Workshop Development for New Frontier of Mechatronics for Mobility, Energy, and Production Engineering

Article history
Received
15 September 2024
Received in revised form
10 November 2024
Accepted
18 November 2024
Published online
30 December 2024

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Abstract

Mechatronics is a multidisciplinary engineering field that integrates mechanics, electronics, control theory, computer science, communications, power, and production manufacturing, reflecting the trend toward deep cross-disciplinary collaboration. With applications in e-mobility, connected and autonomous vehicles (CAV), robotics, and unmanned aerial vehicles (UAV), the expanding mechatronics industry demands a workforce with broad, multidisciplinary training. This paper details the activities and outcomes of an NSF-funded ECR: PEER (EHR Core Research: Production Engineering Education and Research) project, which organized two workshops at Wayne State University (WSU) and California State University Long Beach (CSULB). These workshops aimed to gather insights from experts across academia, industry, and non-profit sectors to shape the future of mechatronics education and production. Over two days, professionals addressed challenges in workforce development for production engineering in mechatronics, covering educational pathways, advancements in teaching methods, and the social impacts of mechatronics technology. The workshops had distinct focuses: WSU concentrated on ground mobility technologies, while CSULB emphasized aerospace applications. A survey conducted at the end of the workshops evaluated their effectiveness, with the results informing future improvements in mechatronics workforce education.

Keywords: Mechatronics, Workforce development, Production Engineering, Workshop.

Introduction

Mechatronics is a multidisciplinary field of engineering that seamlessly integrates mechanics, electronics, control theory, computer science, telecommunications, power, and manufacturing production. The concept of convergence research [NSF 2017] emphasizes not only the inclusion of multiple disciplines but also their deep integration, forming new frameworks that catalyse scientific discovery and innovation. Mechatronics aligns perfectly with this trend of convergence engineering, facilitating deep cross-disciplinary integration. It is driven by the active pursuit of addressing specific societal challenges and opportunities. Developing a robust mechatronics industry requires a highly skilled workforce equipped with multidisciplinary knowledge and practical training.

This paper reports the outcomes of an NSF-funded project in USA aimed at advancing workforce development in mechatronics and its applications in production engineering through the organization of workshops. The project was a collaborative effort between two institutions: The Division of Engineering Technology at Wayne State University (WSU) and the Departments of Chemical Engineering and Mechanical & Aerospace Engineering at California State University, Long Beach (CSULB). The workshops explored educational systems and pathways for workforce development in mechatronics, including pedagogies, tools, and assessment methods; technological advancements in mechatronics; and the societal impacts, such as workforce diversity. A post-workshop survey was conducted to assess the effectiveness of these workshops.

Figure 1 illustrates the elements that comprise mechatronics, which includes knowledge from electrical/electronic engineering, mechanical engineering, control theory, and computer science. A mechatronics system is a complex device powered by electrical and/or mechanical sources, equipped with sensors that detect environmental changes. These sensors send signals to microcontrollers or computers through transducers, which then trigger actuators and mechanical parts to perform one or more tasks automatically using control theories. Mechatronics has wide-ranging applications, including automotive, aerospace, medical, manufacturing, defense, and consumer products. A cyber-physical system is a type of mechatronics system that is computer-controlled and tightly integrated with the internet, with its physical and software components deeply intertwined. In the automotive industry, the latest applications include electric vehicles (EV) and connected and autonomous vehicles (CAV). In manufacturing, robotics and smart factories are prominent, while in aerospace, drones, unmanned aerial vehicles (UAV), and advanced avionics are key applications.

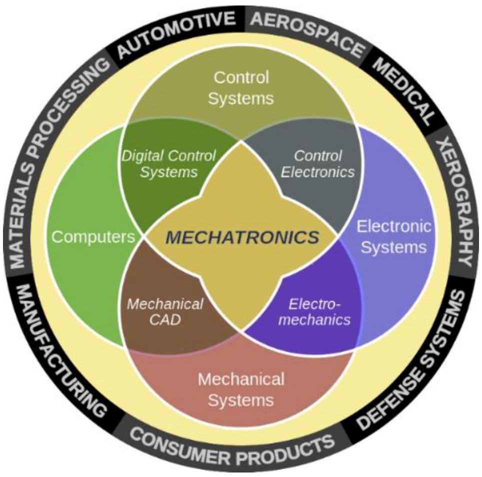

Figure 1. A Euler diagram by K. Craig from RPI's website describes the fields making up mechatronics.

