Board 6: A Program to Improve Manufacturing Learning Using Simulation and Automation

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A Program to Improve Manufacturing Learning Using Simulation and Automation

Abstract

This paper discusses an NSF RET program that focuses on improving manufacturing learning using simulation and automation. The program participants are high school teachers and community college faculty who will develop skills in manufacturing research, technical writing, curriculum development, and conference presentation. The goals of the proposed program are to: 1) provide a STEM-based platform to engage high school teachers and community college instructors in state-of-the-art manufacturing research, 2) explore a sustainable educational model that connects high schools, community colleges, university, and industry to instill future generations with greater awareness and interest in manufacturing, 3) facilitate the development of curricular modules, classroom activities, and other instructional materials that will be implemented in the participating schools and colleges eventually to be disseminated to a broader audience nationally, and 4) help fill the skills gap in U.S. manufacturing and prepare high school and college students for undergraduate studies and/or careers in manufacturing. Both internal and external evaluations of the learning outcomes are ongoing and assessment results are presented.

1. Introduction

The U.S. manufacturing sector is important for the nation's economy and workforce. It is so enormous that if it were a country by its own, it would rank as the tenth largest world economy [1]. Since the industrial revolution, U.S. manufacturing has contributed to higher export potential, better standards of living, and more jobs. Furthermore, manufacturing has a strong multiplier effect on the broader economy. Every dollar spent in manufacturing adds $1.37 to the U.S. economy, and every 100 jobs in a manufacturing facility creates an additional 250 jobs in other sectors [2].

Globalization and the recent advancements in technology have transformed U.S. manufacturing. Today's manufacturing sector relies on advanced technologies and requires specialized science and technology skill sets. According to The Manufacturing Institute, the U.S. manufacturing workforce is older and less educated compared to the other sectors. Moreover, the

U.S. dominance in product innovation is now in question. Studies also show that relatively few Americans are choosing manufacturing for education and careers today [3]. In addition, the skills gap in U.S. manufacturing is widening due to several factors including retirement, ineffective manufacturing education, and economic expansion [4]. It is estimated that over the next decade nearly 3.5 million manufacturing jobs likely need to be filled and the skills gap is expected to result in 2 million of those jobs going unfilled [2].

The future of U.S. manufacturing will be based, in part, on educating the new generations in manufacturing-related STEM and computing skills to prepare them for the skill-intensive jobs. However, most high school STEM teachers and community college instructors do not have training in engineering concepts and there is a dearth of programs and curricular content in this area [5]. An effective way to teach engineering concepts and manufacturing paradigms is through hands-on experimentation with simulation and automation. Professional development programs for teaching manufacturing should be developed to improve STEM educators and students' knowledge and reduce the gap in manufacturing skills.

Manufacturing simulation and automation provides a platform to investigate new research opportunities in science, engineering, and technology to fill the skills gap in U.S. manufacturing. Introducing manufacturing simulation to classrooms will help the high school teachers and community college instructors link the basic STEM concepts to the curriculum and deliver classes more effectively as well as promote manufacturing education at their institutions.

This paper presents the preliminary results from the first year of the National Science Foundation Research Experience for Teachers (RET) Site in Manufacturing Simulation and Automation. The program focuses on bringing in STEM teachers from local high schools and community colleges to the state-of-the-art research on manufacturing simulation and automation at Penn State Erie, the Behrend College. Simulation, which is the imitation of a real-world system and its process, has been widely used in applications in manufacturing, healthcare, and/or service industry. The two major types of simulations are computer simulation and physical simulation. Both require the construction of a model of the system being simulated. Computer simulations demand the development of a computer program and usually require specialty skills. Physical simulations employs hands-on experiments using the prototype of the real system. In order to understand the evolution of manufacturing, both physical simulation through hands-on experiments and computer simulation will be used to study the manufacturing paradigms. The simulation is used as an instructional method where students work in groups and follow a typical manufacturing process to make a product by mimicking the real-world industry. In this process, students are tasked to improve the efficiency of the manufacturing system.

