Experiential Learning for the Mechatronics Workforce in the Upper Peninsula of Michigan

Abstract

Michigan Tech, West Shore Community College (WSCC), and Gogebic Community College (GCC) collaborate on the NSF ExLENT project aims to provide experiential learning opportunities in Mechatronics for a diverse STEM workforce. The program and its impacts are aligned with the regional economic needs of the Upper Peninsula and Northern Michigan areas. The emerging technology field of Mechatronics focuses on developing and implementing advanced automation for industrial applications. Thus, Mechatronics encompasses advanced fields, including robotics, Artificial Intelligence (AI), and cybersecurity. Though the demand for mechatronics expertise is growing, experiential workforce development opportunities in mechatronics are limited. This project will provide ExLENT participants with experiential opportunities through an online Mechatronics Education Portal (MEP), experiential Mechatronics Practice initiatives at Michigan Tech, and a Mechatronics Industry Pathways Rotation organized at WSCC and GCC. The MEP and MP modules will be focused on the five Mechatronics pillars of Robotics, Mechanics, Electronics/Controls, Cybersecurity, and Artificial Intelligence. This project will leverage partnerships among three universities, three nonprofit organizations, and nine regional industry collaborators. Comprehensive program evaluation will ensure that the project meets its objectives in improving interdisciplinary Mechatronics training through experiential learning opportunities, developing a flexible and comprehensive program to promote a diverse and inclusive STEM workforce, and facilitating sustainable collaboration amongst project partners centered around Mechatronic workforce preparation and placement.

Introduction

Advanced industrial processes rely on automation to carry out precise functions and involve technologies from touchscreen tablets and phones to robotic assembly machines. As these new technologies emerge, the industry will require a diverse STEM workforce in electrical, mechanical, computer, robotic, controls, and Artificial Intelligence (AI). The ideal workforce requires interdisciplinary and experiential knowledge in electrical, mechanical, and computer fields to operate, troubleshoot, and develop new physical industrial automation solutions. Mechatronics is the science of receiving, processing, and transmitting sensory data, resulting in advanced automated control of external devices. Mechatronics encompasses all relevant STEM areas; therefore, it is essential for the expected growth in automation and manufacturing in the US and worldwide. Mechatronics is a common degree in Europe and Asia; however, it remains underdeveloped in the US, which limits industrial sectors, including biotechnology, advanced manufacturing, and microelectronics. Due to the current growth of these sectors, which encompass the hybrid technologies of mechanical, electrical, robotics, controls, cybersecurity, and artificial intelligence fields, the demand for mechatronics specialists is growing exponentially. Today, the labor supply does not meet the demand. During the last several years, Michigan Tech has been a leader in promoting mechatronics and industrial robotics, developing curriculum and associated tools. Collaborators on this project have secured several federal (e.g., NSF, DOL) and industrial awards to advance the developments in these fields. As part of these sponsored projects, advanced curricula in industrial robotics and programmable logic controllers

(PLCs) and complementary simulation tools have been developed. These have been disseminated and become popular for teaching robotics and controls; educating faculty; and conducting K-12 teacher/student outreach [1-13]. Recently, the College of Computing at Michigan Tech, pioneering in mechatronics education, launched BS and MS degrees and associated stackable graduate certificates in Mechatronics.
Considering the multidisciplinary nature of Mechatronics, experiential skills in robotics, mechanical, controls, and cybersecurity require significant coordination from university, government, and industry partners. As a result, few educational institutions can afford to launch comprehensive programs. In addition, there remains a lack of resources available to individuals possessing some existing STEM competencies to retool their skills to meet the current demand for mechatronics specialists. Moreover, to better prepare future specialists in mechatronics, learners need hands-on experiential opportunities to understand the future outlook of mechatronics and enhance retention in the field. Thus, there remains an urgent need for the relevant curriculum, software, and hardware developments and implementation at various educational levels to achieve these goals.