The expanding mechatronics industry demands a high-quality workforce with multidisciplinary knowledge and training. This workforce can be sourced from recent graduates of colleges and universities or from workers displaced by automation and robotics in manufacturing. These displaced workers can re-enter the workforce through conventional pathways such as community colleges or through new pathways like industry-provided training programs, academic institutions, or other professional development organizations. The curricula at two-year colleges and four-year universities should be reviewed and updated to meet the emerging challenges of mechatronics in manufacturing. Graduate schools also play a crucial role in preparing higher-level workforces capable of conducting fundamental research and exploring new technologies in mechatronics. K-12 schools are vital in fostering the future workforce for all STEM areas. To effectively analyze workforce needs and organize educational resources, data and information from labor statistics agencies are essential. WSU and CSULB are gathering information from the Workforce Development Agency of Michigan [Michigan n.d.] and The State of California Labor & Workforce Development Agency (LWDA) [California n.d.]. WSU has a long-standing collaboration with the Workforce Intelligence Network for Southeast Michigan (WIN) [Workforce Intelligence Network n.d.] on workforce development in the greater Detroit area and consults the Michigan STEM education network [MiSTEM n.d.] for K-12 STEM education. Plans are in place to further collaborate with federal statistics agencies to collect longitudinal data on factors influencing career pathways, particularly for women, underrepresented minorities, veterans, and individuals with disabilities.

The advancement of mechatronics technologies has also enhanced the tools used to teach the subject. In recent years, affordable microcontrollers, along with peripherals such as sensors and actuators, have become popular in STEM education. Devices like Arduinos, Raspberry Pi, and LEGO controllers enable students to create projects by wiring electrical devices and writing code to control them [Mynderse & Shelton 2014, Reck & Sreenivas 2016]. These microcontrollers are cost-effective yet perform industry-level functions, making them suitable for prototyping or even commercial products. With wireless communication modules, these devices can be integrated with smart systems and controlled via apps, facilitating the development of advanced systems such as cyber-physical systems and the Internet of Things (IoT). The proliferation of desktop 3D printers - another example of mechatronic systems - has further simplified the creation of customized parts for building other mechatronic systems. In the workshops, WSU and CSULB collaborated with educational tool suppliers such as Quanser [Quanser n.d.]. Additionally, virtual reality (VR) has emerged as a promising technology in STEM education and workforce training, providing a platform for remote education. Various pioneers have explored the use of extended reality (XR) in teaching [Hafner et al. 2013, Piguet et al. 2001, Müller & Ferreira 2003] and professional training, including initiatives by Bosch [Bosch Media Service 2018].

Supported by the NSF ECR: PEER program and the Boeing Company, two workshops were organized to discuss the educational systems and pathways for workforce development in mechatronics; pedagogies, tools, and assessment methods for learning; technological progress in mechatronics; and societal impacts, such as workforce diversity. The first workshop was held on September 16-17, 2021, in the Detroit, Michigan area, organized by the WSU team. The second workshop took place on September 17-18, 2021, in Long Beach, California, organized by the CSULB team. Each workshop spanned two days, covering topics such as the current workforce situation in the industry, existing pathways for workforce development, traditional college and university training programs, and K-12 STEM education preparation in mechatronics. The workshop themes varied slightly based on the regional focus of the two institutions. In Detroit, the discussions centered around mechatronics technologies for alternative energy and ground mobility, reflecting Detroit's status as the hub of the automotive industry and its supply chain. In Long Beach, the focus was on aerospace, alternative energy, and related applications. The preparation for these workshops was presented at the 2020 ASEE conference [Chen et al. 2020]. This paper presents the motivation, vision, and outcomes of these workshops. The agendas included the speakers, their affiliations, and presentation titles. The survey results were analyzed and discussed to evaluate the effectiveness of the workshops, with lessons learned to be applied to future similar activities.