2. Program Structure

In 2018, 13 teachers from the NY-PA-OH tri-state region were recruited for RET program. The program runs for six weeks during the summer break of high school and community colleges. The program is a joint effort of a multi-disciplinary team that includes Penn State faculty members, undergraduate and graduate students, learning design experts, industry advisors, as well as internal and external evaluators. The PI serves as the site director, manages the project, and coordinates research activities with curriculum development and evaluation. The graduate and undergraduate students develop research activities and mentor the participating teachers throughout the summer program. Industry collaborators serve as hosts of industrial tours and mentors to provide feedback on the research activities. The learning design experts provide hands-on workshops on designing an engaging curriculum unit that the teachers can take back to their classroom. The external evaluators serve as consultants and share their past experience. The internal evaluator works closely with all parties to collect feedback after each piece of the program.

The general framework of the program, shown in Figure 1, consists of four parts: (1) visiting five local manufacturing companies, each represents one manufacturing paradigm (i.e., craft production, mass production, Lean manufacturing, mass customization, and personalized production), (2) develop manufacturing simulations (using Lego bricks) that imitate the manufacturing paradigms, (3) develop computer/virtual reality simulations for the manufacturing paradigms, and (4) create a curriculum unit based on their developed simulations. All parts take off during the first week and continue throughout the program. By the end of the summer program, all participants are expected to complete the development of a curriculum unit based on their research outcomes. The curriculum units will be implemented in their classrooms in the following fall or spring semester.

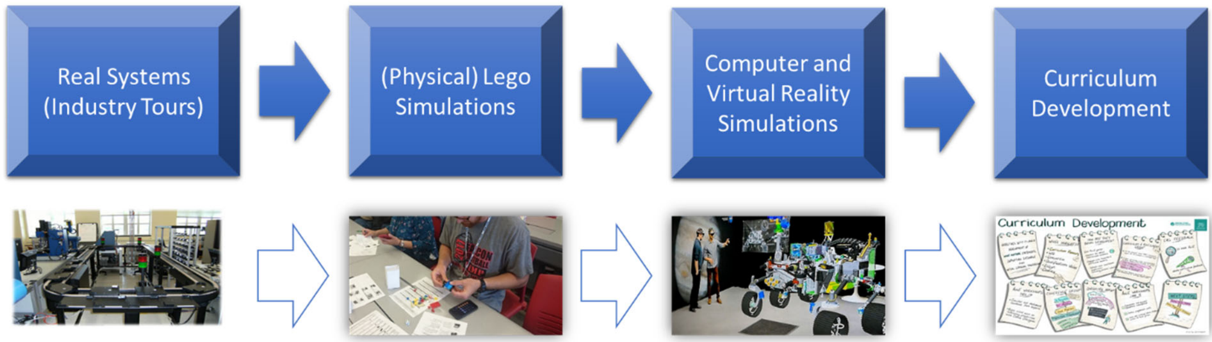

Figure 1. General Research Framework

3. Description of Research Activities

The research projects focus on studying the evolution of manufacturing systems, from craft production to today's personalized production. The research activities utilize manufacturing simulation and automation and are divided into five categories: (1) craft production, (2) mass production, (3) Lean manufacturing, (4) mass customization, and (5) personalized production. Simulation activities are developed for each manufacturing paradigm, which is a model for manufacturing that has inputs and outputs. The inputs are society needs and technological advancements and the outputs are product variety and volume. In this research project, each one of the five paradigms will be simulated to teach the participants the past, present, and future of manufacturing. Table 1 shows the principles of the five paradigms.

Table 1. Characteristics of manufacturing paradigms

Manufacturing Paradigm	Characteristic
Craft Production	Skilled labor production to match customer requirements
Mass Production	Low cost, large volume production
Lean Manufacturing	Eliminating waste to improve overall customer value
Mass Customization	Providing customers with a wide variety of products
Personalized Production	Customer-driven production with unlimited variety

3.1. Industry Tours

During the first five weeks of the program five industry tours were conducted. They were spread out at one each week. Each tour lasts approximately one hour where the RET participants get exposed to real manufacturing systems. During each tour, the RET participates are asked to answer a set of questions to help them connect the experience from the tour with the simulation activities. Examples from the question set include: (1) What is the primary function/purpose of this business?, (2) What type of manufacturing paradigm does the company follow?, and (3) How will this tour benefit your research project?. Figure 2 shows pictures from the industry tours.

