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BOARD # 235: Developing the Next Generation of STEM Innovators: RET Site in Manufacturing Simulation and Automation at the University of Louisville

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Abstract

The NSF Research Experiences for Teachers (RET) Site in Manufacturing Simulation and Automation has recently completed its third year, continuing its mission to enhance STEM education for high school teachers and community college faculty. Hosted by the University of Louisville, the RET program offers an immersive, six-week research experience that equips educators with the latest advancements in manufacturing technology and pedagogical strategies. During this transformative program, participants engage in hands-on research projects focused on manufacturing simulation, automation, and integration of digital twins into manufacturing processes. Educators work in state-of-the-art laboratories alongside faculty and students, gaining practical insights into modern manufacturing practices and emerging technologies. Through collaborative workshops and interactive sessions, participants develop innovative curriculum modules that bridge the gap between theoretical knowledge and real-world applications, which enables them to effectively teach these concepts in their classrooms. The RET Site also features plant tours and guest lectures to provide educators with a comprehensive understanding of the manufacturing landscape and the skills needed for today's workforce. As a result of their experiences, educators return to their institutions equipped with new teaching resources and a deeper understanding of the manufacturing industry, which results in a greater interest in STEM careers among their students. This program has made significant contributions to enhancing STEM engagement, building a robust educational pipeline, and strengthening the connection between academia and industry, ultimately preparing the next generation of innovators in advanced manufacturing.

Keywords: Research Experiences for Teachers (RET), manufacturing, simulation, automation, industry 4.0, virtual reality, digital twins

1. Background

The rapid evolution of manufacturing technologies from Industry 1.0 to Industry 4.0 has significantly influenced the landscape of Science, Technology, Engineering, and Mathematics (STEM) education. Integrating these advanced technologies into educational curricula is essential to prepare students for the complexities of modern industry. The National Science Foundation's Research Experiences for Teachers (RET) program in Manufacturing Simulation and Automation at the University of Louisville aims to bridge the gap between academic instruction and industrial application by immersing educators in cutting-edge research environments.

Each year, the RET team partners with a cohort of teachers and community college faculty from the Louisville metropolitan region (spanning counties in KY and IN) to integrate scientific research into their STEM curricula and expose their students to modern manufacturing technologies and innovations. The RET team includes faculty mentors, undergraduate and graduate students, industry advisors, an evaluator and a curriculum development specialist. During the summer program, STEM high school teachers and community college instructors engage in interdisciplinary research on advanced manufacturing topics. They participate in research talks, industry tours, manufacturing simulation activities, and laboratory experiments under the guidance of faculty mentors. Simultaneously, they attend interactive curriculum development workshops led by an instructional design expert to create their own learning modules. By the end of the summer, participants synthesize their research and instructional activities into a comprehensive curriculum unit to implement in their classrooms. Throughout the following academic year, the RET team continues supporting the teachers and instructors through various initiatives. Participants co-present their projects with faculty mentors at regional and national conferences, receive feedback on their curriculum units from the design expert, and welcome classroom visits from the evaluator during implementation. Additionally, they bring their students for lab tours and competitions, as well as on field trips to local industries.

Focus on Manufacturing: The U.S. manufacturing sector is so significant that, if it were an independent country, it would rank as the world's tenth-largest economy [1]. Manufacturing plays a vital role in the nation's economy and workforce, contributing to higher living standards and job creation since the Industrial Revolution. Its impact extends beyond its own sector, with every dollar spent in manufacturing generating $1.37 for the U.S. economy, and every 100 manufacturing jobs creating an additional 250 jobs in other industries [2].

However, globalization and advancements in technology have brought both opportunities and challenges to the U.S. manufacturing industry. Modern manufacturing increasingly demands specialized science and technology skills, yet the current workforce—less educated compared to other sectors—has been slow to adapt. Compounding the issue, few young Americans are pursuing careers in manufacturing [3], putting the U.S. global manufacturing leadership at risk. Over the next decade, nearly 3.5 million manufacturing jobs will need to be filled, but the growing skills gap is projected to leave 2 million of those positions unfilled [2].

The Need to Develop the Next Generation of STEM Innovators: Manufacturing has evolved through several transformative paradigms driven by changes in market and economic conditions, technological advancements, and societal needs [4]. Four key paradigms have emerged over time: craft production, mass production, mass customization, and personalized production. These paradigms are shaped by globalization, technological progress, and evolving societal demands. Understanding these paradigms enables the prediction of future manufacturing trends [5]. The development of the next generation of STEM innovators is crucial for maintaining economic prosperity and addressing global challenges. STEM education equips students with essential skills for the 21st-century workforce and enables them to compete in a rapidly evolving economy. In manufacturing, the integration of advanced technologies such as automation, robotics, and digitalization is reshaping industry practices. This transformation necessitates a workforce proficient in these technologies. Educational programs that combine theoretical knowledge with practical experience in industrial automation are essential to prepare students for the complexities of modern manufacturing environments [6]. Simulation-based training has emerged as an effective method for developing both technical and non-technical skills in manufacturing. By providing immersive, real-life experiences, simulations enhance learning outcomes and prepare students for real-world challenges [7].

2. Program Structure and Activities

2.1 Participant Selection: Participants are selected from local high schools and community colleges, and they must be current educators in STEM-related fields with a minimum of a bachelor's degree in a relevant discipline. Preferred candidates will demonstrate a strong interest in adopting innovative teaching methods and have a track record of enhancing classroom engagement through active learning strategies. The selection process involves a rigorous application review, followed by interviews with the participants. This process ensures the selection of educators who are committed to driving educational innovations and enhancing STEM learning environments through the practical application of manufacturing lessons.