Background and Motivation

The primary motivation to conduct the workshop was based on the need to understand and bridge the gaps between education and industry related to the preparation of the workforce [Alboaouh 2018]. Several studies have shown that there is a significant disconnect between the educational outcomes of university and college programs and the needs of the industry [Bucak 2007, Brunhaver 2017]. This disconnect has been identified by both industry as well as professional organizations as a significant barrier to ensuring competitiveness in the marketplace [Siemens 2024, National Academies of Engineering 2019, Barton 2023, Sellery 2024]. The skills that industries expect from practicing engineers are not taught in typical undergraduate and graduate programs [Trevelyan 2019, Bilgin 2023]. Some of this is related to the rapid evolution of technology within the industry which is not matched by the evolution of the academic programs [Li 2023]. This is especially true in interdisciplinary STEM areas such as Mechatronics where the rapid evolution in AI, materials and electronics has provided an opportunity for development of novel automated systems. However, the students in traditional STEM degree programs may not be prepared to design or analyze these systems when they join the workforce. One of the solutions that has been proposed is to bring together personnel from industry and academia to identify and bridge these training gaps [Zeidan 2020]. This has been accomplished using several mechanisms including surveys [Fletcher 2017] and workshops [MIT 2021]. Our goal was to conduct the workshop specifically to address the gaps in the interdisciplinary field of mechatronics education.

Mechatronics and Workforce Development

Mechatronics is both a multidisciplinary and interdisciplinary science [Habib 2007] that integrates knowledge from fields such as electronics, mechanics, control theory, robotics, computer science, and even biomedical and chemical engineering. Typically, a mechatronics system involves the automation of electrical and mechanical devices to perform specific tasks. The demand for more complex tasks drives the development of new mechatronics technologies, which, in turn, inspire innovative applications. Traditionally, workforces in the production industry only needed expertise in a specific area of their training. However, as manufacturing systems become increasingly complex due to the integration of mechatronics technologies, workers now face the challenge of communicating effectively with colleagues across different disciplines.

Most of today's workforce has been educated through conventional systems, starting at two-year colleges, progressing to four-year universities, and, for some, continuing to graduate schools. These educational paths typically begin with fundamental STEM courses (mathematics, physics, and chemistry) before focusing on specialized courses in particular professional fields. This approach often leaves little room for incorporating multidisciplinary topics into the curriculum. There is a critical need to emphasize and address interdisciplinary approaches in engineering education [Allen 2006]. The lack of interdisciplinary education and its importance to workforce development have been highlighted by [Mayer-Krahmer 1997]. Mechatronic innovations are often stimulated by an integrated discipline approach [Cintra Faria & Barbalho 2023], and the full potential of interdisciplinary solutions results from bridging the gap between product technologies and engineering disciplines [Mayer-Krahmer 1997, Wikander & Torngren 1998].

To enhance college-level mechatronics workforce education, two approaches can be adopted: First, creating new pathways outside traditional schools, such as training programs provided by industries and social service organizations, which focus on practical, hands-on training. Second, reforming the curricula in conventional schools to incorporate interdisciplinary learning, aligning with the current needs of the mechatronics workforce. Integrating STEM education into K-12 education to develop a STEM-capable workforce has already been explored [Honey et al. 2014]. Mechatronics is a crucial component in preparing K-12 students for STEM careers, necessitating the development of new teaching methods and additional resources for both students and teachers. Ultimately, the design of education and workforce development pathways must align with industry needs, which was a central theme in the workshops.

In addition to modifying and integrating educational systems and strengthening the relationship between schools and industries for STEM workforce development, it is essential to address the technical elements used in both introducing the latest mechatronics technologies and in teaching methodologies and tools. During the workshops, industry professionals revealed current challenges and future trends in both the markets and technologies of mechatronics, while university faculty and researchers introduced the latest inventions and research in the field. Faculty members from engineering education programs at colleges and universities, along with K-12 teachers, shared their experiences and ideas for new teaching methods and tools, particularly those involving innovative technologies like apps, design software, microcontrollers, and virtual reality. Furthermore, experts discussed the social and economic impacts associated with the development of mechatronics technologies and the growing workforce in the production industries.

Workshop Goal and Objectives

The objectives of the workshop on STEM workforce development in mechatronics for production engineering can be summarized into two key areas: workforce analysis and training methodologies, and technology development and its impacts. The planned topics related to workforce education included:

- New providers and pathways of education and training.
- Inquiring the needs of industry employers.
- Examining college and graduate level education and their impacts on STEM workforce readiness.
- Prepare K-12 education for the farther future workforce needs.