Specific project objectives include:

This project aims to provide experiential learning opportunities in Mechatronics to promote a diverse STEM workforce in emerging technology fields, including robotics, mechatronics, and advanced manufacturing. The project is aligned with the regional economy in the Upper Peninsula and Northern Michigan; resources will be broadly applicable and disseminated widely. In pursuit of this goal, project objectives are to:

- Promote a diverse and inclusive STEM workforce through flexible and accessible training programs;
- Improve existing mechatronics education and training by cohesively teaching advanced emerging technology fields in an interdisciplinary fashion for foundational and applied Mechatronics;
- Develop a pipeline centered around mechatronics workforce preparation and placement through a sustainable partnership amongst industry, community colleges, and four-year universities;
- Provide experiential learning opportunities in Mechatronics through state-of-the-art training facilities;
- Demonstrate a career-oriented outlook in Mechatronics through real-world experiences in advanced industry facilities.

Considering that the project is in its first year, no evaluation date is yet available. However, the project team has a solid plan for achieving and evaluating these objectives.
Sense of Belonging is a key component of Michigan Tech DEIS initiatives to promote a diverse and inclusive community conducive to innovative research and students' personal and intellectual growth. Hence, the inherent nature of the cohort rotation will facilitate a sense of belonging in STEM. By having participants conduct experiential activities at Michigan Tech facilities in cohorts, participants will be able to learn and solve multidisciplinary mechatronics problems together. Furthermore, participants will discuss their sense of belonging with their mentor in the ExLENT program. The program will also work to create communication channels for participants (message groups, talks, list-serves, etc.) to promote belonging among the cohorts.

Evaluation plan surveys will be taken to determine areas for improvement in the recruitment and retention of diverse ExLENT researcher enrollment. All proposed activities for cohort building are rooted in evidenced-based research that highlights factors that predict the engagement of underrepresented and/or racially minoritized STEM students. Each project participant will receive $5500 in financial support to cover in-person training at Michigan Tech and during the rotational program with our industrial clusters. The compensation includes a stipend per diem and full coverage of travel and living accommodation costs. The project progression and evaluation data will be reported via publications upon project maturity.

Partnership Vision and Goals

A collaborative partnership among Michigan Tech, WSCC, GCC, eight industrial partners, and three nonprofit organizations will work cohesively to provide ExLENT participants with an accessible and comprehensive experiential training program in Mechatronics. All collaborators on this project have articulation agreements through sub-awards and established collaboration. The shared vision of all partners, shown in Figure 1, is to provide ExLENT participants with experiential opportunities in advanced Mechatronics technology fields, advance professional development required for a 21st century workforce, and demonstrate the job outlook for a career in Mechatronics.

Technology Development Center

Faculty from Michigan Tech will be focused on developing the technology (Phase I) to provide accessible and comprehensive mechatronics education via Mechatronics Educational Portals (MEP) and provide experiential, hands-on training opportunities on state-of-the-art industrial equipment for ExLENT participants. The MEP will provide the foundational knowledge in five critical areas of mechatronics: robotics, mechanical, electrical and controls, cybersecurity, and artificial intelligence. Project participants will be immersed in a five-week, remote, self-paced training utilizing the MEP's advanced educational materials and tools. Upon completing the MEP training, the participants will participate in one-week practical training at Michigan Tech laboratories (Phase II), where the knowledge obtained via the MEP will be reinforced with hands-on activities in all five critical areas of Mechatronics.

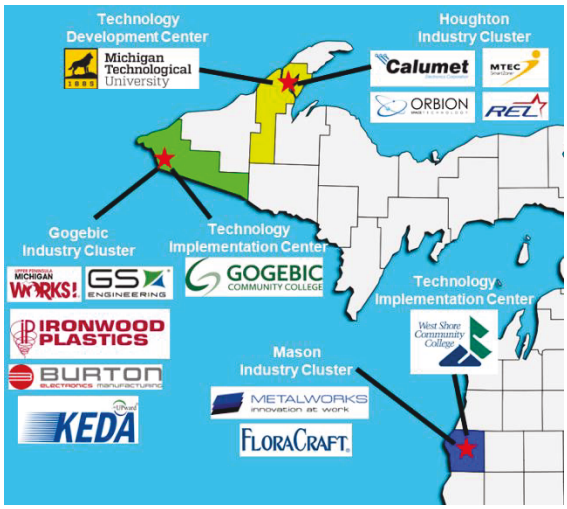

Figure 1. Regional map of partnerships.

