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PEDAGOGICAL RESEARCH AND ISSUES

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Development and Assessment of an Introductory Robotics Course to Adapt Industry 4.0 to Manufacturing and Automation Engineering Technology Programs

ABSTRACT

This paper presents the course development of an introduction to robotics course and its assessment for a manufacturing engineering technology program to echo the trend of Industry 4.0. The course was developed from scratch, starting with a grant proposal, and then fund-seeking for hardware and software, until the course was fully developed. During the four years, the faculty explored different formats of curriculum revision by integrating small-segment robotics modules into a variety of existing courses, culminating in an industrial robotics course that is fully dedicated to robotics, including robot programming, operations, and software simulation enhanced with hands-on projects in a teamwork fashion. To determine the effectiveness of teaching and learning, a student survey was used that indicated students preferred the projects, no matter whether they were as easy as calibrations or as complicated as conditioning logic programming; all projects appeared helpful to simulate students' learning interest and build up their confidence and competence required in an Industry 4.0 environment. The course development and project-based teaching for robotics may be replicated by other institutions that may be teaching Industry 4.0 techniques. In the future, more robotics projects will be incorporated into the course, such as welding, gluing, material handling, etc.

Introduction

The first Industrial Revolution featured water and steam-powered mechanical manufacturing facilities, the second Industrial Revolution featured electrically powered mass production and assembly line(s), while the third Industrial Revolution featured the usage of electronics and computers such as Computer Numerical Control (CNC) machines and other equipment to achieve preliminary levels of manufacturing automation. Now we enter Industry 4.0, which is characterized by advanced manufacturing automation, that is utilized in smart factories where artificially intelligent (AI) equipment is connected to communicate through sensors and high-speed internet to achieve agile flexibility, high productivity in production environments through real-time monitoring, diagnosis, and even to some extent self-faulty correction (Wee et al., 2015). Essentially, Industry 4.0 is a digitalization of manufacturing, or smart manufacturing, as it emphasizes the application of digital technology in production via the Internet of Things (IoT). It integrates sensors and computer networks, which enables the collaboration of multiple departments within an enterprise and their business partners to communicate on a platform (Coşkun et al., 2019). Referring to different sources, the major components in Industry 4.0 may include the IoT, big data, cloud computing, additive manufacturing, advanced robotics, augmented and virtual reality (AR/VR), AI, digital twin, and others, as well as any combination (Zhong et al., 2017). Industry 4.0 integrates the elements of smart technology—sensing inputs, computing power, high-reliability internet connections, AI, and advanced data analytics—into the traditional production process. Used collectively, these technologies unlock new opportunities and bring transformative changes to the entire product life cycle, from product development, production, service, and disposal, which can make factories smarter, more productive, more efficient, and less wasteful (Dhanabalan & Sathish, 2018).

Industry 4.0 was originally a term coined for envisioning future high-tech strategic development at the Hannover Trade Fair in Germany in 2011 to advocate for Germany as a global leader of technological innovation (Ślusarczyk, 2018). The global community has now accepted the word “Industry 4.0” as the icon of advanced manufacturing technology in the 21st century. Stepping into the same domain, many countries around the world created similar strategic policies to usher in the opportunities, challenges, and drastic transforms to align with the new era, such as “New Industrial France” in 2013, “Manufacturing Innovation 3.0” by Korea in 2014, “Made in China” in 2015, “Society 5.0” by Japan in 2016, “UK Industry 2050,” and others (Zhong et al., 2017). Ghobakhloo (2018) commented that manufacturers need to get on board sooner and faster, as Industry 4.0 is no longer a hype.

Since the conceptualization of Industry 4.0, it has been recognized that it must go hand-in-hand with education. The best example is the German “Industry 4.0" policy, which is governed by two ministries: the Ministry of Education and Research and the Ministry of Economic Affairs and Energy. Correspondingly, Education 4.0 is a term created for the same reason—to mark the educational changes that are needed to meet the Industry 4.0 requirements. Industry 4.0 not only revolutionizes manufacturing production and management but also influences the labor market and the educational system by adding new competencies to the workforce and new skill set in curriculum design (Onar et al., 2017). From the industrial human resources and training point of view, Benesova & Tupa (2017) noted that emerging technologies of Industry 4.0 are neither simple nor easy to implement. Instead, they may require a sophisticated and abrupt transformation. Integrating the buzzy “Industry 4.0” into industrial settings may be problematic; therefore, it should be done systematically.

