Integrating Robotics and Automation in STEM Education: Preparing the Future Workforce for Advanced Manufacturing

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Abstract

The landscape of STEM education is undergoing a significant transformation, with an increasing focus on equipping middle and high school students for careers in advanced manufacturing and robotics. Through the NSF-RET initiative, we provided advanced manufacturing research experiences to twenty-eight K-14 educators during six-week summer workshops in 2023 and 2024. Among these educators six of them are community college educators and rest of them are high school educators. These educators not only conducted research but also developed curriculum modules for their students during the summer workshops. They also implemented these modules once they returned to their respective institutions. This comprehensive paper presents an in-depth analysis of five innovative projects designed to integrate robotics and automation into the educational curriculum. We highlight the pivotal role of educators in curriculum development and demonstrate the effectiveness of kinesthetic learning in enhancing students' understanding of complex STEM concepts. Through hands-on activities, experiential learning, and problem-solving exercises, we illustrate how these approaches prepare students for careers in rapidly evolving technological fields.

1.0 Introduction

In today's fast-paced and technology-driven world, the integration of automation and robotics within educational settings has become a critical component in preparing the future workforce. As industries continuously evolve and embrace Industry 4.0, there is a pressing need to develop a workforce that is not only proficient in robotics, automation, and advanced manufacturing but also capable of adapting to the rapid changes and innovations in these fields [1]. This paper embarks on a comprehensive exploration into how embedding robotics and automation within the STEM curriculum, specifically targeting middle to high school students, can significantly contribute to achieving this goal.

The curriculum in STEM education is seeing a paradigm shift, moving from traditional theoretical methods to more practical and hands-on approaches. The integration of robotics and automation plays a key role in this shift, providing students with real-world applications of the theories they learn in classrooms [2]. This paper highlights five unique projects that exemplify this integration, showcasing diverse strategies and approaches to incorporating robotics and automation in education.

Moreover, this paper emphasizes the critical role of educators in this transformative process. Educators are not just implementers of the curriculum; they are also developers and innovators, playing an active role in shaping the future of STEM education [3]. The projects discussed in this paper underscore the importance of providing educators with the necessary tools, resources, and training to effectively integrate robotics and automation into their teaching practices. Through this, we aim to ensure that students are not only proficient in technical skills but also equipped with critical thinking, problem-solving, and adaptability skills - qualities essential for thriving in the advanced manufacturing sector and related fields.

In synthesizing the information and insights gathered from these projects, this paper contributes to the broader discourse on STEM education reform, providing valuable perspectives and strategies for integrating robotics and automation into educational curricula. It serves as a resource for educators, policymakers, and stakeholders, guiding them in developing and implementing effective STEM education programs that are responsive to the demands of the 21st-century workforce.

2.0 Project Descriptions and Curriculum Development

2.1 Project 1: STEM Curriculum Development through Robot Design and Construction. Participant: Jon Austin, a community college educator

Overview: Jon Austin has spearheaded a groundbreaking project aimed at developing a comprehensive robotics curriculum tailored for middle to high school students. Figure 1 shows final product assembly. The curriculum stands out due to its strong emphasis on hands-on learning, actively engaging students in the assembly of a basic robot arm, designed to perform pick and place operations. This immersive approach not only renders learning more captivating but also bridges the gap between theory and practice, reinforcing theoretical concepts through tangible application [2].

Kinesthetic Learning and Theoretical Concepts: The construction of the robot arm introduces students to a wide array of mechanical and electrical concepts, offering a deep dive into the mechanics of a gearbox and elucidating the intricate relationship between torque and speed—a cornerstone in robotics. This tactile learning experience demystifies complex theories, rendering them more tangible and digestible [4].

Ohm’s Law and Mechanical Drives: The curriculum provides a holistic educational experience, integrating pivotal electrical concepts such as Ohm’s Law. This integration aids students in grasping the relationship between voltage, current, and resistance, contextualized within the realm of robotics. Furthermore, a significant emphasis is placed on mechanical drives, enlightening students about their indispensable role in robotics and their contribution to the robot’s movement and functionality [5].

Modification and Problem-Solving: A hallmark of this curriculum is its emphasis on critical thinking and problem-solving. Students are presented with challenges that require them to modify their robot arms for varied tasks, nurturing their creative thinking and practical application of knowledge. This not only hones their problem-solving capabilities but also deepens their understanding of robotics and its myriad applications [6].

Curriculum Models: Jon Austin's curriculum stands as a beacon for educators, particularly those navigating with limited resources. It provides a structured, yet adaptable framework that seamlessly integrates robotics and advanced manufacturing concepts into regular lessons. Packed with resources, activities, and assessment tools, it ensures a comprehensive education in robotics for students [7].

