Educating the Workforce of the 21st Century through Smart Manufacturing Systems in the Classrooms

Roya Salehzadeh, University of Alabama

Roya Salehzadeh obtained her B.Sc. degree in mechanical engineering from Urmia University, Iran, in 2010, and her M.Sc. degree from Amirkabir University of Technology (AUT), Tehran, Iran, in 2013. She is currently pursuing a Ph.D. in mechanical engineering from the Advanced and Intelligent Manufacturing Systems Laboratory at the University of Alabama, Tuscaloosa, AL, USA.

Ms. Salehzadeh's research interests are focused on human-robot interaction, automation, and manufacturing. She is a member of the Alabama Initiative for Manufacturing Development and Education (Alabama IMaDE), where she contributes to the development and teaching of manufacturing courses for the new Manufacturing Systems Engineering (B.S.) program at the University of Alabama.

Additionally, Ms. Salehzadeh is a member of the American Society of Mechanical Engineers (ASME) and the Society of Women Engineers (SWE).

Gustavo Galvani, University of Alabama
Anahita Zargarani, University of Alabama

NA

Prof. Nader Jalili, University of Alabama

Dr. Nader Jalili joined Southern Methodist University (SMU) as its next Dean of Lyle School of Engineering in March 2023 from the University of Alabama where he was a Professor and Head of the Department of Mechanical Engineering. He was formerly a Professor of Mechanical Engineering, Associate Department Chair for Graduate Studies and Research, and Director of Northeastern University Piezoactive Systems Laboratory at Northeastern University. An ASME Fellow and former Chairs of both ASME Mechanical Engineering Department Heads and Chairs (MEDHC) and ASME Southeast Mechanical Engineering Department Heads (SMEDH), Dr. Jalili is an innovative leader and researcher, known for bringing the resources of engineering education and research to undergraduate and graduate students, industry partners and community outreach programs. An active researcher, Dr. Jalili has been PI or Co-PI on more than $17 million in external funding, including grants from the National Science Foundation, the U.S. Department of Energy and the U.S. Department of Defense in the domain of vibration, control and acoustics. He is the author or co-author of more than 350 peer-refereed technical publications, including 135 journal papers, two textbooks and five book chapters. A fellow of the American Society of Mechanical Engineers, Jalili has chaired numerous society committees and edited several engineering academic journals. In addition, he is the recipient of more than 30 international, national and institutional awards for his research, leadership, teaching and service. In his four years as the Head of Mechanical Engineering at the University of Alabama, Dr. Jalili led a significant increase in external research awards and enrollment as well as the creation of the Alabama Initiative on Manufacturing Development and Education (Alabama IMaDE®), designed to better prepare future highly skilled workers through a convergence of education, research and service. The Alabama Initiative has guided multiple research projects in the core areas of automation, human-robot collaboration/integration and augmentation and has partnered with numerous outreach programs to promote new career paths for middle and high school students in the region.

Dr. Daniel J. Fonseca, University of Alabama

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Abstract

Advanced manufacturing technologies have been identified as a critical and emerging field in the U.S. by the National Science and Technology Council (NSTC). Consequently, the U.S. government is encouraging universities and other educational institutions across the country to promote manufacturing programs. These programs could equip their students with the various high-technology skills needed to succeed in the new era of smart automation and adaptive industrial systems. To comply with such demand, a new manufacturing facility was founded at The University of Alabama and launched in collaboration with industrial partners. This facility, The Alabama Initiative on Manufacturing Development and Education (Alabama IMaDE), was founded to support a newly developed bachelor's degree in manufacturing systems engineering, as well as to support local and regional manufacturing activities through education, research, and service with a systems integration and industry mindset approach. This educational center enables hands-on, project-based learning in robotic manufacturing; as well as instruction in the programming, operation, and implementation of automated systems.

To advance the facility's goal and mission, a two-day workshop on Smart Manufacturing Systems (SMS) was held for local high school teachers to introduce them to the concept of SMS and encourage its instruction across the state. The event was intended to expose the teachers to some elements and components of an SMS, connect them with our industrial and educational partners, and help them with the implementation of manufacturing programs at their institutions. During the Workshop, high school educators participated in three training sessions including 1) Introduction to Manufacturing Automation, Industry 4.0 and Smart Sensors, 2) Programmable Logic Control (PLC), and 3) Industrial Robot Programming. Key industrial partners conducted presentations and equipment demonstrations for the participants to help them incorporate the teaching of manufacturing technologies into their institutions' STEM curricula. This paper discusses the imparted workshop, its results, and potential impacts as well as the participants' responses to both pre-workshop and post-workshop surveys.