In an Industry 4.0 manufacturing facility, there are complicated interactions between machine and machine, machine and people, and people and people in addition to the large amount of work involved in managing advanced algorithms, data analytics, commissioning, and troubleshooting equipment. Many times, the tasks involved in an Industry 4.0 setting involve team members who are adequately trained in multi-disciplines such as mechanical/manufacturing engineering, industrial engineering, electrical engineering, computer science, and engineering collectively to conduct software simulation, hardware installations, and maintenance, or other problem-solving elements required in the field, especially since Industry 4.0 requires personnel competencies that heavily weigh on technological components (Fitsilis et al., 2018).

Recognizing the emerging trend, higher education institutions are initiating changes to steer toward Industry 4.0 and Education 4.0. From a macro perspective, Onar et al. (2017) studied a sample of 124 engineering departments worldwide at prestigious universities to understand the characteristics and skills provided via curriculums converging or diverging from different emphases to fulfill the emerging patterns of the new education requirements of Industry 4.0. Coşkun et al. (2019) presented a road map consisting of three pillars in the areas of curriculum development, laboratory concepts/applications, and student club activities to enhance and update their five engineering programs at the Turkish German University (TGU). According to the road map, the first primary change for TGU would be updating its introductory-level computer programming course and statistical data analysis course, which are needed as foundational building blocks for multiple programs.

Industry 4.0 is a complex domain that involves many advanced technological components and their mutual interactions in multiple disciplines. It is unrealistic and impossible to create a curriculum that encompasses all components and fits all the academic programs. Different institutions may start with one thread to adapt engineering education to the Industry 4.0 framework. For example, Chong et al. (2018) introduced and tested a blended learning framework aimed at incorporating Industry 4.0 principles into engineering design instruction. This innovative approach combines traditional, online, and flipped classroom methodologies to foster hands-on learning experiences. By seamlessly integrating Industry 4.0 concepts with practical activities such as 3D product design, modeling, and printing, the model emphasized learning by doing within the classroom environment. Another example focuses on the reconfigurable manufacturing system (RMS) concept embedded in Industry 4.0. Salah et al. (2019) reported on how virtual reality technology was employed to learn the RMS paradigm in conjunction with sustainable manufacturing. The learning evaluation result showed students outperformed in terms of understanding, satisfaction, number of mistakes, and completion time.

Robotics is a key component and plays a significant role in smart manufacturing and Industry 4.0 movement, and studies indicate sustained, unprecedented growth worldwide in robot installations. According to the International Federation of Robotics (2023), there were 517,385 new industrial robots installed worldwide in 2021, which represented a growth rate of 31% from 2020; 50,712 of those were installed as industrial robots in the Americas in 2021, 31% more than in 2020. This results in manufacturing employers needing a highly educated workforce that is competent in the era of Industry 4.0.

Young people can be inspired to enter the manufacturing field by the use of robotics. For example, FIRST (For Inspiration and Recognition of Science and Technology) has successfully used robotics competitions as a tool to promote STEM (Science, Technology, Engineering & Mathematics) education, proving to be an inspiring option for K–12 school-aged students. Robotics competitions are also beneficial for college students, providing a hands-on opportunity to apply their skills and enhance their understanding of STEM subjects (Ahlgren et al., 2006). Ananias & Gaspar (2022) presented the development and testing of a low-cost, 6-axis collaborative robot for electromechanical undergraduate engineering students that included multiple subjects and tasks: design and 3D printing of robotic structure and parts, design and integration of electronic components and circuits, programming, and control. The multidisciplinary and project-based learning approach used in the development of this collaborative robot allowed students from different engineering disciplines to interact with each other and fostered a deeper understanding of Industry 4.0. Tosello et al. (2019) presented a case study in which the framework of Industry 4.0 was introduced to computer science and engineering students at the Master's level, incorporating industrial robots. This course implemented project-based learning and team-based learning, motivating students to pursue optimal outcomes in both lecture (30% of the final grade) and lab (the remaining 70%) activities.

