Investing in the Future: Bringing Research and Industry into Simulation-based Manufacturing Education

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Abstract

Manufacturing makes tremendous contributions to the economy as it increases gross domestic product and exports, creates high-paying jobs, generates meaningful return on investment, and supports many other sectors. The future of manufacturing depends on preparing younger generations for innovation and skill-intensive jobs through Science, Technology, Engineering, and Math (STEM) programs. However, there is a dearth of manufacturing presence in the current curricular content as most STEM high school and community college educators do not have training in manufacturing concepts and likely have not worked in the modern manufacturing industry. An effective way of bringing manufacturing to the curriculum is to include simulation and automation hands-on experimentation. This paper presents the second year of an ongoing Research Experiences for Teachers (RET) Site in Manufacturing Simulation and Automation. The objectives of the program are to 1) improve instructors' research and professional skills, and 2) help them translate the cutting-edge manufacturing research to their classrooms by creating and implementing new curricula. This will stimulate students' interest in the topic and strengthen manufacturing education.

1. Introduction

Since the industrial revolution, U.S. manufacturing has contributed to higher standards of living and employment opportunities. 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 [1]. As technology evolves, the manufacturing industry also becomes increasingly complex and sophisticated. As a result, employees in the manufacturing sector are expected to have specialized science and technology skills. Yet, the current manufacturing workforce, relatively less educated than other sectors, is slow at catching up with the new development. Meanwhile, few young Americans show interest in choosing manufacturing as their career [2]. As the U.S. dominance in the manufacturing industry diminishes, it is estimated that nearly 3.5 million manufacturing jobs will need to be filled over the next decade, yet 2 million of them will be left unfilled due to the skills gap [1].

The future of U.S. manufacturing will be based, in part, on preparing new generation of students for the skill-intensive jobs. Students need to be exposed to modern manufacturing industry and make connections with the STEM classes at school, realizing how such knowledge and skills are applied in manufacturing. However, there is a dearth of programs and curricular content as many STEM high school teachers do not have a background in manufacturing industry or engineering concepts [3]. One way to solve this problem is to invest in the professional development of high school teachers by providing them an opportunity to work on manufacturing-related research projects with college professors. As the teachers conduct research activities, they must also create an instructional unit on a related topic so that they can use to teach a STEM concept required by the school's curriculum. This way, the instructional unit can bridge the gap between textbook knowledge and real-world applications. The high school students will learn the selected concept in the context of manufacturing industry through simulation and automation hands-on experimentation.

This paper introduces the RET program at the Penn State Behrend's site. We will start with a program description, the research and curriculum design components, followed by curriculum implementation and evaluation status to date. A reflection on lessons learned will also be shared.

2. RET Program Description

The RET program recruits 13 teachers and community college faculty each year from regional high schools or community colleges to participate an intense summer program and follow up activities throughout the next academic year. At the heart of the program is the synergy between manufacturing research activities carried out by the teachers and the instructional units they designed to inspire interest in modern manufacturing among their students. The participants play multiple roles throughout the year. In the summer, participating teachers are researchers and curriculum designers. When classes start in fall and spring, they are instructors and mentors for their students. Once accepted in the RET program, however, they are always the collaborators of college professors in current and future research activities.

The summer program typically starts in mid-June and continues until early August with the week of July 4th reserved for families and personal travel. Week 1 of the summer program focuses on building communities and setting up expectations. Participating teachers get to know their peers, and meet with research mentors and industry advisors. The deliverables expected of participants at the conclusion of the summer program, especially the relationship between their upcoming research project, industry tours, and the instructional unit to be designed are explained. Orientation of the research site and research training are also provided. Then, the participants are introduced to a range of research topics, associated objectives, along with research project agenda, expected outcomes, and demonstrations from prior research work. During week 2 to 5, the participants finalize on research topic selection and move forward with their research activities. In the meantime, they select a relevant STEM concept required by the curriculum and develop the instructional unit. In week 6, participants conclude the research activities, complete the development of their instructional unit, and then proceed to project wrap-up and program evaluation. During the following academic term, installation support and lab setup are available for the teachers at their high schools and community colleges. The collaboration continues between the RET team and the teachers to address lab equipment needs, curriculum implementation, data collection and on-site visits. The RET professors actively involved in high school and community college student activities, such as giving guest talks on technical concepts, serving as judges in student competitions or as hosts for high school field trips. In addition, the RET team holds internal meetings to discuss project improvement for the upcoming year.