Technology Implementation Center

After the development of the modules, Michigan Tech, WSCC, and GCC will pilot the educational materials and tools by incorporating all modules or selected topics into their mechatronics curricula. This will provide an excellent formative evaluation tool, allowing project

collaborators to make necessary modifications to the developed MEP curricula. All three institutions will coordinate with their respective Industry Clusters on the participants' site visits at advanced industrial facilities in the Upper Peninsula and Northern Michigan to provide an industry-oriented outlook in Mechatronics (Phase III).

Experiential Learning Activities

This project seeks to address the educational needs in Mechatronics through experiential learning opportunities and create STEM pipeline between 2-year and 4-year institutions while engaging industry partners to offer experiential opportunities in Mechatronics. The ExLENT program experiential learning process flow is shown in Figure 2. Students will participate in online Mechatronics modules through this pipeline to build foundational knowledge in Mechatronics-related STEM topics. Students will then experience Mechatronics labs at Michigan Tech to engage in experiential learning. Participants will end their enrollment in the program through rotational site visits at advanced industrial in the region to provide an industry-oriented outlook for Mechatronics. Outreach and recruitment will be conducted to ensure the participation of diverse and inclusive cohorts within the ExLENT program.

Mechatronics Educational Portal

Based on the solid foundation of an already established robotics and controls curriculum at Michigan Tech, the project leadership propose to develop and launch a standalone Mechatronics Educational Portal (MEP). The proposed MEP will be freely available to individuals possessing some existing STEM competencies, including stackable certificates in STEM or those enrolled in associate's degree programs. The MEP will stand on the five pillars of a mechatronics foundation: robotics, mechanical, controls, cybersecurity, and artificial intelligence. Each pillar will include theoretical modules on the subject matter and relevant simulation and/or virtual training tools to enable laboratory exercises. The pillars are described below.

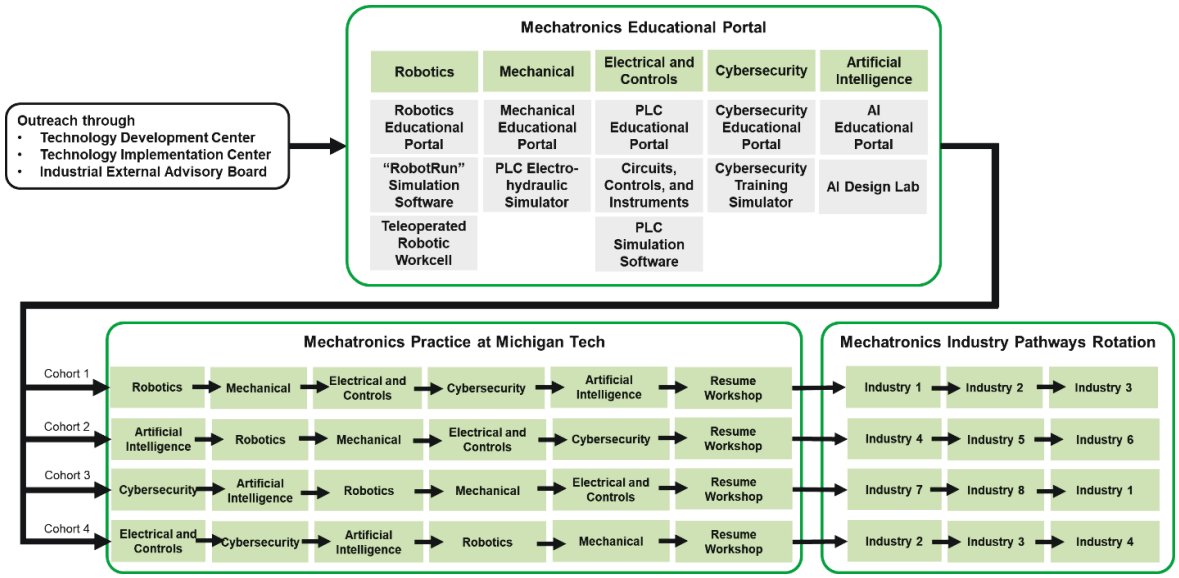

Figure 2. ExLENT program experiential learning process flow.