1 Introduction

The constant development and advancement of the manufacturing sector play an important role in the economic growth of any country [1]. In pursuit of remaining one of the leading economies in the world [2], the U.S. government is promoting early manufacturing education and manufacturing technology development across the country. With the vision of constant development of its manufacturing sector, the United States is pushing educational institutions to develop early manufacturing education programs (as early as pre-K and high school) that will equip young generations with the skills necessary to continue contributing to an evolving manufacturing economy [3]. Hence, American schools and universities are being encouraged to develop programs and courses in advanced manufacturing areas such as Industry 4.0 and smart manufacturing systems (SMSs) [4], [5]. Industry 4.0 and smart manufacturing are characterized by the use of advanced technologies to optimize manufacturing processes and improve efficiency, flexibility, and responsiveness. Real-time data and analytics are used to enhance product quality and reduce waste. Although some components of Industry 4.0 and smart manufacturing, such as robots or programmable logic controllers (PLCs), were available in previous generations of production systems, smart manufacturing is distinct. It leverages advanced digital technologies to optimize the entire process, integrate the physical and digital worlds, and utilize customer data for product design and production. This results in a more efficient, flexible, and customer-centric manufacturing process.[6] [7]. With the adoption and development of Industry 4.0 concepts around the globe, the automation and digitalization of processes have become a priority. To make manufacturing processes more reliable, robust, and cost-efficient, manufacturers have been adopting the use of robots, smart sensors, big data, and other technologies to enhance their production processes [8]. However, the U.S. manufacturing industry has been experiencing a shortage of skilled manpower, mostly due to the misconception people have about manufacturing careers, which leads to a lack of interest in jobs in the field. Nowadays, there exists a prevalent misconception, among younger generations, that manufacturing jobs are manual-labor intensive, dirty, and poorly salaried [9]. To tackle this issue, companies and governmental organizations have been partnering with educational institutions to develop manufacturing education programs [10]. To introduce manufacturing at early levels of education, and with the hope of providing a new perspective on careers in this field, the Alabama Initiative on Manufacturing Development and Education (Alabama IMaDE) at The University of Alabama (UA) united with educational and industry partners to develop an informative workshop where high school teachers were introduced to Industry 4.0 and SMS concepts such as robotics and PLC. The workshop's main goal was to promote early manufacturing education in the state of Alabama. This workshop was created to motivate high school teachers to adapt manufacturing-related courses in their schools and introduce them to potential industrial suppliers as well as innovative platforms that can assist them in the implementation of a manufacturing education program at their institutions. To make the event a more dynamic experience, the team focused on creating hands-on activities, where the participants were exposed to some of the learning tools that can potentially be used in their classes. This paper discusses the expectations and outcomes of the attendees, as well as an analysis of the participants' experiences during the workshop.

2 Study design, procedure, and activities

The conducted workshop was intended to motivate regional high school teachers and educators to implement an early introduction program to Industry 4.0 and SMSs at their institutions. During the workshop, participants were exposed to some of the components of SMSs by learning basic industrial concepts and performing hands-on activities. In addition, the educators had the chance to network with industry and educational partners who can eventually help them with the implementation of an introductory program in smart manufacturing for their students.

The two-day workshop was held at Alabama IMaDE, a manufacturing research facility located at the UA main campus. For advertising purposes, an event flyer was created and distributed across the educational institutions in the state, with the help of educational associates and governmental institutions. The location of the workshop along with other detailed information, such as accommodation, was shared with all the registered teachers via email.

Moreover, participants were asked to complete a pre-workshop survey shared with them before the event started. The registered participants attended the workshop for two days and completed all required activities either individually or with a partner. A faculty member in education sciences who assisted in the participants' recruiting efforts served as an observer, conversing with the teachers, and analyzing the material provided in the workshop activities. It should be mentioned that the attendees were provided with breakfast and lunch each day along with accommodation for the first night of the workshop. The workshop was focused on three SMS topics 1) Introduction to SMS and Industry 4.0, 2) Introduction to PLC programming, and 3) Introduction to industrial robot programming. The workshop schedule is summarized in Table 1.