Robotics Curriculum Development at the University of Northern Iowa

With a history spanning over one hundred years, the Department of Applied Engineering and Technical Management (Applied Engineering/AE) at the University of Northern Iowa (UNI) has established a good partnership with local industries in what we refer to as the Cedar Valley. Graduates from the department's programs provide a good pool of workers for local industries, including nationally known corporations such as John Deere Waterloo Works, Collins Aerospace, and Viking Pump (IDEX Corp), as well as many small and medium-sized manufacturing companies and engineering services. The Manufacturing Engineering Technology (MfgEngTech) program offered at UNI provides a Bachelor of Science curriculum that covers the full spectrum of manufacturing product and fixture design, analysis, production management, and quality control. With the evolution of technology, the MfgEngTech program has added courses in advanced manufacturing technologies such as computer application CAD/CAM, CNC machine tools, computer-aided measurement machines, and additive manufacturing 3D printers. Although the MfgEngrTech program covers fundamentals of automated manufacturing such as G and M codes, CNC programming, simulation, and machine operations, the concept of integrated automation with robotics was missing due to constrained budgets for necessary equipment and faculty professional development.

Automated manufacturing is an emerging trend that today's manufacturing industries—regardless of size—have to face, especially with the push of new concepts from AI and Industry 4.0. Manufacturing industries around Cedar Valley, where UNI is located, need a workforce equipped with adequate education in manufacturing skills to operate within the globally competitive market, where robots have become the norm in the manufacturing sector and many service venues. The faculty within UNI's manufacturing program were fearful of becoming outdated without incorporating and adding advanced manufacturing automation content. Realizing both the challenges and opportunities of the shared view of the MfgEngrTech faculty along with their Advisory Board, the UNI MfgEngrTech program underwent an adjustment to adapt to the Industry 4.0 arena.

PREPARATION AND EXPLORATION

The exploration and preparation of the Industry 4.0 curriculum components was coupled with the interaction and support from local manufacturing employers and the MfgEngrTech Advisory Board (Adv Brd) in which John Deere, being the major employer in the local area, plays an active role.

Seeing the prevailing trend under the premise of Industry 4.0, the department faculty applied and was awarded a John Deere Fellowship in 2018 to support the development of manufacturing automation learning modules based on industrial robots.

The MfgEngrTech faculty first conducted a survey through the ASEE (American Society for Engineering Education) email list and gathered manufacturing automation curriculum information at other universities. Questions were

- Is robotics included in your manufacturing engineering/technology program?
- If yes, how is the course organized? Is it a single standalone course or a component of a course?
- Does it require a computer programming language as a prerequisite?
- What lab equipment and software are used?

After receiving about 20 responses from other instructors from two- or four-year institutions, it was found that all of the surveyed MfgEngrTech programs included robotics automation in their curriculums and most of the schools had one or even two courses dedicated to robotics or related automation. Almost all their automation and robotics courses were supported by hardware and software lab activities. Although basic math and physics were required, not all university programs specifically defined a computer programming language as a prerequisite; it was dependent upon the focus and structure of their overall curriculums. This information was then shared with our Adv Brd members. In addition, the faculty toured local manufacturing facilities and automation laboratories at nearby colleges/universities, in addition to conducting literature reviews. Visits to the manufacturing facilities of Fortune 500 companies and small to medium-sized organizations led to a shared conclusion: the use of robotics and automation is widespread, making adaptation to this trend in manufacturing engineering education not just necessary, but essential. These visits also offered valuable guidelines for curriculum development, including recommendations for robot procurement, software platform alignment, module inclusion, and intended industry applications.

Armed with this new information, the MfgEngrTech faculty decided to first develop a three-week learning lecture module for the introduction of basic robotics. This module included robotic safety, system composition, classification, drive systems, servo systems, vision, and sensing, along with robot applications in object detection and material handling. Considering the introductory nature, the three-week robotics learning module was implemented in the existing Fundamentals of Automated Manufacturing (TECH 2060) course to begin introducing concepts of the Industry 4.0 era. Due to a lack of hardware and software for hands-on or computer simulation lab activities, the developed course module was limited.

PROCUREMENT OF ROBOTS AND TRAINING

The second phase of our project was to seek external funding to procure the necessary robotics hardware and software for the development of a three-credit automation course. Without the robotics hardware and software to equip the lab, it is difficult to teach and learn how robots are programmed, and how they coordinate and collaborate in modern manufacturing facilities to perform loading, unloading, fault detection, logic programming, material handling, and other tasks.