Figure 2. Pictures from the industry tours

3.2. Physical Manufacturing Simulations

Physical simulations were conducted by high school teachers and undergraduate students who worked on simulation experiments to study the different manufacturing paradigms. Performance of each manufacturing paradigm was measured by the total profit the participant groups made by the end of the simulation. Figure 3 shows sample pictures from the simulation activities [6]. Figure 4 shows word clouds from the responses when the teachers defined the manufacturing paradigms after they completed the simulations.

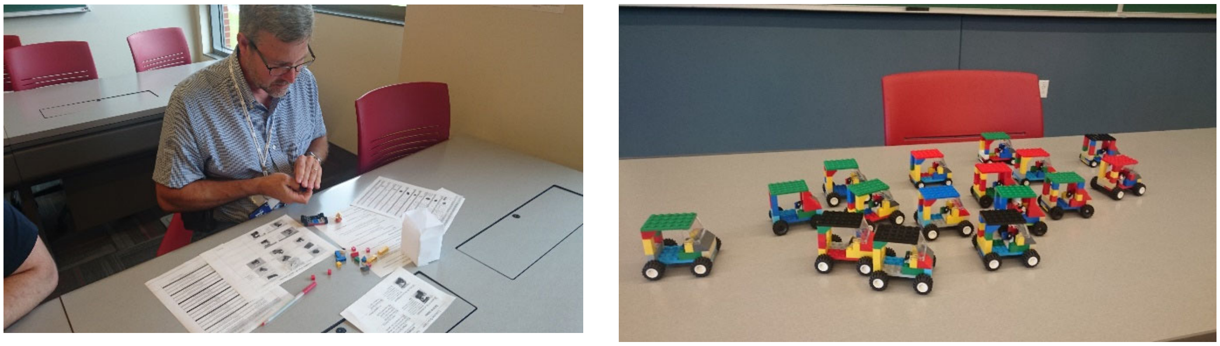

Figure 3. Some pictures for the hands-on activities

Craft Mass Lean Customization Personalization

Figure 4. Word clouds for a sample teachers' response

3.3. Computer Simulations

Computer simulations were also developed for the manufacturing paradigms. Figure 5 shows a discrete-event simulation model for the craft production developed using Rockwell Arena® software. The model was developed by one of the teachers who also participated in the physical simulations and collected data to build the computer simulation [7].