The RET participants also collaborate with undergraduate student researchers and such collaboration has been found mutually beneficial. Students learn about the technical and historical perspectives of manufacturing as more than 50% of RET teachers have years of industry experience; the RET teachers receive assistance from undergraduate students when it comes to software use or simulation model building. Students and teachers work together on research projects related to the main pillars of manufacturing, see Figure 1.

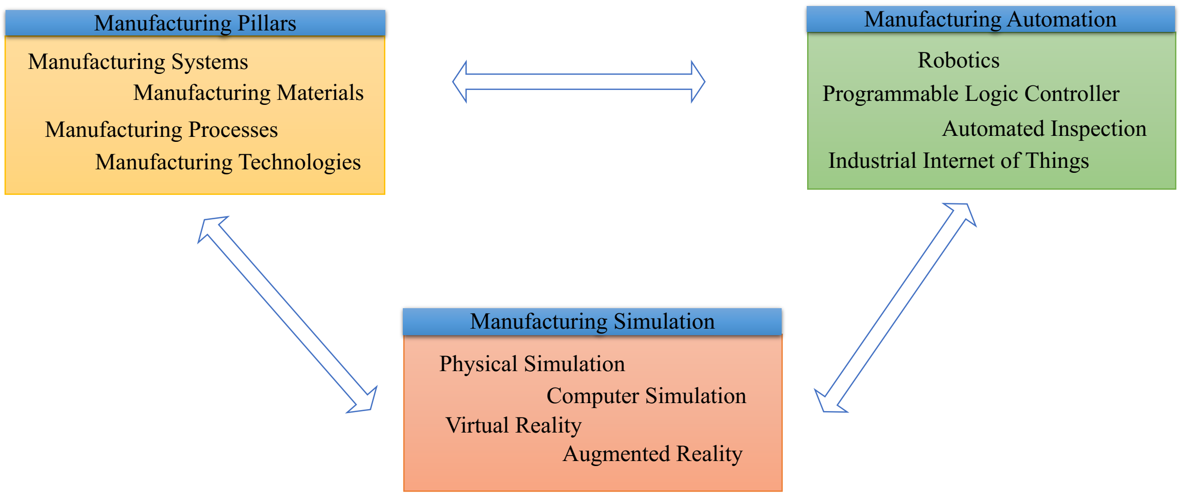

Figure 1. Manufacturing pillars and simulation/automation techniques

2. Sample Research Projects

This section presents sample summer research projects that were implemented by the RET participants. Each project involves two RET participants, one faculty mentor, undergraduate students, and two industry advisors.

Project 1: Manufacturing Simulation and Automation

This project involves developing a simulation game for each of the five paradigms that represent the evolution of manufacturing. This will allow the participants to understand the past, present, and future of U.S. manufacturing and learn the basics of manufacturing systems. The project was conducted over a six-week period. During the first five weeks, each week one simulation game for each manufacturing paradigm is developed. In week 6, participants develop the instructional unit they will use to teach their students and present the project outcomes. On the first day of each week, participants visit a local manufacturing company that has a production system similar to the paradigm being studied. On days 2 to 4, the project leaders develop the structure and documentation of the simulation game and, on the last day of the week, participants run the simulation game and the project leaders collect and analyze the simulation data to study the learning process. *The RET Participant outcomes are* (1) describe the past, present, and future of U.S. manufacturing, (2) articulate the differences and similarities between the five manufacturing paradigms, (3) create simulations to reflect these differences and similarities, and (4) develop detailed instructions for each simulation game and create lesson plans, (5) craft curriculum units and conference papers. Figure 2 shows sample pictures from the summer research activities.