With the help of the UNI Foundation, the Applied Engineering Department faculty successfully applied for and was awarded $225,000 from the Roy J. Carver Charitable Foundation in 2019, to support the project *Realizing Industrial Robotics Instruction at the University of Northern Iowa*. The institutional help along with support from the Advisory Board provided a means to secure the funding needed to begin implementation. With the Carver grant, 10 ABB educational desktop robots were purchased, and 100 seats of ABB robotic software applications were granted to the Applied Engineering Department for training MfgEngrTech students in robotics programming, material handling, and integration with other manufacturing equipment.

Two onsite and one online training from ABB were carried out during the 2019–2020 academic year. As a result, two faculty members proved proficient in all software simulations and hands-on tests, enabling them both to receive the Train-the-Trainer certification. This certificate enabled the faculty members to certify the students upon their completion of learning modules and testing.

INTEGRATION INTO THE CURRICULUM

The robots were integrated into the MfgEngrTech curriculum in two stages. The initial stage was to add modules to different courses on an experimental basis. After seeing significant interest from the students and based on the faculty inputs, a new course solely on robotics was created and included in the curriculum.

Initial integration

The 10 ABB robots and Robot Studio, along with associated learning modules, were integrated into three MfgEngrTech existing courses in 2019–2022:

- Fundamentals of Manufacturing Automation (TECH 2060) to introduce the basics of robotics operation and programming,
- Pneumatics and Hydraulics (TECH 4162) to address advanced and structured robot programming with logic, and
- Computer-Aided Manufacturing (TECH 3147) to focus on software simulation.

In the past, programming logic was missing in the MfgEngrTech program, as the MfgEngrTech curriculum currently does not require computer programming through a formal course or a course component. With ABB robots, students can learn logic programming with Boolean variables directly from the robot's flex pendant, as they can see the motion of the robots immediately once any control logic is implemented through the flex pendant. The new course material enhanced graduate preparation and employability. All three classes had separate exams on the robotics concepts covered in each of the separate courses. The students need to take all three courses to obtain the SMART certification from ABB. NOTE: The ABB certification elements were not used in the final grade for the course because getting certification is an option and not required. Student comments in the fall of 2019 indicated that the robotic modules in TECH 2060 improved their learning experience. Several students shared that the robotics labs made programming theory much clearer, as they were able to see the results of their work by manipulating objects in real time. One student, employed part-time at John Deere, shared that they were able to easily adapt to the robotics system in the workplace because of the learning experience and training gained at UNI.

The ABB robots secured with the Carver grant have also been used in our capstone design class, Senior Project (TECH 4210) in two consecutive semesters, where two different student teams in MfgEngrTech and Electrical Engineering Technology (ElecEngrTech) programs prototyped solutions for a local manufacturing industry that assisted in their need to automate the assembly line for slip ring production. Students designed and 3D printed the slip ring parts, along with the fixtures needed for clamping the parts, and further programmed the robotic automation processes. The teams along with their industrial representatives were successful in the preliminary feasibility study to minimize costs for the client project. These types of school senior projects, in which students also benefit from real industrial projects and problem-solving, is a win-win and showed the success of the faculty's effort to include robotics and automation in the classroom environment.

In addition, the MfgEngrTech faculty have also offered summer robotics workshops to high school industrial technology teachers and to the staff at UNI's Metal Casting Center and Foundry 4.0 Center, which are internationally known for their research in the foundry industry. Through these outreach activities, Industry 4.0 concepts have been disseminated to a large group of audiences in academia and industries.

Comprehensive curricular infusion of robotics

Due to the success of the first Carver Trust grant and positive feedback from student assessments, the Applied Engineering Department applied for and received a second Roy J. Carver Charitable Foundation grant ($149,980) to fund 10 conveyors to use the ABB robots and conveyors as flexible manufacturing cells to take the automation course to a higher integration level. The addition of the conveyors and software significantly increased the technological capability of the MfgEngrTech program while also enabling the Applied Engineering Department to rethink and adjust its academic programs. Along with the courses mentioned previously in the MfgEngrTech program, the ABB robots can also be applied in the department's PLC (Programmable Logic Controller), Power Technology, and other courses in the ElecEngrTech program that are also housed in the Applied Engineering Department.