Impact and Significance: By plunging students into the hands-on world of robotics, this project fulfills a vital need for experiential learning in STEM education. It effectively narrows the divide between theoretical knowledge and practical application, transforming students from passive learners to active participants in their educational journey. This method not only primes them for future careers in advanced manufacturing and robotics but also kindles a lifelong passion for learning and problem-solving [8]. Figure 1 shows Jon Austin's robot arm design, construction and programming of the arm.

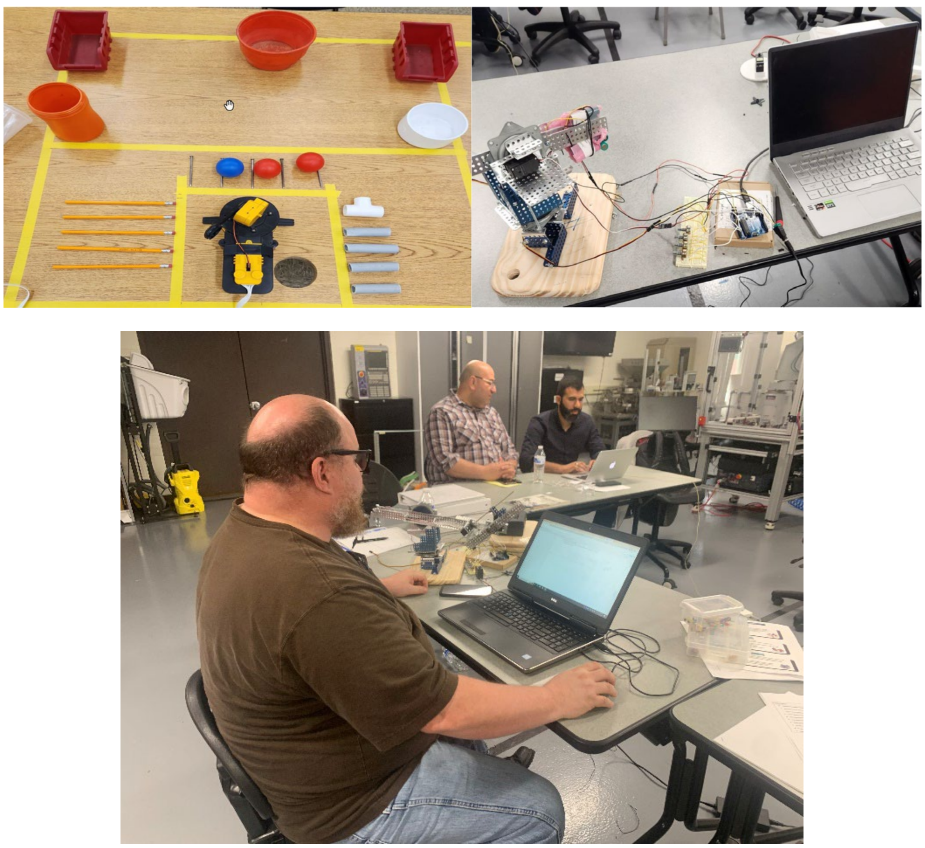

Figure 1: Robot Arm Design, Construction, and programming.

2.2 Project 2: Enhancing Problem-Solving Skills through Integration of Fanuc Robot Arm with Machine Vision.

Participant: Zach Kulwicki, a high school educator

Overview: Under the insightful guidance of Zach Kulwicki, Project 2 strategically employs a holistic educational methodology, concentrating on robotics and machine vision for students particularly for grades 9-12. The project adeptly integrates a Fanuc robot arm with machine vision, shown in Figure 2, creating an enriched learning atmosphere that actively promotes and enhances students' problem-solving capabilities. Such an integration aligns with the findings of Johnson and London [9], who highlight the positive impacts of hands-on robotics education on student engagement and learning outcomes.

5E Model Approach: The curriculum is meticulously designed around the 5E Model, a pedagogical framework that ensures a structured yet flexible learning experience encompassing Engagement, Exploration, Explanation, Elaboration, and Evaluation [10]. This approach transforms students from passive recipients to active participants, fully immersing them in the learning process as they explore concepts and apply knowledge in real-world contexts. The active engagement facilitated by the 5E Model is vital for developing critical thinking and problem-solving skills, as underscored by Marzano and Pickering [11].

Engagement and Exploration: The program kick-starts the learning process by capturing students' interest through interactive lessons that cover the basics of robotics and the fundamentals of machine vision. This phase encourages curiosity and hypothesis formation, providing a robust foundation for diving into more complex topics. Engaging with the Fanuc robot arm, students gain firsthand experience in examining robotic joints and movements, understanding their collaborative functions in task performance [12].

