Work in Progress: Building the Mechatronics and Robotics Education Community

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Building the Mechatronics and Robotics Education Community

Abstract

Mechatronics and Robotics Engineering (MRE) is one of the engineering disciplines that is experiencing tremendous, dynamic growth. MRE professionals are shaping the world by designing smart systems and processes that will improve human welfare. One's ability to meaningfully contribute to this field requires her/him to acquire an interdisciplinary knowledge of mechanical, electrical, computer, software, and systems engineering to oversee the entire design and development process of emerging MRE systems. There have been many educational efforts around MRE, including courses, minors, and degree programs, but they have not been well integrated or widely adopted. Now is the time for MRE to coalesce as a distinct and identifiable engineering discipline. To this end, and with support from the National Science Foundation, the authors have planned three workshops, the first of which has concluded, on the future of MRE education at the bachelor's degree and postgraduate levels.

The objectives of these workshops are to generate enthusiasm and inculcate a sense of community among current and future MRE educators; promote diversity and inclusivity within the community; seek feedback from the community to serve as a foundation for future activities; and identify thought leaders for future community activities. The workshops will benefit a wide range of participants including educators currently teaching in MRE; PhD students seeking academic careers in MRE; and industry professionals desiring to shape the future MRE workforce. These workshops will significantly contribute to the quality of MRE education and increase adoption to prepare individuals with a blend of theoretical knowledge and practical hands-on learning.

Workshop activities include short presentations on sample MRE programs; breakout sessions on topics such as mechatronic and robotics knowledgebase, project-based learning, advanced and open-source platforms, reducing barriers to adoption, accreditation, preparation to teach MRE, and community-building; and open discussion and feedback. In this paper, the outcomes of the first workshop, results of the qualitative and quantitative surveys collected from the participants, and their analyses are presented. Particular attention is paid to attendee demographics, changes in participant attitudes, and development of the MRE community.

1. Introduction

Mechatronics has been defined as "the application of complex decision making to the operation of physical systems" [1], generally emphasizing electromechanical control systems, oftentimes including computer engineering. Robotics is the integration of perception and action through computing [2], placing at least equal emphasis on computer science, and increasingly including artificial intelligence [3]. However, Mechatronics and Robotics appear to be rapidly converging, with computing playing an increasingly important role in the former and physical embodiment in the latter. In this paper, Mechatronics and Robotics Engineering (MRE) refers to the design of systems that could be considered either Mechatronic, Robotic, or both. The question of whether Mechatronics and Robotics should be considered distinct degrees is addressed in subsection 5.1 Content Outcomes.

MRE is experiencing tremendous, dynamic growth owing to recent advances in integrated circuits and electronics, embedded systems and computers, networks, and intelligent systems, as well as democratization of access through open source hardware and software and the Maker Movement. MRE professionals are shaping the world by designing smart and autonomous systems and processes that will improve human life and welfare. MRE requires an interdisciplinary knowledge of mechanical, electrical, computer, software, and systems engineering to oversee the entire design and development process of MRE systems. To prepare students for the needs of industry, many universities and colleges have introduced MRE courses, minors, and degree programs. Furthermore, numerous experimental platforms have been developed and are being utilized to provide engaging, hands-on experiences to students; however, these efforts lack cohesion. Now is the time to unify and standardize educational material, including frameworks, curricula, course outlines, experiments, and assignments to make Mechatronics and Robotics education more widely available.

This paper describes an effort to offer a series of workshops aimed at bringing together MRE educators, students, and professionals, sharing experiences, and initiating efforts towards defining the field. It reports on the results of the first workshop in the series, in which participants discussed recent successes in offering MRE degrees, identified resources and roadblocks to wider adoption of MRE, and contributed to the growing Mechatronics and Robotics education community.