During the academic year 2019–2020, the MfgEngrTech program and ElecEngrTech program faculty worked together and developed a new program, Automation Engineering Technology (AtmEngrTech), by integrating existing courses from both the MfgEngrTech and the ElecEngrTech programs. The synchronized curriculum structure led many students to declare double majors. The ABB robot hardware, software (Robot Studio), curriculum training, and faculty professional development opportunities funded by the Carver Trust played a significant role in the development of the new AtmEngrTech program.

The MfgEngrTech and ElecEngr Tech programs had an ABET (Accreditation Board for Engineering and Technology) accreditation visit during the fall of 2021. During that visit, the ABET review team was impressed with the robotics education being offered and the opportunity for the students to get certified by completing the ABB SMART Certification training for the STEM Programming Course.

Despite positive feedback received, student assessments did indicate that the robotics learning and hands-on activities made the three courses mentioned above too intense. Working with the MfgEngrTech Adv Brd members in the summer of 2022, the MfgEngrTech faculty made additional adjustments to the program curriculum, resulting in a new course, Industrial Robotics (TECH 2065). TECH 2065 would then be fully dedicated to robotics programming and software simulation and was first offered in fall 2023 in a project-based learning approach. Multiple projects were carried out throughout the semester, from simple tasks such as jogging and calibrations to more advanced projects such as measurement of tool mass and center of gravity; conditional programming that mimics material handling defined by different logic conditions such as good or defective parts; and different manufacturing processes or quantities. The summit-level project in TECH 2065 was the design and demonstration of a modern manufacturing cell using a flex pendant and Robot Studio, which consisted of robot controllers, arms, conveyors, and an integrated machine vision system (seen in Figure 1). The project goal is to perform the following tasks:

1) calibrate the vision camera,
2) recognize the targeted object,
3) pick and place the object on the conveyor,
4) track the object along the moving conveyor,
5) pick the object when it travels to the end of the conveyor and grab it, and
6) place it back at its original location.

Figure 1.
Flexible Manufacturing System Integrating With Robots, Conveyors, and Machine Visioning.

The assessment of student performances for this activity was separated into two parts: written exams and hands-on robotics lab activities. Like earlier, individualized hands-on exams must be performed successfully to obtain the ABB SMART certification.

STUDENT ASSESSMENT

At the end of the TECH 2065 class in the fall of 2023, not only was the institution's standardized student assessment deployed, but the MfgEngrTech faculty also distributed a survey questionnaire based on literature (Tosello et al., 2019). The questions utilized are shown in Table 1.

Student feedback was scored on a 1–5 scale, where 1 represented "strongly disagree" and 5 "strongly agree," measuring students' perceived quality of learning through lectures and hands-on lab practice. Sixteen out of 20 students participated in this survey, and the results are displayed in Figure 2. The raw data of students' responses are displayed in Table 2. The scores given by the students for individual questions are shown in Figure 2.

Table 1.
Survey Questions Administered to Industrial Robots (TECH 2065) Class (Fall 2023).

Question Number	Question Instrument	Skills to Be Assessed
Q1	You had good programming skills before taking this class.	Pre-class skills and knowledge
Q2	You have had a good knowledge of robotics before taking this class.	
Q3	The lab hands-on projects helped me understand and apply the theory learned in class.	Project-based learning
Q4	The hands-on projects took a lot of time and work, but it is necessary to learn robotics.	
Q5	The hands-on projects were useful because they satisfied student learning.	
Q6	After the hands-on projects, students gained skills and were able to operate the ABB robots.	
Q7	The complexity of the hands-on projects was appropriate and manageable.	
Q8	The teamwork assigned in the hands-on projects was effective.	Team-based learning
Q9	The teamwork performed in the hands-on project improved students' people skills.	
Q10	Students feel confident about future jobs because of the programming skills learned in this class.	Competence
Q11	Students became more interested in robotics.	
Q12	Students have gained the necessary skills related to Industry 4.0 after this class.	

Figure 2.
Perceived Quality of Learning.

