

Advanced Manufacturing Curriculum Development in Ohio High Schools and Community Colleges

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Abstract

There is a huge lack of qualified personnel in advanced manufacturing in the U.S. Midwest stemming from a lack of student interest compounded with a lack of experienced teachers who usually motivate students. This paper describes the findings of an NSF RET project at Bowling Green State University that successfully addresses the common need to produce STEM graduates in the advanced manufacturing area. The NSF-RET project's unique hands-on research experience combined with local industry collaboration prepare future STEM teachers, who can interject research experience in a classroom learning and tie that with the real-world implementations. The project cements the partnership among BGSU, local high schools, and community colleges in Ohio to address the common need of producing STEM graduates in advanced manufacturing area. This project addresses the workforce needs by producing competent high schools and community college educators, who are capable to blend research with educational activities at their institutions, motivate students for STEM degrees, and build long-term collaborative partnerships in the region. This project focused on two goals: (1) explore a sustainable educational model that connects high schools, community colleges, university, and industry; and (2) play a transformational role in preparing future leaders in advanced manufacturing. This paper explains the need, scope, and nature of the curriculum development process through engaging K-14 educators. This paper will share some of their successful research projects, how they translated their research into actionable curriculum modules, and some lessons learned from implementations.

Keywords

Advanced manufacturing, research-based curriculum, K-14 educators, STEM pipeline

1. 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 [1-3]. 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 [4]. 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. Teachers are not just implementers of the curriculum; they are also developers and innovators, playing an active role in shaping the future of STEM education [5]. 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.

1.1. Regional Mission

Northwest Ohio industry has been experiencing significant growth in advanced manufacturing/robotics. The Ohio Regional Growth Partnership (RGP) projects faster-than-average job growth for the state's core STEM occupational groups [6]. In fall 2016, Economic Modeling Specialists Inc. (EMSI) reported advanced manufacturing on the top ten growing industries in Ohio [6]. STEM and STEM related services were projected to have the fastest growth. Both the public and private sectors in the state are strongly interested in expanding the state's share of regional, national and international trade. The timing is critical, as the state must be ready to accommodate increased manufacturing as part of rapid growth of manufacturing and reshoring initiatives. BGSU is poised to coordinate and implement a regional STEM consortium of both educators and industry to meet this need. Current U.S. Government is making significant policy changes (incentives, tax break for businesses, cancellation of trade agreement) to expedite the reshoring and hence attracting manufacturing jobs in the region. In most cases these jobs require advanced manufacturing skills such as robotics, CNC programming, simulation & modeling, and 3D design & printing.

The U.S. Department of Education reports Ohio's STEM graduation rates are insufficient to meet the regional forecast demand [6]. To address this shortage, multiple campuses in the region, consisting of BGSU, the Owens CC (OCC), Northwest State CC (NWSCC), Rhodes State CC, North Central State CC, and local high schools have united in this effort. BGSU is also part of Northwest Ohio Regional Training Hub Consortium; or NORTH that was funded for three consecutive years in support from regional industries and state grants through Regionally Aligned Priorities in Delivering Skills (RAPIDS) under the Ohio Department of Higher Education (ODHE). This is in addition to having access to two mobile training units (Mechatronics and process control equipment) which are shared with community colleges through RAPIDS program. This summer research program is the direct response to the abovementioned challenges.

2. Description of the Summer Research Workshop

This year, we had several major activities including professional development workshops, industry tour, research activities, curriculum development, and research presentations.

2.1. Professional development workshops: During the first 2 days of the program, the teachers completed a required safety training class and participated in tours of our research labs. We then had "Meet and Greet" workshop where the teachers, faculty mentors, students, and industry advisors met to discuss the research projects. Dr. Sarder, the PI, delivered a brief presentation about the program and its objectives. College Dean also welcomed the first cohort of BGSU RET participants. All attendees were welcomed and gave a brief introduction of themselves. Three Co-PIs and research mentors explained the research projects and timeline. In this meeting, undergraduate and graduate student mentors were assigned to a project and the teachers were asked to update their research mentors as the projects progressed. Industry contacts were also available to answer questions. Finally, Dr. Duran, a professional development expert, engaged with them various activities related to training and curriculum development.

2.2. Industry Tour: We had an industry tour in the 4th week of the program at Kaufman Engineered Systems in Waterville, Ohio. The tour was related to the manufacturing activities being developed that week. Kaufman Engineered Systems is a premier integrator for FANUC robotics offering robotic palletizers, stretch wrapping machinery, automated packing machines, food packaging machines, high-speed picking, and other robotic handling systems.

2.3. Research Projects: 15 teachers were formed into three major research groups. The theme of these group research projects were advanced manufacturing, robotics, and autonomous systems. Within each group, two teachers were engaged in a particular research project. Each week these teachers were engaged with research experiments supervised by the graduate students and mentored by three Co-PIs.