The themes for targeting new and prospective mechatronics technology developments are:

- The trend of mechatronics applications
- New research and technologies in mechatronics
- New education technologies for mechatronics
- Social impacts of new mechatronic technologies

Workshop Organization

Advisory Committee

The successful development and implementation of all proposed activities necessitates a coordinated system for the exchange of information and resources, as well as the effective utilization of institutional strengths. To achieve this, collaboration among faculty, administrators, and industrial partners from both institutions was formalized through the establishment of an advisory committee. Members of the Joint Industry Advisory Boards from both institutions, particularly those from industry, were invited to serve on and advise the committee. The committee members met regularly via online meetings and teleconferences to plan, execute, and monitor the project progress.

Schedule and Location

Two workshops were organized to support mechatronics workforce development in production manufacturing. These workshops targeted university and college faculty, K-12 teachers, graduate students, and researchers in mechatronics-related fields, as well as technical, administrative, professional development, and human resource personnel from industry. The first workshop, managed by the WSU team, took place in the Detroit area and focused on mechatronics applications in ground mobility and alternative energy. The second workshop, managed by the CSULB team, was held in the Long Beach area and centered on mechatronics applications in aerospace. Each workshop spanned two days: the first day concentrated on mechatronics workforce education systems and pedagogies, while the second day was dedicated to current and emerging mechatronics developments and technologies that can be applied to workforce education. The workshops were recorded and live-streamed to the general public via YouTube and other social media platforms. During the Q&A sessions, the live stream was converted into a webinar format to enable in-depth interactions between local and remote participants. The workshop schedule and topics are shown in Table 1 and Table 2, respectively, where the details can be found at [ECR Workshop, 2021].

Workshop Evaluations

An online survey using the Quatrics software on both university websites was given to the participants to evaluate the workshop. The survey had three main categories, regarding the participants' backgrounds (question 1 and 2), their opinions to the workshop setups (question 3 and 4), and their evaluations of the workshop effectiveness (questions 5 - 8). There were a few sub-questions using the five-point Likert scale with 5 being Strongly Agree and 1 being Strongly Disagree [Spooren et al. 2007].

Question 1 investigated the current jobs/positions the participants were. We found the results basically included all the targeted groups. Although there was no industry professional checked in the WSU survey, we believe the two "others" can be counted in this catalog. One of the "others" of CSULB was a CSULB College of Engineering staff member. Question 2 explored the professional specializations of the participants. The CSULB result was very diverse, while the backgrounds of the WSU participants were more concentrated in the electrical and mechanical areas. The 11 CSULB aerospace background and the 2 WSU automotive background participants demonstrated the targeted groups based on the workshop themes. The questions and the results are listed in Table 3.

Table 1. The two-day workshop agenda of WSU[1]

Session Title	Affiliation
Accelerated Mechatronics Program	Macomb Community College
Mechatronics and Model Based Development for EV's and ADAS applications	Siemens Digital Industries Software Engineering & Consulting Services
Modular Educational Certification for Advancing Training Online through Industry Collaboration (MECHATRONIC)	Oregon State University
Online Session: Mechatronics Education Tools	Quanser
Apprenticeship overview Baker College Training Business/Company view Panel Discussion	Mega Session Michigan Department of Labor and Economic Opportunity
Inspiring Tomorrow's STEM Workforce through Project-based Learning	Michigan Square One Education Network
Smart Sensors for Mobility Energy and Production Applications	University of Alabama

Table 2. The two-day workshop agenda of CSULB[1]

Session Title	Affiliation
Multidisciplinary Environment for Research and Education on Increased Autonomy of UAVs	Department of Aerospace Engineering, UAV Lab Director, Cal Poly Pomona
Mechatronics for Automated Test Equipment Development	Boeing Defense Systems
The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) Integration and Test Campaign	JPL MOXIE
Starting High School Students on the Path to Careers in STEM	Sato Academy of Mathematics and Science
A Taxonomy of Modern Mechatronics: Classification and Dissection of Autonomous Electromechanical Systems for Scaffolded Skills-Based	Quanser
Learning Experiences, Mechatronic Systems Design – A Pedagogy	California State University, Long Beach
A Journey in Curiosity: The Lego Pieces of an Engineering Career	Northrop Grumman Corporation
Continuously Evolving Mechatronics Education Challenges for GNC, Mechatronics and Autonomy	The Aerospace Corporation
Exploring the CAVE Collaborative Autonomous Vehicle Ecosystem	The Aerospace Corporation
Talent Development for Workforce of the Future through Skill-based Training	Cypress College

Table 3. Question 1 and 2 and the response frequencies of WSU and CSULB.