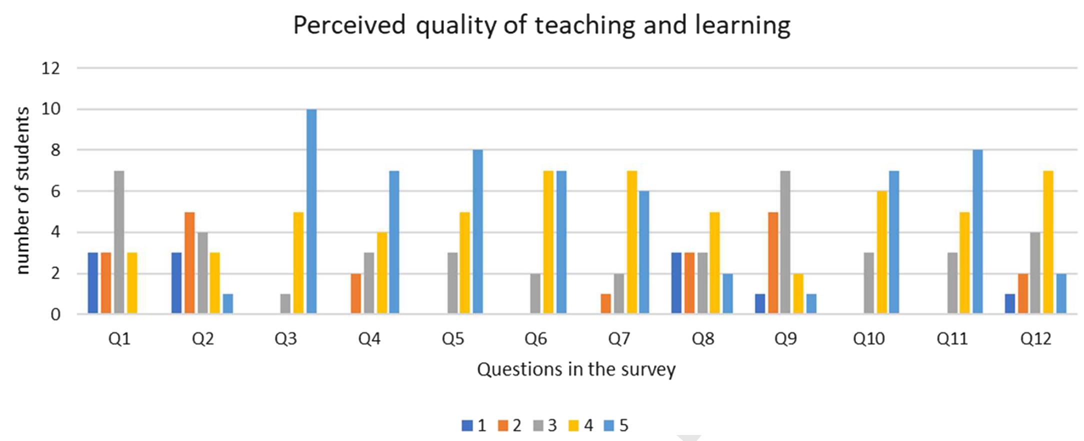

Table 2.
Student Feedback Responses.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Q1	3	3	7	3	0
Q2	3	5	4	3	1
Q3	0	0	1	5	10
Q4	0	2	3	4	7
Q5	0	0	3	5	8
Q6	0	0	2	7	7
Q7	0	1	2	7	6
Q8	3	3	3	5	2
Q9	1	5	7	2	1
Q10	0	0	3	6	7
Q11	0	0	3	5	8
Q12	1	2	4	7	2

Q1 and Q2 reflected students' self-perceived programming skills and knowledge of robotics before taking the course, and the responses show that more than half of the students marked 3 to 5, meaning that they had some level of knowledge, but about 20% of the students indicated that they had no previous knowledge.

Q3 to Q7 examined the effectiveness of project-based learning, and all the responses were skewed to the right, with 70%–80% of students indicating a rating of 4 or 5, which indicated that the majority of students reported positive feedback on the hands-on projects conducted, particularly regarding the operations and programming of the ABB robots as well as the use of the RobotStudio software package. In Q3, 62.5% of students strongly agreed that the lab projects allowed them to apply theory that was taught in class. In Q5, 50% of students strongly agreed and 32.3% agreed that the overall lab experience was useful in terms of personal gratification and growth, which implied that the project-based learning approach in TECH 2065 was effective and students were satisfied. These results show that the accomplishments of lab tasks let students feel that they advanced in their robot programming skills and that they were confident in handling modern industrial equipment. Since this was the first time that TECH 2065 was offered, and it was unknown whether prior experience existed among the students, it was not known whether the complexity and/or workload of the lab projects would be meaningful exercises. The responses to Q7 show that the current class workload was manageable, as there was only one student who disagreed.

Q8 and Q9 explored the teamwork experience implemented in TECH 2065. Twenty students were enrolled in the class, and seven robots were available for use, while the other three robots were set up for other configurations and purposes. To make sure all students were able to have the opportunity to work directly with the robots, the 20 students were split into two sections, with 10 students participating in the exercises for the first hours of class and the remaining 10 students participating for the second hour. The capacity of seven robots for a 10-student session allowed two students to form a team, and the instructor encouraged the team to stay in that team throughout the semester and conduct all hands-on projects together. A few students did have the opportunity to operate a robot on their own. It is understood that teamwork and collaboration are valuable skills in the profession, but the survey responses indicated that most students were not satisfied with the team setup and/or teamwork. Three students reported that teamwork improved their abilities, yet most students had neutral or even negative feelings about teamwork. One student commented, "I liked working in a pair when we first started working in the lab; however, once we understood the basics of operating the robot, I would have had more time to work on programming it individually without a partner." Another student commented, "I believe that robotic programming in the lab is best suited for one person per pendant control. I am a CNC programmer, and in the shop, it is understood that only one person's hands should be on the control panel during programming and edits." These comments made us reflect and rethink the split of the student sessions, the configuration of the robots, and the design of the in-class projects. Therefore, the instructor intends that for the next course offering, all 10 robots will be made available so that students can operate individually. Hence, teamwork will be organized when complicated robotics programming is needed. In addition, a student assistant may be provided in the lab to increase the open lab access hours so that students who would like additional time to practice their programming skills can do so.