Table 1: Workshop Schedule.

Day	Time	Task
1	8:00-11:45 am	Arrival, opening breakfast, pre-workshop survey, invited talk, the introduction of manufacturing automation, SMS, industry 4.0, smart sensors, examples of flexible manufacturing systems in Alabama/ local industry speaker, virtual reality introduction
	1:00-5:00 pm	Speaker, educational partner's presentation, advanced manufacturing lab tour, mobile training lab tour, virtual reality demos
2	8:00-11:45 am	Arrival, opening breakfast, invited talk, intro to PLC, intro to robotics, hands-on activities for robotics, hands-on activities for robotics
	1:00-5:00 pm	Intro to PLC, intro to robotics, hands-on activities for robotics, hands-on activities for robotics, post-workshop survey, feedback, and discussion

2.1 Day 1 activities

Participants completed a preworkshop survey via the Qualtrics platform before the start of the workshop. The first day of the workshop began with breakfast and an opening talk followed by the "Introduction to Smart Manufacturing Systems and Industry 4.0" module with a focus on a high-level explanation of Industry 4.0 and SMSs, an introduction to current manufacturing practices, and local examples of SMSs. Moreover, SMSs were broken down into their foundation components, including PLC, industrial robotics, vision systems, and sensors. These opening talks were provided by our educational partner, Intelitek.

Furthermore, examples of SMSs being used in the state were introduced to the participants, and a local industry member, Mercedes-Benz U.S. International (MBUSI), was invited to give a talk on the type of skills needed to succeed in manufacturing, and how that local industry can help initiate/promote smart manufacturing programs in schools. In addition, to introduce possible and available resources in the state, one speaker from the Alabama Robotic Technology Park (RTP) providing a mobile training lab (MTL) was invited to the workshop to share their impressions with the participants. Since the workshop's main goal was to introduce basic concepts and technologies employed in SMS, virtual reality (VR) was showcased to the participants as a new emerging technology within SMS with the help of our partner, TransfrVR.

On the first day of the workshop, participants were also provided with a tour of Alabama IMaDE and our advanced manufacturing lab (AML) at UA, see Figure 1. This modern facility is equipped with industrial KUKA robots, collaborative robots, ER-4U educational robots, a vision system for quality control, PLCs, and a smart manufacturing setup. Also, the mobile training lab (MTL) with various equipment, including robots, a 3D printer, a 3D scanner, a drone, and forklift simulators, was brought to introduce the attending educators to the world of robotics (see Figure 2). Moreover, participants were trained in how to work with virtual reality (VR) headsets and use them in learning safety concepts while operating robotic equipment (see Figure 3).

Figure 1: Advanced manufacturing lab (AML) tour.

Figure 2: Mobile training lab (MTL) tour.

 

Figure 3: VR demonstration.

2.2 Day 2 activities

On the second day, a representative from the State Community College System (SCCS) presented the statistics regarding the region's job opportunities in the manufacturing sector to the participants. In addition to that, the representative made remarks about the most important skills that manufacturers look for when hiring. The speaker also mapped out a possible future path for industrial jobs and the skills that will most likely be in demand soon.

Following a break, the participants were separated into two different activities (see Figures 4 and 5). One group was assigned to the introduction to PLC lecture; during this lecture, the participants were trained on PLC programming concepts. In addition, they learned the basics of ladder logic, input, and output (I/O) communication, and became familiar with the Studio5000 software (a PLC software by Rockwell Automation commonly used in the industry). The second group was assigned to the Introduction to industrial robot programming section. During this lecture, the participants were introduced to industrial robotic systems, as well as their applications in the industry. Additionally, participants were taught about different robotic simulation software packages, including "RoboCell". The two groups then rotated, and each completed both lecture sessions.

Afterward, the attendees had the opportunity to practice the concepts learned in the workshop sections by performing small tasks using the provided equipment and software. For the introduction to the PLC controller, participants were given an Allen Bradley PLC board and were asked to complete a series of activities with step-by-step instructions. During this activity, the participants were taught how to establish PLC communication with peripheral devices. They coded their ladder logic to interact with the peripheral devices on the board and tested the logic using the provided hardware.