Question 1. Are you a:							
	4y university faculty	2y college faculty	K-12 teacher	4y university student	2y college student	Industry professional	Other
WSU	2	1	1	9	3	0	2
CSULB	6	1	1	22	5	2	1

Question 2. Please indicate your top area of specialization using the list below:										
	Electrical	Mechanical	Computer	Control	Robotics	Chemical	Automotive	Aerospace	Biomedical	Other
WSU	9	2	0	0	1	0	2	0	1	3
CSULB	5	12	6	1	1	1	0	11	0	1

[1] See the full schedule in [ECR Workshop, 2021].

Question 3 asked about the length of the workshop. All of the WSU participants and most of the CSULB participants thought they had right lengths. Question 4 found that most of the participants of both WSU and CSULB felt the workshops had intermediate level of topics and materials. The questions and the results are listed in Table 4.

Table 1. Question 3 and 4 and the response frequencies of WSU and CSULB.

Question 3. Given the topic, was this workshop:			
	Too short	Right length	Too long
WSU	0	18	0
CSULB	1	28	9
Question 4. In your opinion, was this workshop:			
	Introductory	Intermediate	Advanced
WSU	6	10	2
CSULB	9	26	3

The detailed descriptions of Question 5 to 7 are listed in Table 5. Question 5 inquired the workshop contents and materials. Both WSU and CSULB obtained generally good feedbacks (means larger than 4). Only the item "The content was as described in publicity materials" of CSULB survey had a lower score. Question 6 showed the ratings for the speakers. Both WSU and CSULB obtained generally good feedbacks (means larger than 4). Question 7 was for the ratings for attending the workshop. Again, both WSU and CSULB obtained generally good feedbacks (means larger than 4). However, for the item "The workshop was applicable to my job.", both surveys showed lower scores compared with other items in this question. It suggested a potential improvement can be made in the future.

Table 5. The questions 5 to 7 and their sub-questions.

Question 5. Please indicate your ratings for the workshop content:	
5.1	The content was as described in publicity materials.
5.2	The content followed the learning objectives.
5.3	The talks were given in a way that helped me learn.
5.4	The talks were given at an acceptable pace.
5.5	The slides contained sufficient technical information.
Question 6. Please indicate your ratings for the speakers:	
6.1	The speakers are knowledgeable on the topics.
6.2	The speakers stated the learning objectives clearly.
6.3	The speakers presented in an organized manner.
6.4	The speakers encouraged interactions and questions.
Question 7. Please indicate your ratings for attending this workshop	
7.1	My expectations for attending the workshop were met.
7.2	The workshop was applicable to my job.
7.3	I would recommend this workshop to others.
7.4	I would be interested in attending a follow-up, more advanced workshop on this same subject.

Question 8 queried about the hardware and facilities of the workshops (visual, acoustic, in-person, and online), 1 to 5 scales for satisfactions levels (Table 6). The WSU results showed high means (larger than 4) for all the four factors but with also high standard deviations (three larger than 1). The in-person setup and acoustic effects of the CSULB workshop had lower means (below 4), which can be improved in the future for similar activities. All other comments were in Question 9. The means and standard deviations (SD) of the Question 5 to 8 responses are listed in Table 7 and graphically presented in Figure 2. The statistics analysis is based on the full sample spaces from both institutes, for the smaller participant numbers due to COVID-19 restrictions.

Table 2. Questions 8 and the sub-questions.

Question 8 - Please indicate your overall rating for the workshop:	
8.1	Visuals
8.2	Acoustics
8.3	Meeting venue (In-person attendance)
8.4	Webinar (Online attendance)

The Likert scale responses from WSU generally show higher means and lower SDs compared to those from CSULB for most questions, reflecting CSULB's larger participant pool and more diverse areas of specialization (from Question 2).