2.4. Curriculum Development: The instructors participated in a comprehensive series of six workshops as part of the RET program. Given that a majority of the participants held master's degrees in education, the primary goal of these workshops was to refresh their knowledge of selected curriculum design models and enhance their proficiency in evidence-based teaching techniques. These workshops encompassed a wide range of educational topics, incorporating theories of blended learning, formative assessment strategies, active learning methods, and the effective integration of technology into teaching practices. Teachers had the opportunity to actively engage with and take away valuable insights that they could apply in their own classrooms. Each workshop had an approximate duration of two hours, and various topics were covered in the series.

3. Manufacturing Research Experience by K-14 Educators

Several approaches were incorporated into the planned research training. The participants attended preliminary training sessions that included presentations and discussions on the history and fundamentals of systems and machine languages with emphasis on tools for data analytics. Research workshops and seminars introduced them to important engineering ethics, safety protocols, subject privacy, and confidentiality. Participants researched popular engineering case studies and were then challenged to provide in-depth analysis of hypothetical scenarios. We incorporated domain-specific hands-on training sessions together with the study of research articles and books, all run in parallel with the progressive applied engineering research topics that spanned major interdisciplinary fields, particularly in the area of robotics and automation in advanced manufacturing [7]. Reinforced learning tools for experiential learning were deployed to encourage engagement and speed up the learning process. Such tools included visitation of manufacturing sites and the use of animation, videos, and interactive devices. The educators and instructors discussed contemporary issues and searched materials from the library and the Internet. All participants were introduced to advanced manufacturing concepts, literatures, research methodologies, and content of all research modules via Canvas prior to the start of the summer research program. During the six weeks of the summer research workshop, participants were engaged in hands-on research activities and supervised by their mentors. The hands-on activities and labs were designed to learn to collect data, practice on software/hardware tools, build models, investigate different mechanisms, design experiments, conduct statistical analyses, and evaluate outcomes. The participants exercised a set of paradigms to program robots and ran robots based on their programs. They assessed their classroom settings and participated in the technical development process to create teaching materials for training and educational use.

3.1. Scope of Research Experience for STEM Educators

The advanced manufacturing research facilities at BGSU were used by the participating educators with enough early opportunity to engage in research through the design, building, and testing of robotics systems. BGSU focused on robotics systems rather than a few components of the system. In real-life scenarios, students needed to know how to program robots, operate robots, and integrate other systems such as material handling, logistics, manufacturing, and dashboards with the robotics systems using software programming, the Internet of Things, and other means. The following figure showed the scope of BGSU research capabilities in the area of advanced manufacturing systems. In the research projects, BGSU Engineering and Technology (ET) students collaborated with students from other disciplines including computer science, physics, sustainability, and photochemical sciences. In one of the recent projects, mechatronics students collaborated with photochemical science students to develop 3D printed vocal cords and analyzed the performances. In another project, mechatronics students designed an autonomous driving system within the campus. The research workshop utilized BGSU's state-of-the-art advanced manufacturing and robotics facility and industry manufacturing sites. The participants worked on individual research projects under the supervision of faculty members. Industry mentors were also assigned to each research project and each participant. Seniors and graduate students helped the participants with logistics. Last summer, 12 different research projects were set up where participants worked during the 6-week workshop. Below are brief descriptions of some sample research projects.

Sample Project 1: AGVs and Worker Safety in Advanced Manufacturing Workspace

Background: According to the Occupational Safety and Health Administration (OSHA), industry related injuries indicate that from 2015 to 2019, 76% of injuries are attributed to autonomous cars, mobile cars, and automated guided vehicles (AGVs). OSHA states that there were 30 casualties in a human-robot workspace from 1987 to 2019. Due to a significant increase in robot installation worldwide, and the increasing amount of interaction, see figure 6.1, it has become important to investigate the robot(s) locomotion within workspace, examine the probability of accidents, see figure 6.2, and determine a solution to minimize unsafe interaction. **Research Objectives:** This research presented a failsafe method for controlling the path of randomly moving robots or humans during worst case scenario particularly when minimum sensing capabilities are present. **Research Methodology:** The social behavior model of a randomly walking worker and coexisting with other dynamic or static robots in a workplace is developed to follow simple random walk scheme, provided that the robot stops upon the arrival to a predefined destination.

Sample Project 2: Cybersecurity in Advanced Manufacturing and Robotics

Background: In past, the manufacturing industry was connected within the local network but the connection with the outside world was very limited. Most people working in advanced manufacturing industry and robotics have no or little knowledge about cybersecurity. Due the fourth industrial revolution, industries are now being connected to the

Internet world to track and control the production remotely in real-time, plan resources, increase productivity, and make informed decisions. Connecting with the Internet world brings cyber threats to the industry, thus an awareness among industry workforce is critical as well as awareness to teachers who prepare and advise students for the industry is essential. **Research Objectives:** This project aims to train educators on Cybersecurity in the advanced manufacturing

industry and robotics. In addition, this project also prepares them to safely access the Internet.