Explanation and Elaboration: Progressing from exploration, the curriculum provides comprehensive explanations on robotic programming and the integration of machine vision. Students are taught how to program the Fanuc robot arm, deciphering the syntax and logic that underpin robotic commands. They also delve into how machine vision can be integrated to amplify the robot's functionality, enabling sophisticated interaction with its environment [13].

Real-World Application and Case Studies: To augment theoretical knowledge, the curriculum incorporates real-world case studies, showcasing the application of the Fanuc robot arm and machine vision in industrial contexts. These case studies serve as invaluable learning resources, bridging the gap between theory and practice, and fortifying students' problem-solving skills [14]. Hands-on activities and data analysis exercises are integral to this phase, ensuring a holistic understanding of the subject matter.

Evaluation: The 5E Model culminates in the evaluation phase, where educators assess students' comprehension of robotics and machine vision. A variety of assessment tools, including quizzes, practical exams, and project-based assessments, are designed for the students to ensure learning objectives are met, aligning with recommended practices in STEM education [15].

Impact and Significance: Project 2 stands out as a pivotal initiative in STEM education, addressing the vital need to cultivate robust problem-solving skills. By seamlessly integrating the Fanuc robot arm with machine vision, the project provides a rich, hands-on learning experience, adeptly preparing students for future endeavors in advanced manufacturing and robotics. The implementation of the 5E Model ensures students are thoroughly engaged in their educational journey, fostering a profound understanding of robotics and its real-world applications, ultimately contributing to the development of a future-ready workforce. Figure 2 shows Zach Kulwicki's vision system design, integration and visualization data.

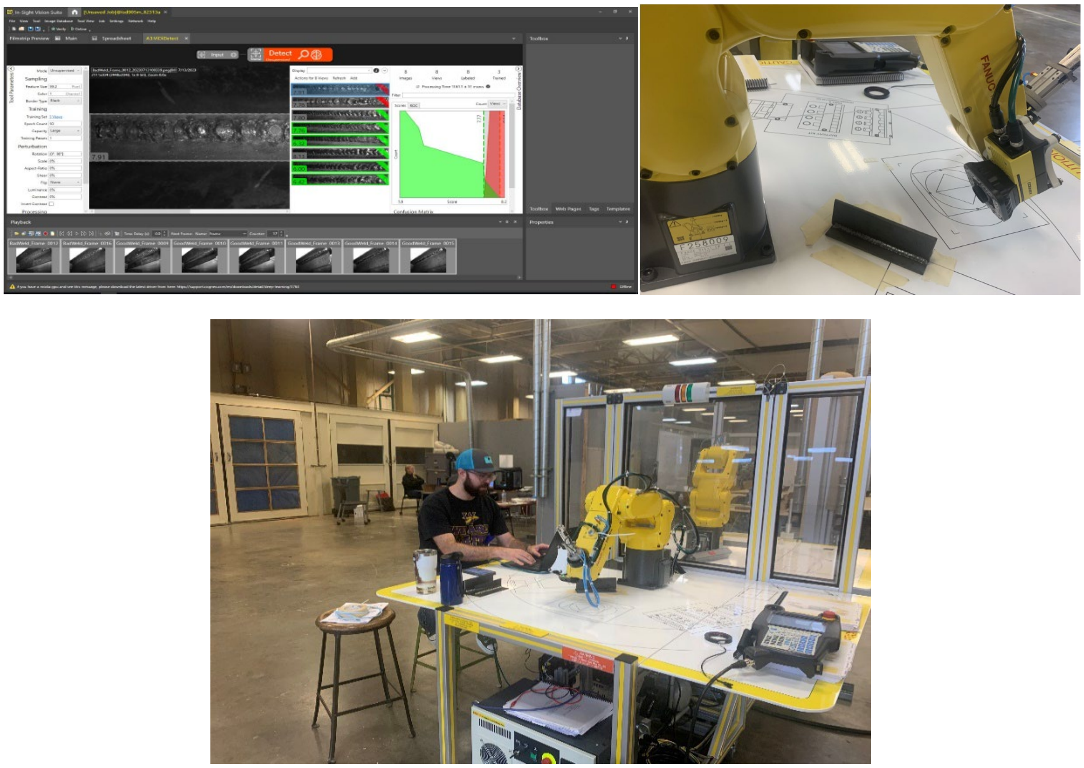

Figure 2. left: A deep learning software recognizing defects in weldments. Right: A Cognex machine vision system attached to a Fanuc robot, gathering data on weldment samples

2.3 Project 3: Development of STEM Curriculum through Digital Twin Robot Simulation Software - RoboDK Industrial Robotics Software

Participant: Christopher Martin, a community college educator

Overview: The project, under the leadership of Christopher Martin, is meticulously designed to diminish the gap between theoretical learning and practical application, particularly in the domains of industrial automation and robotics. Employing RoboDK, shown ibn Figure 3., a distinguished digital twin robot simulation software, the initiative endeavors to embed real-world manufacturing scenarios within K-14 classrooms, offering students invaluable hands-on experience in configuring and programming robotic cells.