Table 7. The means and SDs of questions 5 to 8.

Questions	**WSU**		**CSULB**	
	Mean	**SD**	**Mean**	**SD**
5.1	4.39	0.68	3.86	1.16
5.2	4.47	0.70	4.08	0.95
5.3	4.39	0.89	4.14	0.98
5.4	4.59	0.77	4.25	0.83
5.5	4.50	0.83	4.22	0.95

6.1	4.67	0.94	4.71	0.81
6.2	4.39	1.01	4.26	0.87
6.3	4.56	0.96	4.31	0.85
6.4	4.61	0.95	4.09	1.16
7.1	4.17	1.07	4.23	0.99
7.2	4.11	0.94	4.17	1.03
7.3	4.44	1.01	3.80	1.09
7.4	4.33	1.11	4.06	1.04
8.1	4.39	1.01	4.29	0.78
8.2	4.28	1.04	3.80	0.98
8.3	4.44	1.07	3.32	1.54
8.4	4.53	0.72	4.33	0.80

Critical Reflection Discussion

A lower score in the CSULB survey for Question 5.1 suggests that managing participant expectations through clear communication could improve satisfaction. Future workshops could ensure consistency between advertised objectives and actual content to enhance perceived relevance.

Ratings for Question 7.1 were notably lower across both locations, indicating a gap between the content provided and the practical needs of attendees. This suggests an opportunity to incorporate more job-specific case studies or hands-on sessions tailored to specific industries, making the workshop content more directly relevant to participants' work.

Most participants felt the workshop length was appropriate, and the content was at an intermediate level (Questions 3 & 4). This balance suggests that the workshops successfully catered to a mid-level understanding of mechatronics topics. However, to meet the needs of those seeking either introductory or advanced content, future iterations could consider offering parallel sessions at varying complexity levels, providing a more customized learning experience for diverse participant needs.

Workshop Impacts

Network Building

Oregon State University, also an ECR program awardee in Mechatronics, was invited to share their experience in developing and deploying an online mechatronics certificate curriculum. Both WSU and CSULB established connections with community colleges, laying plans for future collaborations on workforce training and student transfer programs in mechatronics. Additionally, the Michigan Department of Labor and Economic Opportunity outlined state-supported educational and industry resources available for advancing mechatronics. Participants also had valuable opportunities to engage directly with industry representatives to discuss career paths and explore potential job opportunities in the field.