In the "Introduction to industrial robot programming" session, the attendees were trained on "Robocell", a robotic simulation software used for educational purposes. Using Robocell, the participants learned about I/O communication and created their own smart manufacturing work cell, where they exercised moving an industrial robot within different coordinate systems, creating task programs to explore the different types of motion and speeds, and using subprograms for code optimization, as well as performing assigned robot programming tasks.

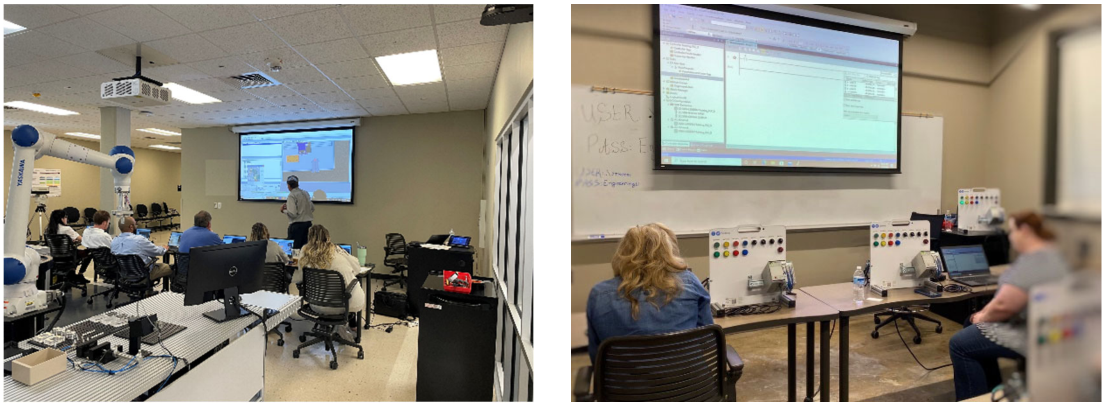

Figure 4: Robotic and PLC training sessions.

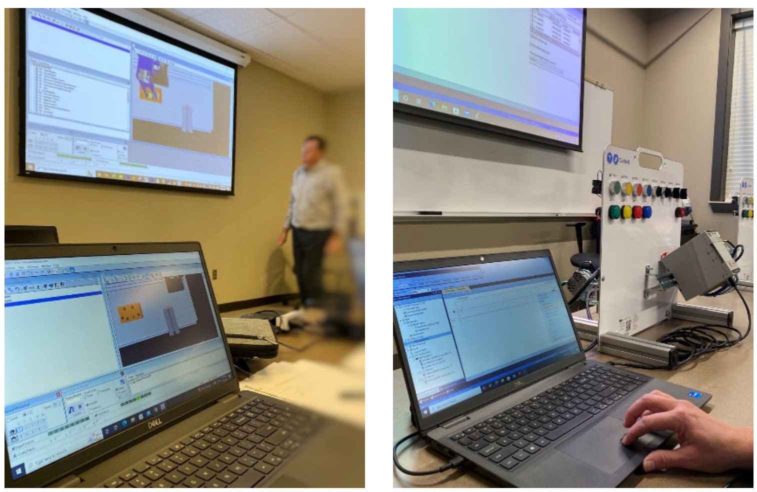

Figure 5: Robotic training with Robocell and PLC training with Studio5000 software.

These training sessions were conducted by Intelitek, and following the conclusion of the training sessions, participants were asked to complete a post-workshop survey to obtain their feedback on the provided training materials as well as the effectiveness of the workshop.

Potential funding sources to establish educational programs in manufacturing systems (grants) were introduced to the participants during the presentation on Day 2. In addition, there was a brief discussion at the end of the day about how teachers could access the courses offered at Alabama IMaDE, apply for grants, and get in touch with local industries and educational partners. This discussion aimed to provide teachers with more information on how to take advantage of the opportunities available to them and enhance their professional development.

3 Results

To get a deeper understanding of the effectiveness of the workshop, the team conducted a thorough analysis of the results gathered from the pre/post-workshop surveys. Both questionnaires were developed to explore the intent of the participants in attending the workshop, the effectiveness of the content presented, and how the overall workshop experience could be improved. The Statistical Package for the Social Sciences (SPSS) software was used to analyze the data, and the results are presented and discussed in this section.