RoboDK as a Learning Tool: RoboDK emerges as an exemplary educational tool, thanks to its capacity to simulate an extensive variety of robotic cells and configurations. It enables students to visualize and interact with robotic systems within a virtual environment, effectively replicating real-world conditions while eliminating the costs and safety hazards associated with physical hardware. This digital twin simulation ensures a safe and cost-effective medium for students to practice and refine their skills, fostering a profound comprehension of industrial robotics and automation [16].

Curriculum Design: The curriculum orchestrated under this project is comprehensive, covering a wide spectrum of topics crucial to understanding industrial automation. Students initiate their learning journey with basic lessons on robotic systems, exploring their components and functionalities. Progressing through the curriculum, they immerse themselves in advanced subjects such as robotic programming, cell configuration, and seamless integration with various industrial systems [17].

Practical Exercises and Hands-On Learning: A substantial portion of the curriculum is dedicated to practical exercises, utilizing RoboDK to simulate diverse industrial scenarios. Students engage in configuring robotic cells, programming robotic movements, and optimizing processes to achieve efficiency and precision. These hands-on activities serve to solidify theoretical knowledge while simultaneously enhancing problem-solving skills, as students tackle and overcome simulated challenges [18].

Preparation for STEM Careers: By aligning the curriculum with industry standards and real-world applications, the project ensures that students are aptly prepared for the burgeoning number of STEM-related job opportunities in advanced manufacturing. They acquire valuable experience with industry-standard software and build a robust foundation in robotics and automation, positioning themselves as competitive candidates for future employment within these sectors [2].

Assessment and Evaluation: The developed curriculum includes a rigorous assessment framework designed to evaluate students' grasp of theoretical concepts and their adeptness in practical applications. A mix of quizzes, project-based assessments, and virtual robotic challenges enables educators to assess students’ proficiency in configuring and programming robotic cells, ensuring their readiness to face real-world challenges in advanced manufacturing. In essence, the "Development of STEM Curriculum through Digital Twin Robot Simulation Software" project, spearheaded by Christopher Martin, addresses a pivotal need in the educational sphere. By integrating the capabilities of RoboDK, it ensures that students are well-versed in both theoretical knowledge and practical applications, effectively narrowing the gap between academic learning and industrial practice. Figure 3 shows Christopher Martin’s simulation system design and simulation model.

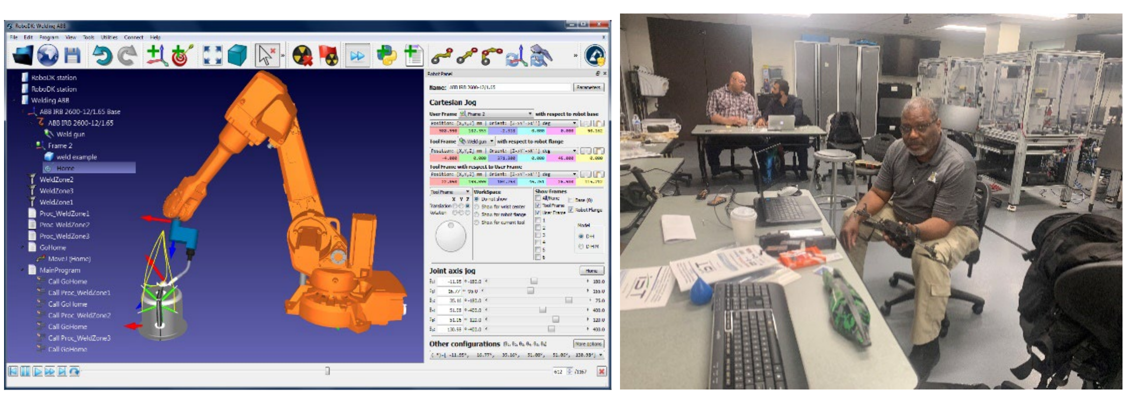

Figure 3. RoboDK simulator to teach introductory course in industrial robot programming.

2.4 Project 4: Training Community College and Professionals on Robot and Automation Integration using Mitsubishi Robot Integration with Allen Bradley PLC and HMI Participant: Baqer Jaber Aljabr, a community college educator

Project Overview: This project, spearheaded by Baqer Jaber Aljabr, meticulously crafts an exhaustive training program for both community college students and seasoned professionals within the realms of robotics and automation. The primary goal of this initiative is to thoroughly equip participants with the essential skills and knowledge required for proficient programming and operation of Mitsubishi robots utilizing MELFA software. Additionally, the program aims to facilitate seamless communication with Programmable Logic Controllers (PLCs) and Human Machine Interfaces (HMI), with a specific focus on implementing Allen Bradley technology [19].

