclusive community: The workshop definitely contributed toward the development of an MRE educational community, that is diverse in some respects (institution types, faculty rank), and not diverse in others (gender, underrepresented minorities).

7. Recommendations and Future Work

We recommend the following actions:

- Extend future workshops to full-day or multi-day events. Time limitations were identified as the most challenging aspects of the workshop because there are "*no hard and fast definitions of anything in MRE*."
- Provide more direction during interactive sessions to enhance their effectiveness. Some participants suggested that would allow for better use of the limited time.
- Spend more time on MRE curricula. Future workshops might target those with established programs to participate in discussions on program and curriculum development, standardization, and accreditation.
- Spend more time on training for delivering MRE courses. Many participants were not ready to consider degree programs and were hoping for more emphasis on course design and delivery, explaining why accreditation and the development of degree programs were identified as the least helpful topics by some participants. "*I would have liked to learn more about what people are teaching and how*."
- Establish a mentoring program where faculty from established programs can guide newly emerging programs. Examples where mentorship could help include: how to develop and

allocate resources for MRE and how to build a strong case to university administration for adopting MRE.
- Redouble efforts to partner with professional societies, which would be necessary for developing program-specific ABET accreditation criteria.
- Make workshops more relevant to industry by being more responsive to industry needs.
- Do more to encourage more diverse participation. The majority of participants were white or Asian men suggesting that more attention must be paid to promote diversity and inclusivity within the MRE community [18][19].

Following these recommendations, the authors are planning additional workshops that will further the vision of MRE as one of the most impactful disciplines of engineering.

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