2. Background and Motivation

In recent decades, academic interest and activities in Mechatronics and Robotics have grown considerably from individual courses, or minors, in CS, ECE, and ME departments to mature fields that merit separate academic programs. In November 2016, one of the authors (VK) organized a Mechatronics Education Innovation Workshop at New York University with financial support from the National Science Foundation and industrial partners [4]. Based on NYU's experience in building a Mechatronics and Robotics program, he held this workshop to initiate a conversation on mechatronics education with other educators in the field. This workshop was attended by more than 70 academic and industrial professionals from around the world. The main conversation topics included: required skillset 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, with support from one of the industrial partners, Quanser, two of the authors (NL, VK) launched the Mechatronics Education Community [5]. The main website provides an overview of community activities along with a Forum where instructors can connect with colleagues and ask 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 program or improving an existing one.

So far, the aforementioned online community has attracted more than 160 educators and professionals from around the globe. Following the growth in membership and aiming to further engage the community, the Mechatronics Education Community expanded with the addition of a new Mechatronics Education Innovation webinar series in September 2017 [6]. The main goal of the webinars is to connect our community to other MRE programs around the world. Despite numerous success stories in implementing MRE programs, there still seems to be a lack of cohesion and unity among MRE educators. Furthermore, considering rapid technological advancements and 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 series of workshops.

2.1. ***Engineering Education in Mechatronics and Robotics Engineering***

According to [7], in the early 1990s it was difficult for American companies, unlike their Japanese counterparts, to find U.S. institutions offering mechatronics programs or graduates with formal mechatronics education and training. Several U.S. institutions then launched a variety of mechatronics offerings, e.g., an undergraduate course at University of Arkansas, an undergraduate laboratory at Louisiana State University, the first ABET-accredited mechatronics engineering degree at California State University Chico, and a graduate mechatronics program at University of California Berkeley. However, as of the late 1990s, the U.S. engineering academic community had yet to fully embrace mechatronics and did not envision it gaining a foothold as an independent, viable engineering field [8]. Despite this backdrop of skepticism, in 2003, mechatronics was identified by Technology Review [9] as one of the top 10 emerging technologies with potential to change the world. Over the next decade, many more U.S. engineering institutions began to offer courses, laboratories, and minors in mechatronics. By the late 2000s there were three U.S. undergraduate degree programs in mechatronics: California State University Chico, a joint North Carolina State University / University of North Carolina Asheville, and Colorado State University Pueblo [10].

Robotics did not exist as an undergraduate engineering degree program in the US until 2007 [11], although universities have offered courses in robotics for over four decades and many introductory-level robotics textbooks are available. Leaving aside engineering technology degree programs, a recent survey found that there are now seven Robotics B.S. degree programs in the U.S. [12]. However, many other universities offer courses on various aspects of robotics and mechatronics, including robot programming, mechatronic analysis, mobile robots, automatic control, industrial automation, and cyber-physical systems. Several universities offer a cluster of robotics courses, such as concentrations, minors, threads, or focus areas.

In teaching mechatronics and robotics courses, instructors typically find that students are highly engaged and meet or exceed course objectives. This is not surprising, as these courses include Resnick's 4Ps – projects, peers, passion, play – for developing as creative thinkers [13]

2.2. ***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, the authors are organizing a series of workshops on the future of MRE education at the bachelor's degree (four-year) and postgraduate levels. Each workshop will be held at a different technical conference, resulting in three different (but overlapping) audiences. The main objectives of these workshops are as follows:

- Generate enthusiasm and a sense of community among current and future MRE educators

- Promote diversity and inclusivity within the MRE community
- Seek feedback from the MRE community to serve as a foundation for future activities
- Identify thought leaders for future community activities

The workshops are expected 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

4. Workshop Description

The first workshop in our proposed workshop series towards revolutionizing the future of Mechatronics and Robotics Engineering was held in conjunction with the Dynamic Systems and Control Conference (DSCC) in Atlanta, GA, USA on September 30, 2018. This conference is known to bring together a balanced mix of academic scholars and industrial professionals in the fields of Control, Robotics, and Mechatronics. Although the majority of the conference participants are involved in MRE-related research, little attention is typically given in such technical conferences to the educational aspects of the discipline. Therefore, holding our first workshop in this conference would potentially bring in a new perspective from these individuals.