The Robotics Educational portal (REP) will comprise the "RobotRun" robotic simulation software, robotic tutorials, and online lectures developed via this project. The robotic tutorials will be established assuming the user has limited initial robotics knowledge. Online lectures will complement the tutorials, and industry-like scenarios will be incorporated into the "RobotRun" software. The portal will include self-assessment tools. The Teleoperated Robotic Workcell (TRW) will enable remote training on industrial robots by providing users from anywhere in the world remote access to the robot via the internet in a safe environment.
The Mechanical portion of this program will include both theoretical and hands-on work. The theoretical work will comprise the Mechanical Educational Portal (MechEP) and Electrohydraulic System Simulator, which will be carried out in a virtual environment. The hands-on work will comprise basic hand calculations, laboratory demonstrations, and experiments at Michigan Tech.
Programmable Logic Controllers Educational Portal (PLCEP) comprises a set of open-source and online learning modules designed to give students interactive, hands-on experience with programming PLCs on a standard desktop or laptop computer. The learning modules will include multimedia materials that introduce the content. Utilizing the Advanced Circuit Controls and Instrumentation (ACCI) module, the individuals will be trained in designing, analyzing, and enhancing advanced circuits and control systems in high demand. The main mechatronics objectives are the interdisciplinary skills to manipulate a complex control system and measure variables with instruments. A combination of worksheets, presentations, simulation manuals, and hands-on projects will be developed as open-access learning modules. PLC Simulation Software is an integral part of the PLCEP and allows users to simulate advanced mechatronics systems commonly present in today's manufacturing processes.
Cyberattacks are becoming more common, sophisticated, and damaging as mechatronic technologies become more interconnected. A pressing issue is the need for a well-trained and well-prepared cybersecurity workforce. Developed via this project, a Cybersecurity Educational Portal (CEP) will provide hierarchical knowledge of cybersecurity threats to Industrial Control Systems (ICS) and the security controls to mitigate those threats. A Cybersecurity Training Simulator (CTS) will be developed as an online lab platform to provide students with simulated demonstrations and practice in best practices for cybersecurity. The CEP and CTS will be tailored to participants without a deep background in cybersecurity or ICS.
AI is an essential tool for modern industrial processes, including electrical, mechanical, computer, robotic, control engineering, and cybersecurity. While Industry 4.0 brings new technologies, the industry faces challenges of a shortfall of skilled workers in AI, particularly to service advanced Mechatronics technologies. An AI Educational Portal (AIEP) and AI Design Lab (AIDL) three-module approach is proposed to address this issue. The modules are fundamental concepts, software implementation with Python programming, and advanced applications such as production analytics and vision-based robotics. The modules include tutorials, recorded online lectures, and virtual practice implementation.

Mechatronics Practice

Following the MEP, students will engage in experiential Mechatronics Practice (MP) at Michigan Tech. The proposed MP will apply experiential knowledge of the content presented in the MEP in each of the five pillars as described below. The MP will take place in Michigan

Tech's state-of-the-art labs. The MP curriculum will be conducted amongst cohorts to promote a diverse workforce and a sense of belonging.

Figure 3. Michigan Tech's FANUC laboratory.

Robotics: Participants will perform labs utilizing FANUC industrial robots, shown in Figure 3, and FANUC Industrial Roboguide Simulation Software. Practical labs will target the following topics: industrial robotic safety, robotic coordinate systems, the configuration of robot inputs and outputs, program language and instructions, macro commands, operating Fanuc robots in teach and production modes, and file manipulation.
Fanuc offers a state-of-the-art industrial simulation environment that allows users to configure and program the robotics work cell without downtime in the production processes. The participants will learn the features of the Roboguide software and how to set up, program, and execute robotic operations. Knowledge of the software is critical for robotic specialists because of its frequent utilization in various industry sectors.