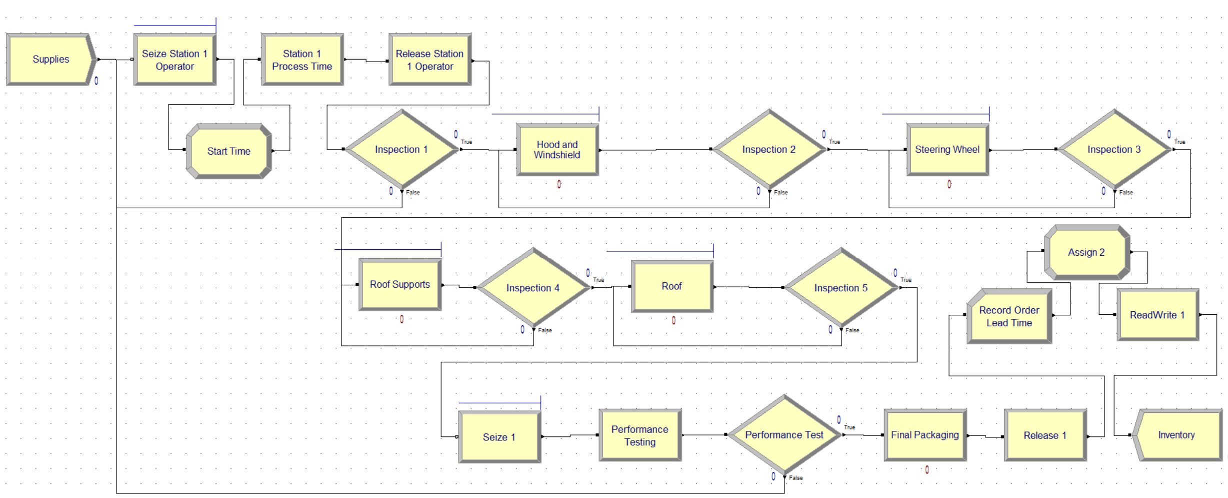

Figure 5. A computer simulation model for the Mass Production paradigms

3.4. Manufacturing Automation

PLC Training Workshops: Kits were purchased for each participant that include an Allen-Bradley Micro820 Programmable Logic Controller (PLC), an Allen-Bradley PanelView 800 graphical touchscreen Operator Interface Terminal (OIT), and input/output (I/O) devices including industrial push buttons, a selector switch, pilot lights and a control relay. Four one-day workshop sessions introduced the participants to PLCs and gave them a starting point for further investigation. The first day included an overview of PLCs and how they are used in industry, as well as an introduction to hard-wired relay logic. The second day was an introduction to PLCs, including how they were originally used to replace relay logic. The third day was an introduction to OITs, and how they are used to replace hardwired buttons, switches and indicators. The fourth day was an introduction to more advanced applications such as batch control and using an OIT to display more complex information. In each session, participants were given enough information to get started, such as instruction on how a relay works, basic PLC instructions, basic OIT configuration, and how to program a sequential operation. Participants were then given progressively more complex problems to solve, such as how to hard-wire a circuit to control a motor, program a PLC to control a motor, configure an OIT to interface to a motor, and ultimately to develop a PLC program with a touchscreen interface to control a mixing system used to make cake batter. Participants worked in teams of two to develop and implement solutions. They worked at their own pace, receiving help as needed from the workshop leader and an undergraduate research student. For

Industry 4.0: two teachers and two undergraduate students worked on installing and testing an automated station for testing 3D printed parts. Shown in Figure 6, the automated station is controlled by PLC and it uses high resolution camera to test the parts.

3.5. Curriculum Development

The teachers attended four workshops throughout the RET program. In addition, they were given hands-on design and development time to create their curriculum unit. Since most of the participants hold a master’s degree in education, the workshop series was intended to be a refresher of selected curriculum design models and an enhancer of evidence-based teaching practices. The workshops blended learning theories, formative assessment strategies, active learning techniques, and effective use of technologies that teachers could experience and take back to their own class. Each workshop was approximately two hours. The topics covered by the workshop series include: (1) Team building activity, (2) Reflections on engineering education, (3) Curriculum standards, (4) TPACK design framework [8] and the Backward Design model [9], (5) Raising meaningful questions and engineering challenge, (6) Writing measurable learning objectives, (7) Formative and summative assessment strategies, (8) The art of storytelling and forester curiosity, (9) Discovery-based learning, (10) Interleaved course design.

In each workshop, the participants had the opportunity to work individually or with a partner to design their curriculum unit. Throughout the face-to-face interactions and online, the teachers shared their educational challenges, resources, their plan to integrate the RET program with their subject area, as well as the implementation plan of the developed curriculum unit. The participants also had access to meet with workshop leaders to discuss their curriculum unit and receive feedback.

