Enabling K-14 Educators in Developing and Deploying Advanced Manufacturing Curricula

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Abstract

Manufacturing is undergoing rapid changes due to the demands of product complexity and variety, and therefore factories are demanded to become smarter and more efficient. This transformation is known as advanced manufacturing and will require a new generation of skilled employees. There is a huge lack of qualified personnel in advanced manufacturing 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 an US university that successfully addresses the common need to produce STEM graduates in the advanced manufacturing area. We recruited fifteen high school and community college STEM educators for a six-week immersive summer research experience in the state-of-the-art robotics laboratory. At the end of their research workshop, they developed customized hands-on advanced manufacturing curricula for their students. This project produced fifteen competent high school and community college educators, who are capable of blending research with educational activities at their institutions, motivating students for STEM degrees, and building long-term collaborative partnerships in the region. 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. This paper will also explain the evaluation process and share the results. 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.

Introduction

This NSF-RET research-based training program established a new summer research program for high school and community college educators. This training program enhanced educators' knowledge and skills in advanced manufacturing/robotics. The trained educators then returned to their institutions, developed advanced manufacturing curriculum modules, and sparked the interest of their students. This project created an efficient recruitment, transfer, and support system for students from regional high schools (HS) to the participating community colleges (CC) and into 4-year engineering and technology programs in mechatronics, electronics and computer, mechanical and manufacturing, and systems engineering.

Manufacturing is undergoing rapid changes due to the demands of product complexity and variety, and therefore factories are required to become smarter and more efficient. This transformation is defining the factory of the future, which is also known in the US as advanced manufacturing, and it will require laborers to come to terms with complex processes, machines, and components. There is a huge lack of qualified personnel in advanced manufacturing stemming from a lack of student interest compounded by a lack of experienced educators who usually motivate students. This project is a direct response to such concerns, producing competent educators who are capable of blending research with instructional activities at their institutions, motivating students for STEM degrees, and building long-term collaborative partnerships in the region.

Project Justification

During the eighties and late nineties, many US manufacturing companies mass outsourced their operations to overseas and experienced a significant job loss. Some experts argue that outsourcing takes up the lower-level jobs and that allows Americans do perform the higher value jobs [1-3]. Nevertheless, that argument does not address the negative impact it had on the Americans especially; US Midwest residents who were laid off and did not immediately find new employment. They were unemployed for a lengthy time; many of them lost their homes and other properties they once owned. This, of course, affected the American economy in a negative way. Outsourcing seems be losing luster in the US as the majority (around 70%) of industry seems to have had a negative experience with outsourcing, according to a survey of 25 large organizations, with a combined $50 billion in outsourcing contracts [4-6]. According to Reshoring Initiatives, more than 237 U.S. companies brought their operations back home and created significant manufacturing jobs. When reshoring, many companies are being located in areas where manufacturing and logistics infrastructures are in place. For instance, Ohio and Michigan rank top ten in attracting reshored companies (see Table 1). This phenomenon will create more manufacturing job opportunities in the region. The only caveat is that these jobs are not traditional manufacturing jobs rather advanced manufacturing/robotics jobs.

Skill-biased technical shift has been a pervasive feature of today's American economy. Technology-skill complementarity has also been widespread over the past century with new technologies from those associated with internet and computer revolution to the robotics revolution, which as of today has been primarily shaping the future of the world manufacturing industry. However, according to Ohio Manufacturing Association 2015 report, there is more than 670,000 traditional manufacturing jobs in Ohio, ranking the third in manufacturing employment nationally, and providing more than $52 billion in products to 216 countries and territories [7, 8].

Table 1: Reshoring by State			
State	Total Jobs	# of Companies	Avg. Jobs/Company
SC	7780	7	1111
MI	6721	13	517
CA	6014	28	215
KY	4612	5	922
TX	3712	12	309
OH	3611	18	201
GA	3005	7	429
TN	2490	11	226
NY	1089	17	64
NC	1020	14	73
ID	1000	2	500
KS	1000	2	500
CO	738	6	123

In response to the global technology shift and worldwide competition, a large percentage of these traditional manufacturing operations will undergo organizational transformation and technology investment in adaptive and intelligent manufacturing, which encompasses many sectors including automotive, energy, food, defense, medical, and pharmaceutical industries. Manufacturing is undergoing rapid changes due to the demands for product variety, thus necessitating factories to become smarter and more efficient. This transformation is defining the factory of the future, also known in the US as advanced manufacturing, and it will require laborers to come to terms with complex processes, machines, and components. The impact of technology has not been uniform across the US, but it has recently been transforming the automotive industry, particularly the production facilities in the Northwest Ohio region. These facilities are implementing robotics and automation systems that render the factories adaptive, fully connected, analytical, and more efficient.