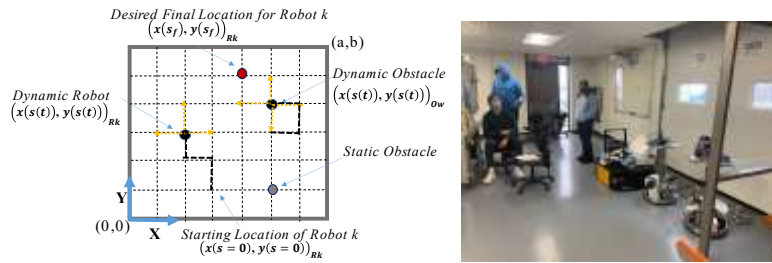


Fig. 1 Mobile material handling systems (a) Concept of robots and obstacles interactions in confined workspace. (b) Collaborative mobile robots with navigation capabilities.



Fig. 2: BGSU eFactory without Cybersecurity

4. Development of Manufacturing Curricular Modules

A formal advanced manufacturing curriculum supported by their teachers/faculty and their institutions could make a significant difference in attracting students to this discipline and meeting the workforce needs in our region. The proposed curriculum was based on participants' research experience and employed the principles of the Understanding by Design [8] framework and aligned outcomes to state curriculum standards (OH), as well as the Next Generation Science Standards. The curriculum development was facilitated through a series of weekly curriculum design workshops during the 6-week summer research program. These workshops focused on topics such as Understanding by Design [8], the engineering design process, fostering student engagement, and teaching through problem-based and active learning. Additionally, one workshop session was dedicated to a panel discussion from faculty who shared experiences and insights for the participants to consider when working with their students. Each session also included hands-on curriculum design time dedicated to writing specific components of the curriculum modules. The workshops culminated with a sharing session during which teachers could provide one another with feedback and suggestions. At the end of the summer program, the curriculum modules were submitted and reviewed to ensure that they aligned with program goals and state/national standards, reflected best practices, and utilized active, problem-based learning strategies to foster learner interest, engagement, and achievement. Lastly, continuous improvement of the curriculum, implementation, and evaluation occurred during the school year and involved classroom observations, student surveys, and instructor interviews. Feedback and information collected during the implementation and evaluation phases supported ongoing revisions and enhancements to curriculum design workshops. Future curriculum design workshops would include additional time to interact with expert teaching faculty, more exemplary activities, and more frequent peer review towards the end of the residency when participants were well-versed in research and could think deeply about applications in the classroom. 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 [9]. Teachers 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 [10]. 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 [11].

5. Program Evaluation and Assessment

There were fifteen K-14 educators participated in this research project and developed manufacturing curricula for their respective institutions. As part of the evaluation plan, external evaluator conducted a pre-survey and a post survey among the participants. Basic components of the program evaluation are two-fold. The first component tracks the

number of educators who complete the program throughout the project years. Second component tracks the satisfaction of the program participants vis-à-vis their reasons to partake and expectations on translating their growth in knowledge and experience into improved classroom materials and pedagogy. This second component used a pre-workshop and post-workshop survey structure. The survey was designed in a collaborative effort by the PI team and the external evaluator.

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. It was administered on June 12, 2023, 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 15 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 total, 9 of the 15 (60%) participants had prior industry experience, most of which were listed to be in the manufacturing sector. Again 9 of the 15 educators had research experiences (not the same 9 participants). Three of those with research experience had team-based

experiences, of which 2 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 BGSU and NSF while becoming a better teacher).

The post-survey tool was finalized and sent to the PI team for administration (completed on the 25th of July, the last of the program). 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 were 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

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.

6.0 Conclusion

The unique significance of this project is to instill robotics research experience within STEM educators through six-week summer research projects at the state-of-the-art robotics research lab (e-Factory) at BGSU under the supervision of robotics faculty mentors. This unique hands-on research experience combined with local industry collaboration prepared fifteen future STEM teachers, who would be able to interject research experience in a classroom learning and tie that with the real-world implementations. The research modules/curriculum, derived from Ohio Department of Higher Education advanced manufacturing initiative, was focus on contemporary advanced manufacturing topics including modern sensors and actuators, advanced robot programming using 3D simulation software, RoboDK, CNC programming, CAD/CAM, 3D printing, and e-Factory. The participating teachers translated their research experiences and knowledge into classroom practice customized for their students. The research program's overarching goal is to increase the awareness and number of Ohio STEM graduates to meet the growing regional employment need in robotics/advanced manufacturing. As part of that goal, the project produced a cohort of motivated educators with experience in advanced manufacturing research and skill sets. These trained educators went back to their institutions and have been implementing the developed manufacturing curricula for their students.

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