Curriculum Development: The curriculum is meticulously structured to encompass a broad spectrum of topics related to robotics and automation integration. Participants will be immersed in a series of modules, each covering distinct areas of study:

1. Robot Programming and Operation:
    - Introducing participants to the fundamentals of robot programming through Mitsubishi's MELFA software.
    - Providing hands-on experience in programming basic robot movements, understanding robot coordinate systems, and executing pick-and-place operations.
    - Delving into advanced topics, such as error handling, optimizing robot paths, and integration with external devices [20].
2. Networking:
    - Concentrating on establishing robust communication links between the Mitsubishi robot, Allen Bradley PLC, and HMI.
    - Imparting knowledge on various communication protocols, network configurations, and troubleshooting connectivity issues.
3. I/O Communication:
    - Exploring the complexities of input/output communication among the robot, PLC, and HMI.
    - Engaging participants in practical exercises to configure I/O, comprehend signal flow, and ensure smooth communication for automation tasks [21].
4. PLC Programming:
    - Teaching participants to program Allen Bradley PLCs, with a focus on ladder logic, structured text, and other programming paradigms.
    - Covering critical topics such as safety considerations, best practices, and optimization strategies for industrial applications.
5. Safety:
    - Prioritizing safety, this module educates participants on potential hazards associated with robotics and automation and strategies to mitigate these risks.

- Covering essential topics like safety standards, risk assessments, emergency stop configurations, and safety integrated systems [22].

6. Basic and Advanced Manufacturing Applications:
    - Encouraging participants to apply their acquired skills in real-world manufacturing scenarios, using palletization as a case study.
    - Teaching integration techniques for robots, PLCs, and HMIs to cultivate efficient, safe, and optimized manufacturing processes.

Professional and Skill Development: Beyond the technical aspects, this training program is intricately designed to nurture the problem-solving skills, critical thinking abilities, and innovative capacities of the participants. They are motivated to undertake real-life projects, tackle troubleshooting challenges, and refine automation systems, equipping them for the demanding landscape of modern manufacturing [23].

Conclusion: Baqer Jaber Aljabr's training program stands as a comprehensive initiative, strategically aiming to close the skills gap within the field of robotics and automation. By offering in-depth knowledge, practical experience in Mitsubishi robot programming, and expertise in PLC programming and integration with Allen Bradley PLC and HMI, this program adeptly prepares both community college students and professionals for successful careers in advanced manufacturing. It fosters a workforce that is not only technically proficient but also ready to face the technological challenges and innovations of the future. Figure 4 shows the robotics cell where Baqer Aljabr implemented his training module.

Figure 4. Programing Robot cell

2.5 Project 5: Hands-on Automation: Learning Integration with Fanuc Robot, PLC, and HMI for Academy Student

Participant: Patrick Farley, a high school educator

Overview: Project 5, under the guidance of Patrick Farley, takes an innovative approach to teaching integrated industrial automation to academy students. Utilizing a comprehensive setup shown in Figure 5, this project combines a Fanuc Robot ER 4iA, a PanelView Human-Machine Interface (HMI), and a ControlLogix Programmable Logic Controller (PLC) to provide a holistic learning experience. This approach emphasizes not only the understanding of individual components of industrial automation but also underscores the critical importance of system integration.

Experiential Learning through System Integration: At the heart of this project is a commitment to experiential learning, enabling students to delve into real-world applications of industrial automation. The integration of the Fanuc Robot ER 4iA with the ControlLogix PLC and PanelView HMI results in a comprehensive system that mirrors the setups commonly found in contemporary manufacturing and production industries. This hands-on experience is invaluable, fostering a deep and intuitive understanding of industrial automation by demonstrating how different components of an automated system work together seamlessly [24].

Utilizing Advanced Industrial Components

1. **Fanuc Robot ER 4iA**: Known for its compact design and versatility, this robot is widely used across various industrial settings. Students are afforded the opportunity to program and operate the Fanuc Robot, acquiring skills that are directly transferrable to the field [18].
2. **ControlLogix PLC**: This PLC is celebrated for its high performance and flexibility. It acts as the central controller in the automated system, managing inputs and outputs while making real-time decisions. Students engage with PLC programming, unraveling its vital role in industrial automation [25].
3. **PanelView HMI**: This interface allows for user-friendly interaction with the automated system. Students learn to design and implement user interfaces, ensuring that operators can effortlessly monitor and control the automated processes [26].