The state of Ohio remains a leader in the United States in manufacturing production as well as training the next generation of leaders to enter the advanced manufacturing workforce. In 2016, the state of Ohio's 12,660 manufacturing firms and 687,000 manufacturing workers (12.5% of the state's nonfarm employment) produced over $106 billion in output, or almost 17% of gross state product (GSP). Ohio manufacturers exported $49.1 billion, or 92% of the state's total exports in 2016. Ohio's manufacturing industry is very diverse, with large sectors in petroleum and coal ($14.5 billion), chemical products ($13.3 billion), motor vehicles and parts ($12.1 billion), fabricated metal products ($11.2 billion), machinery ($8.4 billion), and aerospace ($4.8 billion). The Toledo region is one of the state's manufacturing centers, with over 700 firms employing approximately 43,000 workers (an increase of over 2,300 workers since 2013). Toledo has been labeled the "Silicon Valley" of manufacturing sector because of the presence of high-tech advanced manufacturing. A 2017 study by the Brookings Institution found the Toledo region has over 2,374 industrial robots (an increase of 28% from 2010) or 9.0 per thousand workers, which ranks 1st in the United States among the Top 100 metropolitan statistical areas. Proposed project like this is not only very critical for the state of Ohio, Michigan, Indiana, but also for all US manufacturing hubs [9].

In June 2017 advisory panel of key business and industry representatives from across the state of Ohio were identified and invited to review the Engineering and Science Technologies and Manufacturing Technologies Content Standards and advise the Ohio Department of Education with an objective to prepare students for careers in design, operations, manufacturing and STEM. The outcomes of the review have standardized multiple competencies that can lead to career pathways in advanced manufacturing and robotics, including robotics operation, robotics programming, computer integrated manufacturing, digital electronics and circuits, operational management and many others [10]. Manufacturing companies are becoming part of a more complex virtual ecosystem due to the revolution of communication, which is driven by information sharing across multitude of interconnected automation systems in supply chain, and beyond the organizational boundaries. The Ohioan-manufacturing jobs in the area surrounding Northwest Ohio will soon have the highest demand for skilled workers who will be part of the future advanced manufacturing industry that combines "real" and "virtual" systems. Such skills gap – if not narrowed - is expected to take the biggest toll on skilled production jobs and will likely widen as time passes [11]. A published study by the US. Department of Labor identified that on average, technology has increased the demand for workers who have good math, communication, problem solving, and teamwork skills. Therefore, there is a need to equip students at early stage of high school with the right transferable technology skill set, which fosters innovation and adapts to the ever-changing industry needs.

Northwest Ohio has the highest African American population within the state of Ohio (27%) [13], yet only 13% of our engineering technology students are minority students. Female students are also disproportionately low (12%) in engineering technology program. The proposed project targets these two underrepresented populations (UP's) by recruiting representative (including minority and female) HS and CC educators who teaches predominantly minorities and female students. The proposed project activities will create collaborative engagement with regional community colleges and high schools. This collaboration will improve 2-yr to 4-yr transfer rate, increase traditional high school students, incite interest in advanced manufacturing among high school students through trained educators, and improve awareness among STEM community.

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 [14]. In fall 2016, Economic Modeling Specialists Inc. (EMSI) reported advanced manufacturing on the top ten growing industries in Ohio [14]. 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. Our university 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 [14]. To address this shortage, multiple campuses in the region, consisting of 4-year institutions, 2-year community colleges, and local high schools have united in this effort. Our university is part of the 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.

Description of the Summer Research Workshop

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

1. Professional development workshops: During the first two days of the program, the teachers completed a required safety training class and participated in tours of our research labs. Following this, we hosted a "Meet and Greet" workshop where the teachers, faculty mentors, students, and industry advisors convened to discuss the research projects. The principal investigator of the NSF-RET project delivered a brief presentation about the program and its objectives. Our college dean also extended a welcome to the first cohort of NSF-RET participants. All attendees were greeted and provided a brief introduction of themselves. Three Co-PIs and research mentors elucidated the research projects and their timelines. During this meeting, undergraduate and graduate student mentors were assigned to projects, and the teachers were instructed to update their research mentors as the projects progressed. Industry contacts were also available to address any queries. Finally, a professional development expert associated with this project engaged them in various activities related to training and curriculum development.
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 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.
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.
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, covering various topics throughout the series.

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 an 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 [15]. Reinforced learning tools for experiential learning were deployed to encourage engagement and speed up the learning process. Such tools included visits to manufacturing sites and the use of animation, videos, and interactive devices. The educators and instructors discussed contemporary issues and searched for materials from the library and the Internet. All participants were introduced to advanced manufacturing concepts, literature, 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.