3.1 Demographic information

Eleven participants (*N*= 11) attended the manufacturing workshop. All the participants completed preworkshop-postworkshop surveys, and their responses were analyzed (male = 44.4%, female = 55.6%). Teachers of various backgrounds and experiences (i.e., STEM teachers, engineering teachers, education specialists, and modern manufacturing instructors) were recruited from different counties in the state. The attendees had an average age of 40.22 years and 10.11 years of experience on average. The education level of the participants was reported to be a bachelor's degree (e.g., BA, BS) 33.3%, master's degree (e.g., MA, MS, MED), 55.6%, doctorate or professional degree (e.g., MD, DDS, Ph.D.),11.1%.

3.2 Pre-workshop results

In the pre-workshop survey, participants' reasons for attending the workshop were assessed. Some were motivated to improve their technical expertise, with comments such as *"More knowledge," "Learn more about manufacturing,"* and *"Enjoyment and knowledge."* They also expressed interest in transferring this knowledge to their students and upgrading their manufacturing labs, with comments such as *"I am interested in building on my lab"* and *"understanding for the betterment of my students."*

The pre-workshop survey also evaluated participants' understanding of flexible and smart manufacturing. They defined smart manufacturing as *"Fewer resources and more efficient," "Flexible and smart manufacturing allows for more efficient production," "Something along the lines of LEAN manufacturing,"* and *"The ability to identify, understand, and adapt to the operating environment to maximize manufacturing performance."* However, some participants had no prior knowledge of smart and flexible manufacturing.

Finally, the pre-workshop survey asked about participants' expectations from the workshop. They expressed their expectations as *"PLC knowledge," "I have a lot to learn in this area and I am really looking forward to seeing the HS side of things and tweaking it for elementary students," "Just looking to learn something new that may motivate students and/or something new to incorporate into classes,"* and *"To learn about Manufacturing 4.0."*

3.3 Post-workshop results

3.3.1 Evaluation of workshop sessions

Participants were asked to evaluate the content of each of the workshop sessions and rank their effectiveness on a scale of 1 to 5, where 5 stands for the most effective. Figure 6 shows the collected ranks and according to the results, all of the sessions had a mean value greater than 4. Also, the robotic training session was ranked as the best session of the workshop by participants.

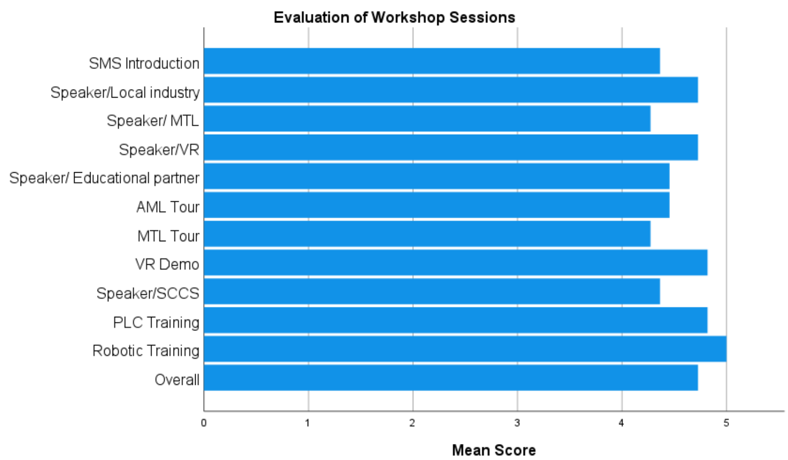

Figure 6: Mean score for the evaluation of different workshop sessions.

Moreover, participants ranked each of the workshop sessions by ordering them from most to least interesting. Table 2 displays the summarized results of the evaluation. According to the collected data, 63.6% of the participants ranked the top three most effective sessions as follows: robotic training as first, PLC training as second, and virtual reality demo as third.

Table 2: Participants' interest in each of the workshop sessions in percentage.

	Lectures (%)	AML Tour (%)	MTL Trailer (%)	VR Demo (%)	PLC Training (%)	Robotic Training (%)	Speakers (%)
Rank1	-	-	9.1	18.2	9.1	**63.6**	-
Rank 2	9.1	-		9.1	**63.6**	18.2	-
Rank 3	-	9.1		**63.6**	9.1	9.1	9.1
Rank 4	9.0	27.3	18.2	-	18.2	-	**27.3**
Rank5	9.1	**36.4**	**36.3**	-	-	-	18.2
Rank 6	**36.4**	27.2	18.2	-	-	-	18.1
Rank 7	**36.4**	-	18.2	9.1	-	9.1	**27.3**

Since the workshop contents, including the speeches and training sessions, were presented by various industrial and educational partners, workshop attendees were asked to provide us with their feedback on which contributors/partners could be more of a help when implementing a manufacturing program at their school/education center. Participants ranked the contributors by ordering them from most to least helpful and the results are summarized in Table 3.