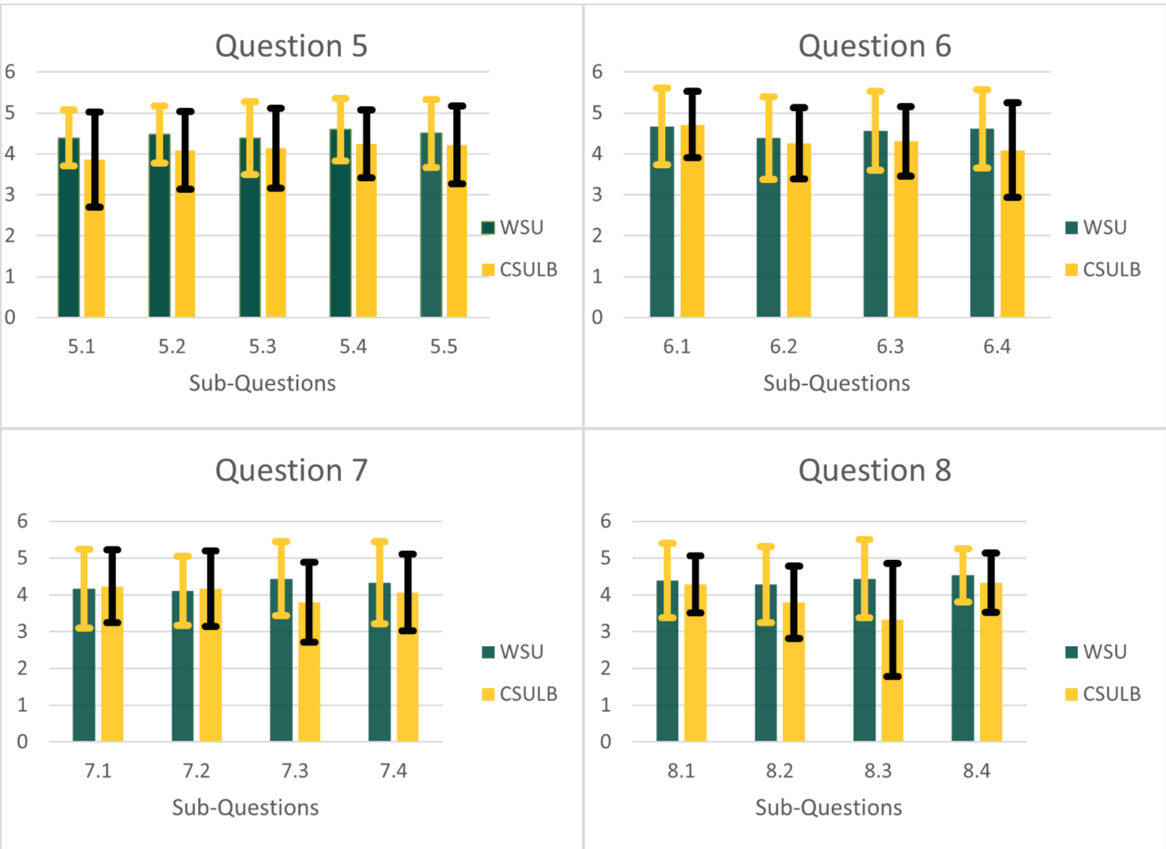

Figure 2. The means and standard deviations of the Question 5 to 8 responses.

Advanced Knowledge in Mechatronics

The industry leaders, including Siemens, Boeing, Northrop Grumman, and The Aerospace Corporation, presented the latest advancements in mechatronics technologies, offering participants valuable insights into current industry developments. Quanser also introduced their educational tools for mechatronics, which hold significant potential for use in mechatronics courses.

Mechatronics Course Development and Updates

The knowledge and materials presented during the workshops have informed and enhanced curriculum development at both institutions. For instance, new materials are incorporated into the course of ET 5100 Fundamentals of Mechatronics and Industrial Applications on sensors, controllers, and electric and automotive vehicle technologies at WSU, and MAE 476 Mechanical Control System I at CSULB. Additionally, some laboratory equipment was upgraded to align with the latest industry standards discussed during the workshops.

Conclusion

This project recognized an emerging and imminent need for workforce with skills in mechatronics technology for production engineering and manufacturing. High-quality workforces serving knowledge-intensive jobs provided by the innovative enterprises that lead to discovery and new technology are the assurance of the U.S. economy and American people's living standard. Mechatronics is one of the significant technologies that change and impact the future living style, community and society, and economics. The most current and popular applications of mechatronics include e-mobility, connected and autonomous vehicles (CAV), robotics, and unmanned aerial vehicle (UAV). The growing mechatronics industries demand high quality workforces with multidiscipline knowledge and training. Wayne State University (WSU) and California State University Long Beach (CSULB) were funded an ECR: PEER (EHR Core Research: Production Engineering Education and Research) project from NSF to organize two workshops to address this issue of workforce development in mechatronics.

We present in this paper our efforts and results of these two workshops. The workshops took two days, with professionals invited to address the current challenges of workforce development in mechatronics for production engineering. The topics include education opportunities and pathways, technical development of teaching methods and tools, as well as social impacts related to mechatronics technology. The workshop themes were partially different based on the expertise and locations of the two institutes. WSU focused on the mechatronics technologies in production engineering for ground mobility, and CSULB concentrated on production engineering in aerospace applications. A survey was designed and provided at the end of the workshops, while the statistics and results were analyzed to evaluate the effectiveness of the events and the overall results were positive. Although the NSF project was completed, the program is still active in both institutes to promote mechatronics and the corresponding workforce training. Certainly, the experiences and lessons we obtained from these workshops will be applied in the future events, to strengthen the program and encourage more students to pursue advanced studies and careers in the growing mechatronics applications in the industry.

Acknowledgement

This work was supported by NSF ECR PEER 1935633.

Conflict of Interest

The authors declare no conflict of interest.

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