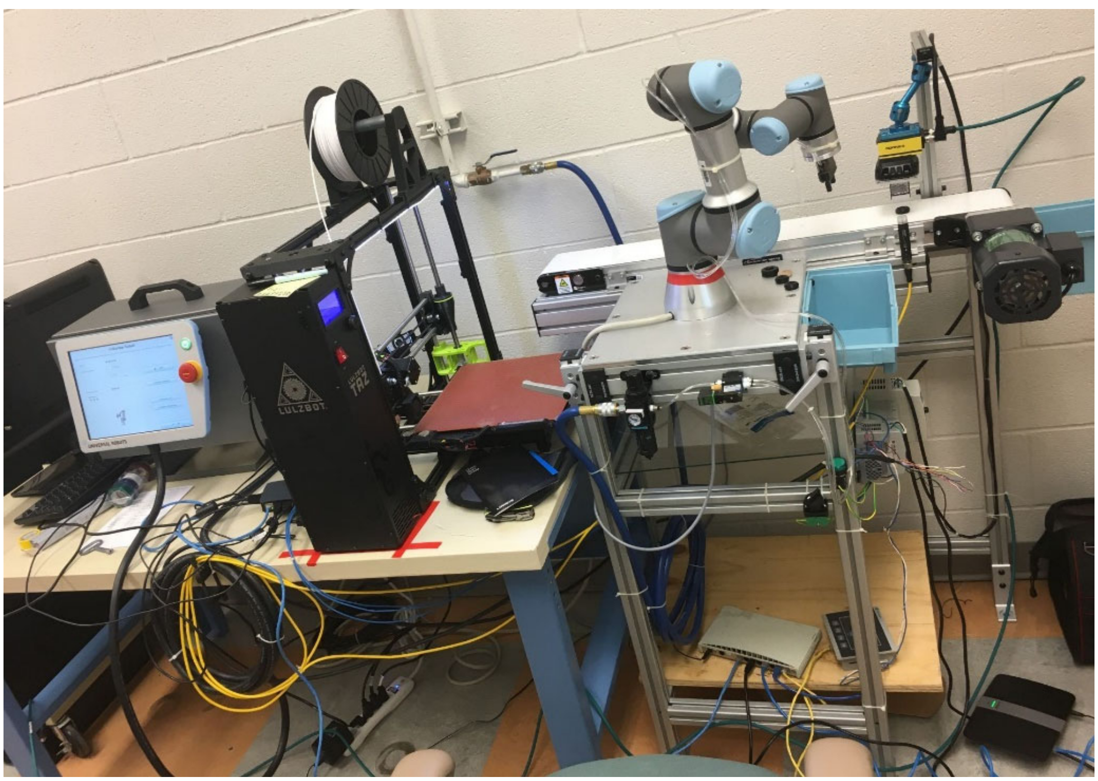

Figure 6. Automation workstation for inspecting 3D printed parts

4. Program Evaluation

The program is evaluated in two phases. The first phase is to collect participant feedback at the end of the 6-week summer program. Participants filled up an online anonymous survey and were invited to attend a focus group to provide detailed feedback. All participants indicated that Penn State Behrend was well suited to host the RET program and they are interested in applying to the program again.

The second phase of evaluation is conducted through on-site visits when the curriculum unit is implemented. This phase of the evaluation focuses on obtaining feedback from teachers and students about how the curriculum has impacted teaching, learning, and student interest level in their chosen STEM career. The evaluation consists of four parts: (a) Open-ended short essay questions for the instructor to reflect their preparedness prior to the observed lesson, (b) student survey on their interest in the STEM field before and after the unit implementation, (c) on-site observation, and (d) Open-ended short interview of the instructor to reflect on the lesson observed.

Since not all schools implemented the curriculum unit in the fall, and some units need a few more weeks than others, the pre- post-surveys from students are still undergoing. However, collected responses thus far from (a), (b), and (d) above show that the RET program is valuable to the teachers. All teachers observed agree that going through the curriculum unit design process helps them to be “very prepared to teach”. In answering “what did you learn from teaching this unit?”, one teacher did not hesitate to share how well the physical simulation has benefited the class: “The unit is organized and that helped a lot, particularly for students who were not understanding, not knowing what's expected as they checked out when that was covered. I realized our kids are more capable of doing more. They handled complex subjects well although they don't like the part of having to do more work. This lesson should be the model for the rest of the curriculum to build on.”

Below is another example question and responses:
“What aspects of this unit do you anticipate will spark student curiosity or interest in the topic?”

- “These are 9th grade students, so I expect some to be excited about using Legos. I also feel the competitive nature of the assignment (students working in teams to compete Lego car assembly) will engage many of my students.”
- “The simulation is designed to represent craft production from the late 1800's. Students will be excited about its game style learning opportunities.”
- “Students like to get hands on with research. They will get the opportunity to use a CNC machine and cut many samples. We will then be able to collect data on those samples using a clamp-on Amp meter and a light sensor. Due to the fact that they were the ones that cut the samples, I think they will take more ownership on the data collection portion and get better results.”

5. Conclusions

Manufacturing simulation is an effective technique to teach the basic principles of manufacturing systems in a realistic way. In the first year of the RET program, 13 high school teachers and two undergraduate students were engaged in summer research activities related to manufacturing simulation and automation. The RET participants visited local manufacturing companies that represent the different manufacturing paradigms and then develop simulations activities for each paradigm. Participants developed curriculum units and implemented them in their classrooms.

In the second year of the program, new participants will be recruited. For the research activities, the participants will develop physical, computer, and virtual reality simulations of the different manufacturing paradigms. For curriculum design, participants will be reminded of the expected alignment between industry tours, simulation building, and curriculum unit they will design. More hands-on design time and peer discussion opportunities towards the latter half of the program will be scheduled.

Acknowledgement

This research is funded by the National Science Foundation NSF RET- #1711603: RET Site in Manufacturing Simulation and Automation. Any opinions, findings, or conclusions found in this paper are those of the authors and do not necessarily reflect the views of the sponsor.

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