Table 3: Participants' ranking for the contributors.

	University AML (%)	Educational partner (%)	VR (%)	RTP (%)	Industry partner (%)	SCCS (%)
Rank1	**27.3**	9.1	**27.3**	9.1	9.1	18.2
Rank 2	18.2	**27.3**	9.1	**27.3**	-	9.1
Rank 3	9.1	9.1	18.2	9.1	**27.3**	9.1
Rank 4	**27.3**	-	18.2	9.1	18.2	9.1
Rank5	9.1	27.3	9.1	**36.4**	-	9.1
Rank 6	9.1	9.1	-	9.1	27.3	9.1
Rank 7	-	18.2	18.2	-	18.2	**36.4**

Participants were asked to compare the three training methods used in the workshop, i.e., 1) simulation, 2) hands-on activities, and 3) a combination of simulation and hands-on activities. According to the results, 54.5% of participants considered the sessions designed with simulation and hands-on activities as the most efficient while 45.5% ranked the sessions with hands-on activities as the second most efficient training method. No one believed that training through only using simulation could be beneficial.

Moreover, most attendees expressed their satisfaction with the usefulness of the workshop in improving their understanding of smart and flexible manufacturing. They expressed their opinion as *"Yes! I came in with zero background knowledge and left with quite a few ideas for implementing in the classroom"*, *"Yes. I learned more about programming and the manufacturing industry and how engineering plays into this"* and *"Yes. I came in with very little knowledge of smart and flexible manufacturing and now I understand the current and future needs and how I, as an educator, can help"*. Participants explained that the workshop helped them to become familiar with some basic components of flexible manufacturing, *"Yes, helped understanding PLCs and robotics",* and also emphasized the importance of hands-on activities on why the workshop was a success as one participant mentioned, *"Yes... hands-on experience provides a more sustainable understanding."*

The workshop was deemed successful in introducing some of the available resources and opportunities to the participants as one of the participants stated *"Yes, I had very little knowledge when it comes to smart manufacturing, as well as all of the opportunities available in Alabama"*. Also, it provided participants with new insights and ideas as mentioned by two of the participants: *"very much so. It gave me insight into some newer things and how to implement them into my* *program"* and *"Yes. Was exposed to many ideas and concepts that unaware of nor had the concept of usage in 2022."*

The results as shown in Table 4 indicate that participants could nurture some ideas based on the material to involve their students in advanced manufacturing and get them familiar with local industries.

Table 4: Participants' opinions on how the provided workshop material could help them as instructors.

All of the information on the manufacturing industry / how many opportunities our students have if we can begin implementing coding and manufacturing at younger ages.
the hands-on activities and being able to have access to the supplies.
technologies that are available to the industry and how they can be used.
PLC's.
The needs of local industries were the most important and useful. It was a great reminder that industries are still looking for people with "success skills" and robotics, programming, etc. experience.
We need to interact with children 6-8 grade and below to get them involved in this type of industry at an earlier age.
I am not a teacher, so probably all of the information I can share with people I know about the industry.
What skills are incoming students lacking as incoming college freshmen?
new grants and the new technology
The contacts I made and where certain information can be accessed too.

3.3.2 Workshop information sharing

Participants showed interest to share the information learned in the workshop with their students or colleagues through different methods such as hands-on activities, videos, and writing in the school newsletter, as summarized in Table 5.

Table 5: Participants' intention to share workshop information.

Yes. Through hands-on activities and videos.
I would talk to them about it.
Yes... share info about organizations that presented.
Yes, hopefully, will be able to purchase the robot. The learning curve will be smaller.
Yes, I plan to discuss my notes with colleagues and the administration. I also plan to discuss the needs with students to continue to motivate them. Hopefully, I will be able to integrate some of the new technology in the future.
Yes. I will share resources I learned about during the workshop.

Yes, general conversation.
Yes. I will write a newsletter for my school and some of the information I gathered will be shared in the letter.