2.2 Research Components: During the six-week summer experience, RET participants work on manufacturing research projects in collaboration with undergraduate and graduate students and under the mentorship of faculty members. Below are three sample projects:

Physical Manufacturing Simulation: This project involves developing hands-on simulation activities for the different manufacturing paradigms (craft production, mass production, mass customization, and personalized production). Teachers develop the instructions for the simulations, run the simulation with participants during the summer and refine the simulation based on feedback from the participants, and then take back these lesson plans to their classrooms. Figure 1 shows sample visual instructions from the craft production simulation where participants assemble and test toy cars using plastic bricks.

Figure 1: Sample visual instructions from the craft production simulation

Virtual Learning Factory: This project involved an undergraduate and graduate student working on the development of the virtual learning factory with a high school teacher helping with CAD modeling and preparing instructions as well as running experiments. The virtual reality factory showcases the evolution of manufacturing systems, starting with early craft production and progressing through mass production, mass customization, lean manufacturing, and personalized production processes. Each production process is housed in a dedicated room. Figure 1 provides an angled top view of the virtual factory layout. The facility also includes a tutorial room with two workstations where participants can practice basic manufacturing tasks and familiarize themselves with the VR environment. Additionally, a storage room holds completed products. Upon exiting the storage room, participants enter a central hub (see Figure 2), where they can view the various production rooms and access them after completing the previously assigned tasks.

Figure 2: Part of the hub of the production rooms in the virtual factory.

Virtual Reality Digital Twin: This project involved a team of a high school teacher, an undergraduate student, and a graduate student working together to develop a virtual reality based digital twin for a manufacturing system that consists of 3D printers and robots. Figure 3 shows a snapshot from the digital twin which is used to monitor and control a physical production system that consists of 3D printers and robots.

Figure 3: A snapshot from the virtual reality digital twin

2.3 Collaborations: The RET Site engages high school teachers and community college faculty with university faculty, graduate students, industry mentors, and REU (Research Experiences for Undergraduates) students. This multidisciplinary collaboration is designed to enhance the transfer of knowledge and innovative practices between academia and industry. Faculty and graduate students provide academic mentoring and share cutting-edge research insights, while industry professionals contribute real-world applications and mentorship, ensuring that the educational content is current and industrially relevant. REU students participate alongside the educators, offering fresh perspectives and assisting in the research and development of new teaching materials. This collaborative mentorship expands through the development of curriculum modules, in which the educators benefit with the resources help to translate their learning into classroom activities. Working together with Industry mentors are part of RET program, providing real-time perspectives enhances the research experience. Industry mentor delivers guest lectures, manufacturing plant tours and their perception into the application of new technologies. These interactions help educators understand the current demands and challenges in the Smart manufacturing field. REU students act as an additional layer of collaborating and learning. These Undergraduates actively participate in research, project activities as learners and junior mentors.

3. Curriculum Development

The process of developing curriculum modules and classroom activities within the RET Site is a structured, research-driven endeavor. Educators engage in a systematic approach where they first participate in immersive research experiences alongside university faculty and industry experts to gain deep insights into advanced manufacturing processes. This hands-on research forms the foundation upon which curriculum modules are built, ensuring that the content is both academically rigorous and aligned with real-world applications. Following the research phase, educators collaboratively design curriculum modules, integrating their newfound knowledge into classroom activities that are directly applicable to their teaching environments. The module creation process is iterative, allowing for continuous refinement based on feedback from peer reviews and pilot tests in classroom settings. This ensures that the modules are effective in enhancing students' understanding of complex STEM topics and are adaptable to evolving educational needs and technological advancements.

The implementation of curriculum modules the teachers involves a strategic integration into participants' home institutions and national dissemination.

4. Outcomes and Impact

Educators who have participated in the RET Site provided positive feedback about the program and the projects they worked on. Through detailed evaluations, educators noted enhanced confidence and competence in integrating advanced manufacturing concepts, such as digital twins and automation systems, into their teaching practices. The feedback from these educators frequently emphasizes the value of experiential learning and peer collaboration, which have enriched their pedagogical strategies and led to a more engaging classroom environment.

5. Challenges and Lessons Learned

During the implementation of the RET Site program, some challenges were encountered that required creative and collaborative solutions. A primary issue was the disparity in resources and technological infrastructure across the participant institutions. Participants from institutions with limited access to advanced manufacturing equipment and software may face difficulties in implementing and applying the concepts introduced in the program. This inequality posed a risk of creating gaps in participant engagement and learning outcomes. To address this challenge, we adopted a flexible approach to project selection, identifying and designing activities that could be scaled to the specific capabilities of each institution. Another challenge was the alignment of academic schedules and priorities among participants from different institutions. Coordinating collaborative activities and workshops often required adjustments to ensure maximum participation. This was resolved by developing a detailed schedule with flexible timeframes, along with providing asynchronous learning materials to accommodate diverse academic calendars. Furthermore, participants occasionally faced difficulties in bridging the gap between theoretical concepts and their practical applications in manufacturing. To address this, we incorporated hands-on projects and real-world case studies, which facilitated experiential learning and reinforced the practical relevance of the topics. Regular feedback sessions allowed participants to voice concerns, enabling iterative improvements to the program's structure and content. From these experiences, several key lessons emerged: (1) Ensuring equitable access to tools and resources is critical for successful program implementation. Cloud-based and virtual platforms proved invaluable in addressing resource disparities. (2) Programs should remain adaptable to accommodate the varying needs and constraints of participants and institutions. (3) Direct engagement with industry partners enriched the program by providing real-world perspectives and ensuring the content remained aligned with current technological trends. (4) Providing continuous support beyond formal sessions greatly enhanced participant confidence and success in applying the concepts learned.

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