Mechanical: The participants will first perform basic hand calculations of hydraulic components like extension force, retraction force, and the volumetric flow required from the circuit to gain an appreciation for some of the basic requirements in designing a system. Afterward, a series of laboratory demonstrations and experiments using fluid power trainers will be introduced. Facilities and equipment for experiential learning in mechanical systems will include commercially available fluid power trainers and specialty-designed systems capable of delivering hands-on labs for 20 students at a time. System Simulator will provide hands-on training.
One advantage of this project is that participants will be prepared for certifications from the International Fluid Power Society (IFPS) [18]. To sustain the project, a curriculum will be developed with the National Fluid Power Association (NFPA), which provides a forum for fluid power and maintaining an educated workforce. Seven certifications are available through NFPS, from Fluid Power Specialist to Accredited Instructor and Job Performance Monitor. The MEP will prepare students for Fluid Power Engineer Certification, which requires IFPS Specialist Certification, Hydraulic Specialist Certification, Pneumatic Specialist Certification, Electronic Controls Certification, and Connector & Conductor test.

Figure 4. Mechanical electrohydraulic control system at Michigan Tech.

Electronics and Controls: Participants will perform a series of labs focused on basic electronics, followed by control labs emphasizing PLC programming. The first stage of experiments focuses on basic electronic circuits that will be physically built and simulated in MATLAB. The second stage experiments are designed to gain an understanding of the transfer function of various linear control systems. The last stage of experiments focuses on understanding a PID controller's purpose. Participants will use MATLAB to evaluate PID controllers with proportion, integral and derivative gains to understand the controller performance under different perturbation scenarios.

In addition to circuits and controls, the experiential training programming Allen Bradley 5000 PLCs on state-of-the-art Amatrol Trainers, shown in Figure 4, at Michigan Tech will be provided. The training will target PLC hardware architecture and its component operation, understanding fundamentals of logic, performing basic PLC programming, developing a fundamental understanding of PLC wiring, and interpreting ladder logic diagrams, programming timers, counters, and Human Machine Interface (HMI).

Cybersecurity: Participants will explore Mechatronics Industrial Control Systems through a cybersecurity lab environment and build a simulated enterprise network. The experience will include real-world implementation in Michigan Tech's Mechatronics laboratory. ExLENT participants will simulate common threats and mitigation methods using OpenPLC, Python, and VirtualBox. Cyber-attacks will be simulated in the lab to demonstrate possible errors in the industrial environment due to malicious actor participants. Each cohort will develop a presentation detailing lessons learned and best cybersecurity practices for the successful and secure implementation of Mechatronic systems in practical environments.

Participants will, therefore, be provided with real-world cybersecurity experience in Mechatronics to prepare them for securing systems in real-world environments. Participants will practice implementing cybersecurity practices already taught at Michigan Tech by leveraging a degree program that follows the ACM Cybersecurity Curricular Guidelines and the National Institute of Standards and Technology (NIST) National Initiative for Cybersecurity Education (NICE) Workforce Framework.

AI: Participants will conduct Mechatronics labs to solve complex problems using the AI tools taught by the MEP. Specifically, participants will develop AI algorithms for a visual camera inspection and classification of process faults based on real-world data. A visual camera inspection will be conducted by leveraging the capabilities of Michigan Tech's Mechatronics lab, with multiple objects placed in various configurations for a pick-and-place task. Participants will program an AI approach that will identify possible faults with the object and the object's location for grasping. Participants will practice using a shared repository to develop their code within their cohorts. Furthermore, participants will view demonstrations of advanced AI techniques in the context of Mechatronics to understand the state-of-the-art in AI.

Through these practices, ExLENT participants will be able to demonstrate the foundations of applied mathematics and statistics for AI In addition, ExLENT participants will acquire fundamental programming skills for general advanced technology fields. ExLENT participants will also be provided opportunities (datasets, general problems, etc.) to practice their skills after completing the program.

Mechatronics Industry Pathways Rotation

All MP cohorts will receive a resume workshop for professional development at the end of the modules. Furthermore, the ExLENT program will host hybrid seminars throughout the MEP and MP to provide information about opportunities and experiences in Mechatronics. At the end of the proposed MP, cohorts will conduct a Mechatronics Industry Pathways Rotation (MIPR). ExLENT participants will be placed within the Industry Cluster that aligns with their regional economic interests.