In addition, the attendees were asked to share their ideas of implementation and application of the knowledge acquired during the workshop in their classrooms. The objective of this specific question was to get a better understanding of how participants are transmitting their knowledge to the students, and perhaps, determine if the workshop made a positive impact on their teaching style. Some of the answers obtained are listed as follows:

1. By talking about the role that such aspects play in the industry.
2. I can integrate it with everyday elementary standards and communication skills.
3. By combining simulation and hands-on training rather than focusing on one more than the other.
4. labs and bringing in some of the speakers to the class and information gathering will be incorporated.
5. Hands-on activities and simulations.

Regarding the needed resources to teach manufacturing-based courses at their school/education center, several items were mentioned by the participants, including *"access to the curriculum of the manufacturing program at the university and the supplies that go along with it"*; *"speakers"*; *"equipment"*; *"licensing"*; *"trained professionals that can teach the content"*; *and the "computer software"*. In addition, participants who had some equipment for a basic understanding of SMSs and robotics at the elementary level expressed their interest in adding some of the equipment introduced in the workshop, particularly the virtual reality equipment and the educational robots to expand on what they already have.

Participants' responses regarding the challenges that they might face when trying to develop a manufacturing education program at their educational institutions were also collected. According to the results, financial issues could be considered the most important barrier in adopting new and advanced technologies in educational programs, as it was mentioned by the majority of participants in statements such as *"Money", "Financial Flexibility", "Funding is my challenge.", "Getting the supplies and funding for the supplies" and "Mainly financial barriers".* Moreover, some of the participants stated their concern about the difficulty of teaching manufacturing concepts because *"Making it understandable for elementary-aged kids", "Understanding industry needs, "Principal and understanding of what manufacturing is and how it can benefit our community",* and *"Convincing that TECH cannot be taught successfully the same way academic instruction is".*

3.3.3 Instructors and workshop team's performance

As previously mentioned, the conducted workshop was held with the support and cooperation of our educational and industrial partners. The lectures and hands-on activities were presented by an experienced team of experts in the field; however, their performance needed to be evaluated for the sake of future workshops. Participants were asked to give a score on a scale of 1 to 5 to each instructor based on metrics such as domain knowledge, communication skills, and willingness to cooperate. Overall, participants were satisfied with the instructors' performance, as the mean score for instructors' knowledge, communication, and cooperation were 4.91, 4.82, and 4.91, respectively.

Moreover, the organizing team's performance on communication, information sharing, and organizing the workshop was evaluated, and the results revealed positive feelings about the team (the mean score for the organizing team's performance on communication was 4.73, on information sharing was 4.55, and on organizing the workshop 4.82).

3.3.4 Future actions

To improve the quality of the workshop in the future, participants were asked to provide any suggestions they had. The followings are some of the received comments:

1. More hands-on activities.
2. If targeting K-12 teachers, provide direct takeaways that can be used in the classroom (not just knowledge, but tools/exercises/etc.)
3. Shorter module times.
4. Fewer speakers in a row on Day 1.

It should be noted that most participants (90.9%) stated that they would like to participate in another training workshop with similar technical content. Also, all the participants (100%) mentioned that they would suggest attending similar workshops to their colleagues or students. Furthermore, 63.6% of the participants were interested in taking some of the manufacturing courses offered by the University of Alabama or encouraging their students to do so, while 36.4% remained skeptical of its effect.

4 Conclusion

In this paper, the results of a two-day workshop on Smart Manufacturing Systems (SMS) held for local high school teachers at a university facility were provided. The goal of the workshop was to introduce the concepts of SMSs and their associated technologies, such as industrial robots, programmable logic controls (PLCs), and smart sensors, to the attendees, as well as to provide them with resources to promote manufacturing programs in their educational centers/schools. The workshop combined technical lectures, hands-on activities, lab tours, virtual reality (VR) demonstrations, local industry talks, plenary speeches, and educational stakeholders' presentations. The results of the post-workshop survey revealed that participants found all of the workshop sessions and content material helpful for them to start new manufacturing initiatives. The robotic training, PLC training, and VR demonstration were identified as the most interesting sessions by the participants since they had the chance to do hands-on activities during these sessions. The workshop attendees deemed the university-based workshop organizing institution as the key resource to support their efforts in promoting manufacturing and robotics programs in their educational institutions. However, they stated financial issues as the most important barrier in this path. Overall, participants were satisfied with the level of instructors' knowledge and communication, and the organizing team's performance; and stated their interest to share the workshop information with their colleagues.

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