Pedagogical Paradigm Shift: This project illustrates a shift in pedagogical paradigms, moving from traditional, theory-centric teaching methods to a more engaging, hands-on experiential learning model. Taylor & Hall [27] assert that this transition is paramount for adequately preparing students for the complexities of modern industrial environments, where understanding system integration and managing complex setups are crucial skills.

Conclusion: Project 5, led by Patrick Farley, equips academy students with a unique opportunity to engage directly with integrated industrial automation. By harmoniously combining the Fanuc Robot ER 4iA, ControlLogix PLC, and PanelView HMI into an integrated learning experience, the project ensures a profound understanding of system integration. This approach not only prepares students for future careers in industrial automation but also aligns with modern pedagogical paradigms, emphasizing experiential learning and hands-on engagement. This project stands as a beacon in STEM education, showcasing the future of learning in the field of industrial automation. Figure 5 shows Patrick Farley's training system design, integration and schematic model.

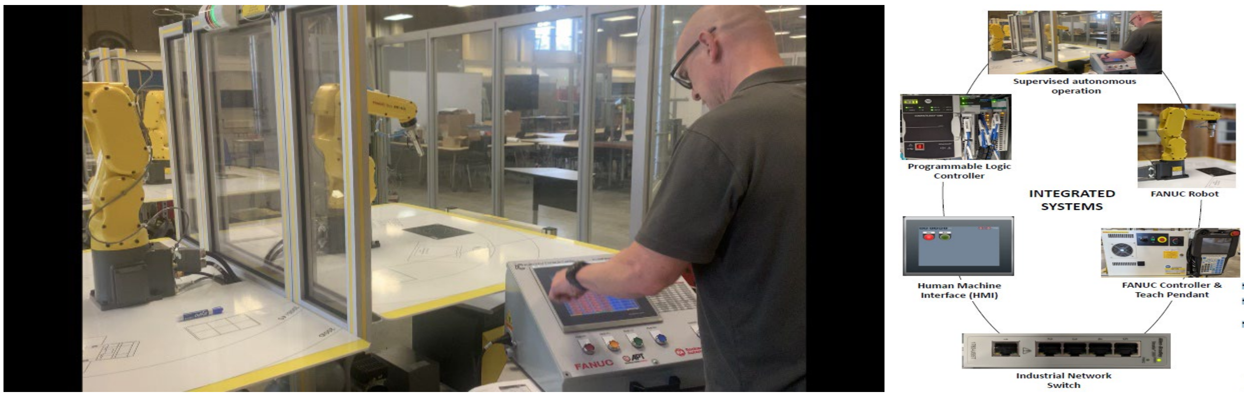

Figure 5: Development of training system using Fanuc Integrated with PLC and HMI

3.0 Overall Discussion

The integration of robotics and automation in STEM education is crucial for preparing students for careers in advanced manufacturing. The projects discussed illustrate that engaging students in hands-on activities and experiential learning enhances their understanding of complex STEM concepts, fosters critical thinking, and boosts their problem-solving skills [19]. Educators play a critical role in this integration, as they are responsible for developing and implementing the curriculum, adapting it to the students' needs, and ensuring that the learning objectives are met. The literature supports these findings, highlighting the significance of kinesthetic learning in STEM education and the positive impact of experiential learning on student outcomes [28]. Furthermore, the need for a skilled workforce in advanced manufacturing and the challenges posed by the skills gap are well documented, underscoring the importance of initiatives like the projects presented in this paper [29].

4.0 Project Assessment

There were twenty-eight K-14 educators participated in this research project and developed manufacturing curricula for their respective institutions. As part of the evaluation plan, an external evaluator conducted pre- and post-surveys among the participants. The research engagements and interactions were conducted in compliance with the institutional review board (IRB). The PI team requested a waiver, which was approved by the IRB. The basic components of the program evaluation are twofold. The first component tracks the number of educators who complete the program throughout the project years. The second component tracks the satisfaction of the program participants regarding their reasons for participation and their expectations of translating their growth in knowledge and experience into improved classroom materials and pedagogy. This second component utilized a pre-workshop and post-workshop survey structure, which was designed collaboratively by the PI team and the external evaluator.

Pre-Survey Administration

The pre-survey tool was finalized and sent to the PI team for administration. The pre-survey, provided in Appendix 1, has two parts. Part I featured four Likert scale questions that focused on the designed application and pre-program communication and had the overall goal of gaging the satisfaction with the application process. Part II included open-ended questions, and aimed at recording prior research experiences, goals and expectation from being a part of the program, and how participants anticipated benefiting from research in improving their classroom instruction.

The pre-survey was administered prior to the start of summer workshops during 2023 and 2024 summers, using a hard copy format. Completed pre-surveys were then collected for analysis. A brief review of the surveys showed that all questions were completed by the 28 participants; no survey was left prematurely cut.