4.1. ***Participants***

The workshop was publicized through various venues including personal recommendations, advertisements on the aforementioned MRE community website, and emails to technical and engineering education societies. Furthermore, professional societies such as Society of Hispanic Professional Engineers, National Society of Black Engineers, and Society of Women Engineers were contacted to ensure diversity and inclusivity among workshop participants. To promote participation in the workshop and to encourage participation by underrepresented individuals and academic professionals with limited financial resources, workshop travel support had been considered for 20 participants. To this end, an online questionnaire was used to collect information about prospective workshop participants so that travel support recipients could be selected. Three main categories of target audience were considered in designing this questionnaire. More specifically, the workshop participation was assumed to be under one of three categories: current faculty, students/future faculty, and industry professionals. In addition to background information from the applicants, the following questions were asked in each category

- Current Faculty:
  - What concentrations or degree programs does your institution offer in Mechatronics and Robotics Engineering?
  - Please describe/summarize the Mechatronics and Robotics Engineering courses that you have taught, currently teach, or plan to teach (list representative sample).
  - What challenges do you face in Mechatronics and Robotics Engineering education at your institution?
  - Please describe/summarize why you want to be part of this workshop.
- Students/Future Faculty:
  - Please describe/summarize the Mechatronics and Robotics Engineering courses that you have taken at your institution (list representative sample).
  - What challenges do you face in Mechatronics and Robotics Engineering education?
  - Please describe/summarize why you want to be part of this workshop.
- Industry Professionals:
  - How does your industry benefit from Mechatronics and Robotics Engineering graduates?
  - What skills or experience do you need in graduates of Mechatronics and Robotics Engineering programs?
  - Please describe/summarize why you want to be part of this workshop.