Scope of Research Experience for STEM Educators

The participating educators utilized advanced manufacturing research facilities, providing them with early opportunities to engage in research through the design, building, and testing of robotics systems. Our focus was on complete robotics systems rather than isolated components. In real-life scenarios, students needed to understand how to program robots, operate them, and integrate them with other systems such as material handling, logistics, manufacturing, and dashboards, using software programming, the Internet of Things, and other means. The scope of our research capabilities in the area of advanced manufacturing systems is depicted in the following figure. In the research projects, our Engineering and Technology (ET) students collaborated with students from other disciplines including computer science, physics, sustainability, and photochemical sciences. For example, in one recent project, mechatronics students collaborated with photochemical science students to develop 3D printed vocal cords and analyzed their performance. In another project, mechatronics students designed an autonomous driving system within the campus.

The research workshop utilized our state-of-the-art advanced manufacturing and robotics facility as well as industry manufacturing sites. Participants worked on individual research projects under the supervision of faculty members, with industry mentors assigned to each project and participant. Seniors and graduate students assisted participants with logistics. Each summer, 12 different research projects were set up, with participants working during the 6-week research workshop. Due to the limited 6-week duration of funding, the scope of these research projects was restricted. Participants did not conduct literature reviews as they possessed the necessary background knowledge. Instead, they formulated appropriate hypotheses and tested them through experimental research activities. These projects are recognized as authentic research experiences for K-14 teachers according to the NSF-RET solicitation. 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.

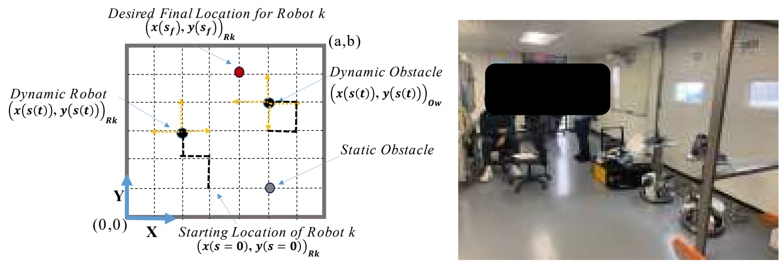

Fig. 1. Mobile material handling systems (a) Concept of robots and obstacles interactions in confined workspace. (b) Collaborative mobile robots with navigation capabilities.

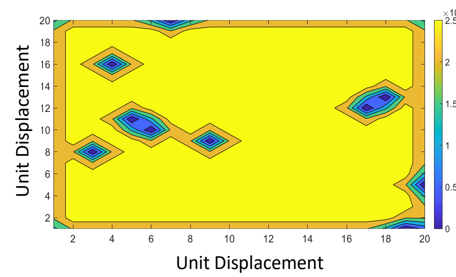

Fig. 2. Probability of collision for

Sample Project 2: Cybersecurity in Advanced Manufacturing and Robotics

Background: In the past, 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. 3. Our eFactory research facility

Sample Project 3: Development of Safe and Efficient Material Handling System Using Fixed Automation

Background: In a given fixed material handling system where workers or industrial robot arm and automated conveyer system are coexisting, and their movements are not coordinated due to loss in communication or human error; the development of an onboard safeguard system becomes a necessity to reduce accidents while the production efficiency is uncompromised. The purpose of this project is to develop efficient material handling system that safely transfer specified objects between two independently controlled conveyors by using custom made robotics arm. ***Research Objectives:*** This project aims to convert traditional robotic and automation systems into smart industry 4.0 systems (1) Obtain a small-scale robotics and automation manufacturing system (i.e., Industry 3.0), (2) automate material transfer processes and identify associated cost of production with/out safety features, (3) implement an automatic optimization model coupled with multi-level safety zoning algorithm that maximize the production and mitigate collision or injury risk in real-time (Upgrade system from Industry 3.0 into Industry 4.0).

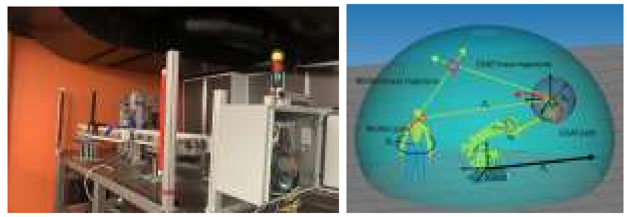

Fig. 4. Fixed material handling systems: (a) Customized material handling system constructed by senior design students. The system is comprised of conveyor belts, Cartesian robot, PLC, laser safety curtain, safety motor controllers, safety switches and distributed presence sensors. (b) worker within unsafe working zone of industrial robot arm [2].

Development of Manufacturing Curricular Modules

The HS students were mostly barely familiar with advanced manufacturing, while CC students were somewhat familiar with it but lacked advanced knowledge in this area. 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 [16] 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 [16], 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 to the curriculum development expert assigned to this RET project for review. The expert reviewed the modules 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.

Program Evaluation and Assessment

Fifteen 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.

Summer 2023 Evaluation

<u>Component 1:</u>

Program participants: 15, or about 42% of the intended total across project years.

<u>Component 2:</u>

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.

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 2. 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 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 4-year institution and NSF while becoming a better teacher).

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 teachers 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 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 3. 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.

Conclusion

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

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