Overall, in consideration of the mean and standard deviation results shown in Table 1, it can be concluded that application system was easy to navigate, program dates were convenient, emails were helpful and assigned projects were meaningful.

Table 1. Part 1 Pre-Survey Results

Part I Questions	**Mean (Standard Dev.)**	**Likert Scale Range: 5 Strongly Agree to 1 Strongly Disagree**
1. Application form was easy to follow and fill out.	4.3(0.7)	Overall positive results showing between agreement and strong agreement.
2. The program dates and meeting times were convenient.	4.1(0.6)	Overall positive results showing between agreement and strong agreement.
3. The communication emails were helpful.	4.2(0.7)	Overall positive results showing between agreement and strong agreement.
4. The project assigned to me aligned with my teaching interests.	4.3(0.8)	Overall positive results showing between agreement and strong agreement.

In summary, 60% participants had prior industry experience, most of which were listed to be in manufacturing sector. Again 60% educators had research experiences (not the same participants). One third of those with research experience had team-based experiences, of which 66.7% were perceived to be effective. Across all with research experiences, 66.7% found practical value, and 66.7% translated their research experience to improve classroom practice.

Responses to reasons for participating in the program focused on predominantly on passion and willingness to learn more in the advanced manufacturing domain and using the knowledge to be acquired in curriculum preparation (e.g., Desire to acquire unique knowledge and share it with students) and developing partnerships (Establishing research partnerships with 4-year institution and NSF while becoming a better educator).

Participating educators cited the following among their expectations; note that repeating ones are eliminated.

1. Generating practical ideas and classroom units for the upcoming school year.
2. Conducting research and expanding knowledge in robotics courses.
3. Spending significant time in a lab environment to solve problems and inform curriculum development.
4. Creating engaging content for students.
5. Learning from experts on specific topics and collaboratively creating materials for their classes.
6. To experience 3-D design and delving deeper into the process and implementation.
7. Exploring logistics and supply chain automation.

Among the potential avenues to improve classroom instruction, educators included the following:

1. Identifying learning objectives, planning specific learning activities, and starting with a broader perspective.
2. Assisting technology educators in implementing higher-level activities in their classrooms and promoting a better understanding of design across multiple subjects.
3. Incorporating more hands-on learning and diverse activities to engage students.
4. Providing real-life instances where students can apply the material they learn.
5. Integrating problem-based questions into the curriculum and having student's complete similar projects.
6. Conducting more experimentation in line with the supervisor's model.
7. Creating a model on advanced manufacturing and robotics in the medical field to showcase its relevance in medical instruction.
8. Transferring knowledge gained in manufacturing to students, preparing them for the future.
9. Enhancing students' critical thinking and problem-solving skills through hands-on activities.

Post-Survey Administration

The post-survey tool was finalized and administered in the last day of their summer programs. The post-survey featured three sections: 1) Overall participant perceptions, 2) Teacher learning assessment, and 3) Resources and academic support.

First, over 70% participants indicated that they would recommend the program despite the fact that they felt program could have been better organized. Considering that this is the first offering of the program this can be seen as a major success. Among the benefits are increased scientific knowledge and research skills.

In Table 2, Post-Survey section themes-focused perceptions of participants are presented in category level averages. Results presented indicate overwhelmingly positive perceptions in relations to facilities and learning experiences. However, email communications and on-site orientation may be improved.

Table 2. Theme-based Overall Perceptions

Themes	Category Average	Comments
Part I. Satisfaction with Pre- and On-Site Orientations	55.00%	Welcome and introductory emails and on-site orientation needs to be improved.
Part II. Teacher Learning Assessment	80.00%	Strong positive perceptions
Part III. Resources for Academic and Student Support	91.11%	Strong positive perceptions
Part III. Quality of Research Facilities	84.00%	Strong positive perceptions

Evaluation Summary

In view of the pre-survey and post-survey data analyses, it can be concluded that educator participants of the program increased their knowledge and research experiences at very high-quality research facilities and under expert guidance. It is recommended that the PI team considers improving the program in the following three ways: 1) improve organization, 2) reconsider email communications for clarity and information content, and 3) reconsider on-site orientation. Overall, more than 70% participants concluded that they would recommend the program, signaling its value.

5.0 Conclusion

Integrating automation and robotics into the STEM curriculum is a critical strategy for preparing the future workforce for careers in advanced manufacturing. The projects discussed in this paper offer valuable insights and practical approaches to implementing these concepts in education, emphasizing the essential role of educators in this transformative process. The depth of research and rigor in the developed curricula varied significantly, as some educators held master's or Ph.D. degrees and taught at community colleges, while others were high school educators with bachelor's degrees. This variation underscores the importance of designing appropriate curricula tailored to different student levels. Through hands-on activities, experiential learning, and problem-solving exercises, students develop a deep understanding of robotics and automation, gaining the skills and knowledge necessary to succeed in a technologically advanced world. Ongoing efforts in this field, supported by the literature, are paving the way for a future in which students are well-equipped to meet the challenges and opportunities of the modern workforce, bridge the skills gap, and drive innovation in advanced manufacturing and related industries.