The MIPR will allow cohorts to view real-world applications of the mechatronics content they learned throughout the MCEP and MP through an industrial facility visit. Each visit will include two four-hour visits with industrial partners, a four-hour visit with a local Workforce Development Agency, and a facilitated discussion. During industry visits, employers share operational and business models with cohorts through presentations, tours, and hands-on activities. The facility visits will conclude with networking events to form connections with the cohorts for future work opportunities. Thus, by experiencing rotations at multiple industry partners within an Industry Cluster, ExLENT participants will experience multiple implementations of advanced Mechatronics solutions and expand their network beyond what they could have received without participation in the ExLENT program.

Project Diversity and Inclusion Principles

Michigan Tech is nationally recognized for supporting students from low-income families and serving a broad population of people from disadvantaged STEM backgrounds, including many

from the remote and rural Upper Peninsula of Michigan. Mechatronics is a field that is sorely in need of a diverse workforce. For reference, Zippia's 2021 survey shows that the Mechatronics workforce consists of 14.6% self-identified females, which is well below the 56.8% female workforce participation in the US as a whole, as noted by the Bureau of Labor Statistics. Furthermore, the racial demographics in Mechatronics were determined to be 67.6% White, 16.9% Asian, 7.9% Hispanic, 3.1% Black or African American, and 0% Indigenous Peoples. Therefore, the proposed project will target ExLENT participant demographics to be higher than the current reported demographics in the Mechatronics workforce. For instance, in an ExLENT cohort totaling 20 participants, we will aim to recruit more than 25% of the cohort to be female participants, which would result in an absolute minimum of 5 females participating in a cohort, resulting in 75% increase to the average reported by the Bureau of Labor Statistics. The proposed ExLENT program will identify, recruit, and engage underrepresented participants through existing partnerships.

WSCC hosts an early middle college school on its campus known as ASM Tech. Students within ASM Tech tend to be predominantly Hispanic and are often the most active group of participants on Student Senate, in registered student organizations, and at student events. This group will be approached with the opportunity represented by the Experiential Learning in Mechatronics, which will likely lead to Hispanic participants. Furthermore, the community of Baldwin lies approximately 30 minutes from WSCC's campus and is home to a large African American population. This community was heavily targeted for a summer bridge program that WSCC is hosting this year. Project management will utilize the recent momentum from their participation in the summer program to recruit additional members of an underrepresented population into our experiential learning program. GCC will recruit students from the Manufacturing Engineering Certificate and Mechanical Engineering Technology programs. Women represent 25% of the total enrollment over the past three years. About 17% of the population of Gogebic County is below the poverty line. Students in GCC County lack STEM exposure and awareness in both late primary and secondary education.

All applications will be reviewed by the ExLENT managers to screen students for eligibility criteria with respect to the capability of advancing a diverse Mechatronics workforce. After recruitment, the ExLENT program will provide students with all necessary materials needed for participation, including temporary technology accommodations, professional attire, and professional talk rehearsal.

Conclusion

This NSF-sponsored project develops a STEM pipeline through partnerships among 2- and 4-year institutions and industry to encourage 2-year students, displaced workers, and individuals looking to retool their skills to match current industry need to explore opportunities in Mechatronics. Through this pipeline, participants will participate in online mechatronics modules to build foundational knowledge in each of its STEM topic areas. The participants will then

undertake practical, experiential learning training in Mechatronics labs at Michigan Tech. Then, the participants will conduct site visits at advanced facilities in the Upper Peninsula of Michigan that will provide an industry-oriented outlook for Mechatronics. Thus, these learning experiences are grounded in effective practices, especially among underrepresented groups in STEM [14-17]. This experiential learning approach transforms students from dependent to independent thinkers, giving them a sense of accomplishment and exposure to potential end-users and experiences that otherwise would not be possible. The benefits of this approach include the participants' gains and an increased number of underrepresented students in STEM graduate school programs [14]. It has been shown that problem-based learning enables students to be more effective in acquiring strategic knowledge, enhancing problem-solving capabilities, and developing learning effectiveness [17,20]. Social cognitive theory has proven that experiential learning increases students' self-efficacy and confirms interest and engagement in engineering and technological disciplines through career exposure activities [14], the foundation for developing employability [19].

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