Q10 to Q12 assessed the competence level of robotics skills that students perceived themselves to have after taking the class. Of all students, 43.8% strongly agreed and 37.5% agreed that programming an industrial robot, as practiced with the in-class projects, made them feel confident about a future job with robots. Of all students, 50% strongly agreed and 31.3% agreed that TECH 2065 stimulated their interest in learning robots. More than 50% of students felt that they had acquired the necessary skills in the arena of Industry 4.0, whereas only 3 out of the 16 students surveyed did not feel the same way.

The following inferences may be drawn from the survey:

- Inclusion of robotics in the curriculum has significantly increased the interest in the students towards Industry 4.0 and programming.
- Offering the content in a single class helped the students to concentrate and grasp the concepts easily. Also, the students will not miss the opportunity to get certified due to course rotations. (The certification was previously distributed in all three of the previous courses.)
- Students appear to be more comfortable learning programming when it is combined with simulation skills.
- Some students preferred to work individually on the robots.

Conclusions and Future Work

This paper presents the course development of an introduction to robotics course for a manufacturing engineering technology program to echo the context of Industry 4.0, along with the fund-seeking process to support software and hardware procurement. During four years, we progressed from having no resources to fully developing and disseminating the course, exploring various formats and approaches for integrating small-segment robotics modules. This ranged from distributing the concepts across multiple courses to consolidating them into a single course, resulting in our best fit being a single Industrial Robotics course (TECH 2065). TECH 2065 is fully dedicated to the introduction of robotics, including robot programming, operations, and software simulation enhanced with hands-on projects and teamwork. The effectiveness of student learning was demonstrated through the student survey, revealing that regardless of the project's complexity, whether it involved simple calibrations or intricate tasks like conditioning logic programming or distinguishing batches or parts, all activities proved beneficial in stimulating student learning interests and enhancing their confidence to contribute to Industry 4.0 ideals and practices. The addition of this robotics course enhances the skills of MfgEngrTech graduates, enabling them to adapt swiftly to the modern manufacturing environment. One student noted in the survey that they were able to learn robot operations and programming in his part-time job because of the knowledge he gained in class, despite working with a different brand of robots. This project significantly benefited the MfgEngrTech program by improving student learning in industrial automated manufacturing through hands-on experiences in robotics design, operation, programming, and simulation within the revised curriculum and new course offerings. Additionally, it enhanced graduate preparation and employability by providing credentials in robotics for UNI students and others seeking to advance their education.

The development and assessment of the Industrial Robotics course (TECH 2065) has paved the way for several exciting avenues of future work that can enhance the curriculum and further align it with the principles of Industry 4.0. Key areas for future exploration include the following:

- Individual robot engagement: To deepen hands-on experience, we aim to provide each student with the opportunity to work independently with a robot by soliciting more resources and sponsors. By fostering individual interaction, we anticipate that students will develop a stronger sense of ownership and mastery over robotic technologies, ultimately enhancing their confidence and skills.
- Incorporation of "cobots" in the curriculum: As cobots are increasingly utilized in modern manufacturing environments, the inclusion of cobots will provide students with cutting-edge technologies, preparing them for the reality of Industry 4.0 era where cobots play essential roles in enhancing productivity and safety.
- Expanding on more applications and industry collaboration: Future learning modules will delve into specific applications such as welding, material handling, gluing, and assembly operations. By leveraging diverse robotic tasks, students can gain a comprehensive understanding of the versatility and adaptability of robotic systems in various manufacturing scenarios. This could also include case studies from industry partners to illustrate real-world applications.
- Continuous feedback and improvement: Establishing a mechanism for ongoing feedback from students and industry stakeholders will be beneficial in refining the curriculum. Regular surveys will be conducted to help assess the effectiveness of new modules and technologies, allowing for agile adjustments that meet the evolving demands of the industry.

By addressing these areas, the aim is to continually enhance the robotics course, ensuring it remains relevant and effective in preparing students for careers in the rapidly changing landscape of manufacturing and automation technology.

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