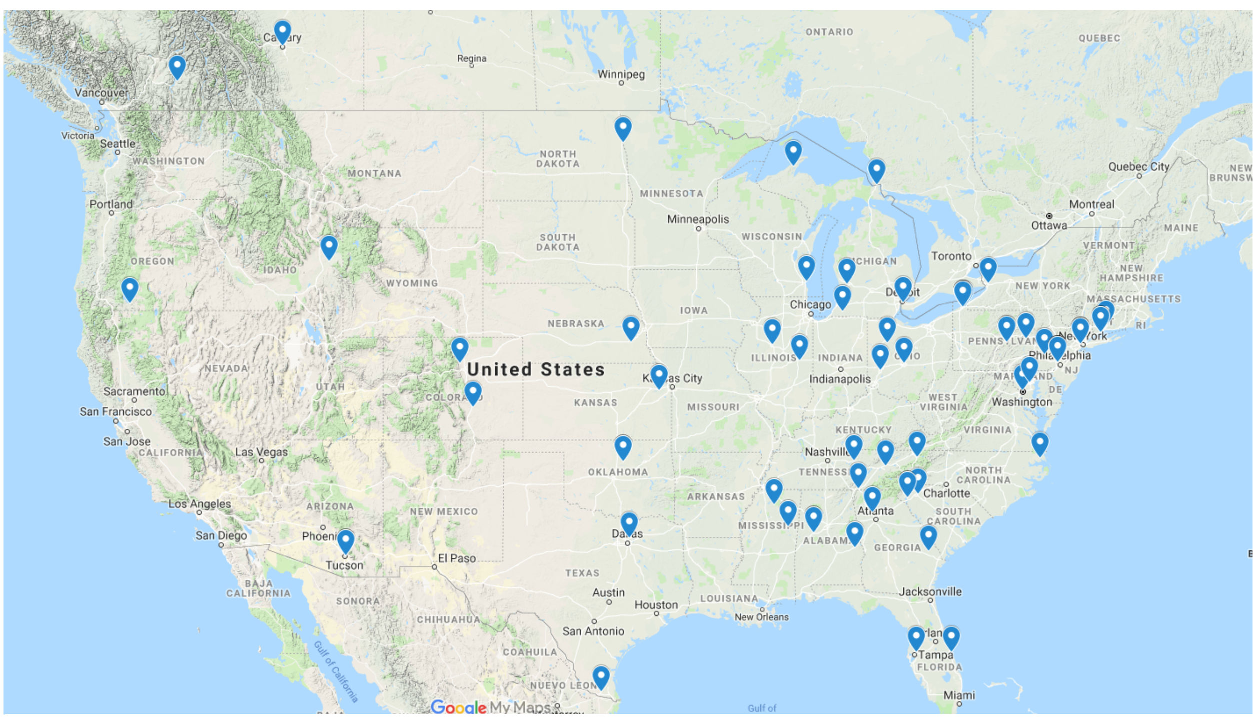

Figure 1. Geographic distribution of support applicants from North America.

At the end of the application deadline, a total of 81 responses from around the world were recorded. Due to the limitations of the funding source, which only allowed travel in North America, only applications received from U.S. and Canada were considered. Figure 1 shows the geographic distribution of workshop travel support applicants from North America. From among these applications, support was provided to 18 participants. Our industrial partner, Quanser, also graciously provided travel support for four additional participants. The main consideration in selecting the travel support recipients was ensuring diversity in applicants' academic rank, prior experience, and industry representation. More specifically, 6 assistant professors, 6 associate professors, 4 full professors, 2 PhD students, and 2 industrial representatives were offered travel support. A total of 34 individuals attended the workshop.

4.2. ***Format***

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 sessions with a break in between. The sessions were intended to provide an opportunity for the workshop participants to discuss important topics related to MRE education. More specifically, at the beginning of each breakout session, the participants were asked to divide into smaller groups based on their topic of choice. Each topic was moderated by one of the organizers at a round table. The topics discussed during the breakout sessions included

- Breakout Session 1
    - Mechatronic education knowledgebase
    - Robotics education knowledgebase
    - Project-based learning in MRE
    - Advanced & open-source platforms
- Breakout Session 2
    - Reducing barriers to adoption
    - Accreditation
    - Preparation to teach MRE
    - Community-building

These sessions were met with great enthusiasm from the participants (Figure 2) as various important MRE-related problems and possible solutions were discussed. The breakout sessions were followed by a brief wrap-up conversation among the organizers and the participants.

Figure 2. Workshop Interactive Session

*4.3. **Evaluation***

The project includes frequent formative evaluation activities. At the conclusion of each workshop, participants are 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 the first workshop and participants were encouraged to complete the survey using a personal device prior to leaving the workshop. As there was not an event immediately following 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. An additional report by the evaluator will be completed at the conclusion of the workshop series.

5. Outcomes

The first workshop produced two distinct outcomes. On the one hand, the attendees generated many useful ideas around the nature of Mechatronics and Robotics Engineering Education. These are the content outcomes summarized in the next subsection. Another outcome was the formative assessment conducted at the conclusion of the workshop and the insights thereby gained.

5.1 Content Outcomes

The interactive sessions generated many good ideas that the community should consider to advance MRE education, including:

- There is no clear boundary between Mechatronics and Robotics. This applies in many contexts: program goals, student outcomes, courses, projects, and jobs. Although Mechatronics education knowledgebase and Robotics education knowledgebase were in separate breakout groups, the groups generated highly similar content.
- A corollary of the above is that if specific engineering accreditation criteria were to be developed for MRE, a single unified set of criteria for both Mechatronics and Robotics should suffice, rather than distinct sets of criteria.
- There is a need for interdisciplinary thinking to develop program like these at the intersection of traditional disciplines. This, despite some resistance from traditional departments.