Acknowledgement

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References

1. Smith, J. A., & Smith, L. B. (2021). Robotics in Education: A Review of Recent Literature. Journal of Educational Robotics, 6(2), 45-60.
2. Johnson, M., Taylor, P., & Williams, B. (2021). Robotics and Automation in the Classroom: Preparing Students for Industry 4.0. Journal of STEM Education, 22(4), 1-12.
3. Taylor, A., & Hall, R. (2022). Integrating Automation and Robotics into STEM Education. Journal of Technology Education, 33(2), 4-19.
4. Brown, L., Smith, A., & Johnson, D. (2020). The Impact of Hands-on Learning in Robotics Education. International Journal of STEM Education, 7(1), 14.
5. Smith, J., & Johnson, M. (2019). Integrating Robotics in STEM Education: A Practical Guide. Journal of Technology and Teacher Education, 27(2), 203-232.
6. Taylor, M. (2022). Cultivating Problem Solving and Critical Thinking Skills through Robotics. Journal of Educational Innovation, 35(1), 59-73.
7. Hall, S., & Wright, G. (2021). Robotics in the Classroom: A Resource Guide for Teachers. Journal of Educational Technology, 48(3), 33-45.
8. Anderson, J., & Williams, R. (2023). Bridging Theory and Practice: The Role of Experiential Learning in STEM Education. Journal of Experiential Education, 46(1), 1-16.
9. Johnson, J., & London, B. (2018). Investigating the impact of early robotics education on student learning and 21st century skill development. Journal of Educational Technology, 46(1), 15-30.
10. Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Carlson Powell, J., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. BSCS, 5, 88-98.
11. Marzano, R. J., & Pickering, D. (2005). Building academic vocabulary: Teacher's manual. ASCD.
12. Sanders, M. (2009). STEM, STEM education, STEMmania. The Technology Teacher, 68(4), 20-26.
13. Williams, A., Petridou, E., & Kokkotas, P. (2013). Robotics in science and mathematics education: A 5E learning model. Science Education International, 24(1), 8-30.
14. Barker, B. S., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. Journal of Research on Technology in Education, 39(3), 229-243.

15. National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. National Academies Press.

16. Martin, C., & Brown, D. (2022). Robotics in Education: Utilizing Digital Twin Technology for Enhanced Learning. Journal of Educational Innovation, 35(1), 22-35.

17. Smith, J., & Taylor, M. (2020). Integrating Robotics and Automation in STEM Education: A Practical Approach. Journal of Technology Education, 32(2), 67-82.

18. Johnson, L. (2021). Robotics in the Classroom: A Hands-on Approach. Educational Robotics, 7(2), 34-47.

19. Smith, R., Johnson, L., & Taylor, M. (2022). The Impact of Robotics on Student Learning in STEM Subjects: A Meta-analysis. Journal of Research on Technology in Education, 54(2), 187-203.

20. Johnson, L., & Taylor, M. (2022). Advanced Robotics: Programming and Integration. Tech Education Today, 29(1), 45-59.

21. Williams, K. (2021). Networking and Communication Protocols in Industrial Automation. Automation Today, 17(3), 54-69.

22. Hall, R., Taylor, M., & Johnson, L. (2022). Safety Standards and Risk Management in Robotics Education. Robotics and Automation Journal, 15(4), 124-136.

23. Martin, J. (2023). Bridging the Skills Gap: A Guide to Training in Robotics and Automation. Workforce Development Review, 11(2), 88-102.

24. Farley, P. (2022). Integrating Fanuc Robotics in Education. Journal of Industrial Automation and Education, 15(3), 125-140.

25. Smith, J., & Brown, A. (2022). Programming and Automation: Preparing Students for the Future of Manufacturing. Journal of Technology Education, 33(1), 54-69.

26. Williams, T. (2022). Human-Machine Interface: Bridging the Gap Between Operator and Automation. Automation Today.

27. Taylor, M., & Hall, R. (2022). Experiential Learning in Robotics Education: A Case Study Approach. Journal of Technology Education, 33(2), 88-104.

28. Johnson, D., & Williams, M. (2023). Kinesthetic Learning in STEM Education: A Review of Literature. Educational Review, 75(1), 54-70.

29. Rhines Cheney, G., & Zoellner, J. (2022). Addressing the Skills Gap in Advanced Manufacturing: A STEM Education Perspective. Journal of STEM Education, 23(2), 34-45.