- Hands-on and active learning are important for students learning the content and educators learning how to deliver the content. Fortunately, MRE is especially amenable to meaningful project work.
- Open source platforms can make it easier for faculty to adopt new courses and methods.
- There remains a need to incentivize faculty to further their professional development. It is hard for faculty to develop adequate knowledge on their own and on their own time.
- Challenges remain in bringing together a diverse and inclusive community.

5.2 Formative Assessment Outcomes

At the conclusion of the workshop, participants were asked to complete an on-line survey. The 34 attendees included six organizers and representative from the industry sponsor. Of the remaining 28 participants, 21 responded to the survey.

Overall, participants left feeling more knowledgeable and confident about MRE education. Although 67% agreed that they knew a lot about MRE education prior to participating in the workshop, 95% agreed that their confidence as MRE educators increased, and 100% agreed that their knowledge of MRE education increased after participating in the workshop.

Another set of questions solicited open-ended responses around participant backgrounds, workshop expectations, content, and recommendations. Ninety percent had prior experience as instructors of MRE-related topics, either in college courses or labs. However, at their current institutions, 41% reported having MRE courses and/or well-equipped MRE lab resources, 35% had some, and 24% reported having no courses or lab resources.

Question	Disagree a lot	Disagree a little	Agree a little	Agree a lot	Mean
I knew a lot about mechatronics/robotics engineering (MRE) education prior to participating in the workshop.	2	5	10	4	2.76
After participating in the workshop, my confidence as a MRE educator has increased.	1	0	13	7	3.24
After participating in the workshop, my knowledge of MRE education has increased.	0	0	12	9	3.43
After participating in the workshop, I feel better prepared to teach MRE concepts.	1	4	8	8	3.10
Even if I try very hard, I will not teach MRE as well as I teach other subjects.	14	7	0	0	1.33
I found the activities/discussions during the workshop difficult.	10	8	2	1	1.71

A community of MRE educators was successfully built at the workshop.	0	1	9	11	3.48
I feel like I belong within the MRE community.	0	1	9	11	3.48

Participants reported that they attended the workshop to share experiences and resources with the hopes of 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."*

Almost all participants (95%) agreed that a community of MRE educators was successfully developed at the workshop and that they experienced a sense of belonging to the MRE community. Participants identified peer interactions as the most enjoyable aspect of the workshop.

> *"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!"*

Participants reported that the most helpful and/or interesting topics were Mechatronics knowledgebase, Project-based learning, and Preparation to teach mechatronics and robotics engineering. They also reported that the most challenging aspect of the workshop was time limitations.

> "*It easily could have been extended to a full day workshop where participants were expected to come back from round table discussions with concrete lists of recommendations or guidelines.*"

Participants came from a variety of institutions, some of which have more established MRE programs and courses than others. 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.*"

6. Conclusions and Lessons Learned

Revisiting the original workshop outcomes, one can evaluate the workshop as follows:

- Standardize components: There was general consensus on the need for standard components and progress was made on identifying them, although a single workshop did not result in an agreed-upon set of standard components.
- 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 several professional societies, and industry was involved through an Advisory Board. Nonetheless, a more concerted effort is needed to create true partnerships with professional societies.
- Prepare faculty to teach MRE: As noted by several attendees, scheduling future workshops for a day or more would better prepare faculty to teach MRE.
- Foster a diverse, inclusive community: The workshop definitely contributed toward the development of an MRE educational community, which is diverse in some respects (institution types, faculty rank) and not diverse in others (gender, under-represented minorities).

7. Recommendations and Future Work

We recommend the following actions:

- Extend future workshops to full-day or multi-day events.
- Provide more direction during interactive sessions to enhance their effectiveness.
- Spend more time on MRE curricula.
- Spend more time on training for delivering MRE courses.
- Establish a mentorship program where faculty from established programs can guide newly emerging programs.
- Redouble efforts to partner with professional societies.
- Make workshops more relevant to industry.
- Do more to encourage more diverse participation.

The first workshop was successful overall. Lessons learned will improve the next workshops and provide a foundation for larger, more comprehensive efforts in the future.

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