Figure 2. Sample pictures for the simulation activities

Project 2: Manufacturing of Solar Cells

During the last two decades, dye-sensitized solar cells (DSSCs) have opened up one of the most hopeful prospects for wide-spread, clean, renewable energy due to their competitive material and fabrication cost [4]. However, to date, the large-scale production is limited due to the relatively low device efficiencies (~14%), high-price catalytic materials and high-temperature processing conditions [5]. New materials and structures, together with an optimized manufacturing process, are needed to lower production costs while maintaining efficiency such that DSSCs are economically viable. In this project, we study the working principle of DSSCs, fabricate DSSC devices in the laboratory, test their performance using basic equipment, and propose the route to mass-produce DSSCs. The objective of this project is for participants to identify the key factors that affect DSSC performance, manufacturing time, and cost, and explore the manufacturing routes that could push the DSSCs toward the market. The RET outcomes are: After finishing the project, participants should be able to (1) teach how a DSSC converts light waves into electricity; (2) design and build DSSC from basic components and fruit dye; (3) refine the solar cell design through comparison of various dyes; (4) evaluate DSSC's performance in comparison to a silicon solar cell. Figure 3 shows sample pictures from this project. The three graphs below show the results obtained from the different components for the solar cells (blackberry, strawberry, and blackberry + strawberry).

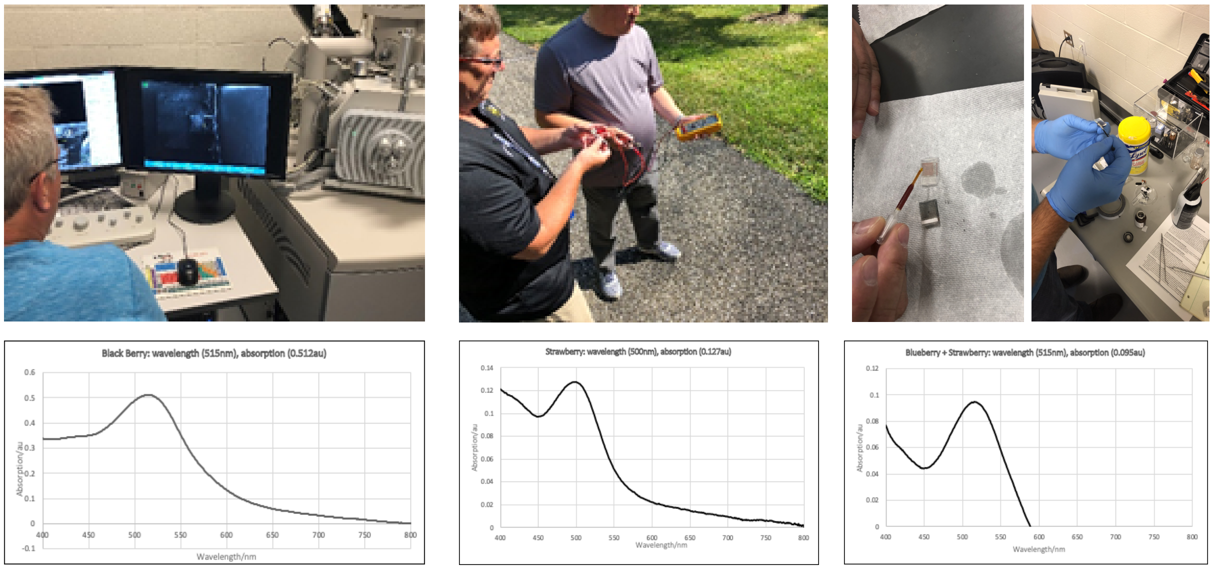

Figure 3. RET Participants using SEM and measuring DSSC efficiency

Project 3: Additive Manufacturing

Additive manufacturing is commonly shown to students through low cost 3D printers. The majority of previous RET participants have 3D printing labs at their home institution. In this project, the RET participants will develop a set of modules which can be integrated with a design project given at both the high school and college curriculum levels to explore principles of manufacturing and design (e.g., dimensioning and tolerancing, Design for X, Proof of Concept). The participants identify one or more products in which these principles can be applied and then develop a set of constraints the students need to consider when making the products. The objective of this project is to identify best practices for teaching 3D printing and develop projects to illustrate the application of the manufacturing principles through 3D printing. The RET participant outcomes are: Upon completion of this project, participants will be able to (1) explain important principles of design and manufacturing, (2) demonstrate those principles using 3D printed parts, (3) develop several projects that can integrate these principles in an open-ended design project (4) develop detailed instructions for each project suggestion and lesson plans, (5) develop a complete curriculum unit and draft conference/journal papers. Figure 4 shows sample pictures from this project.

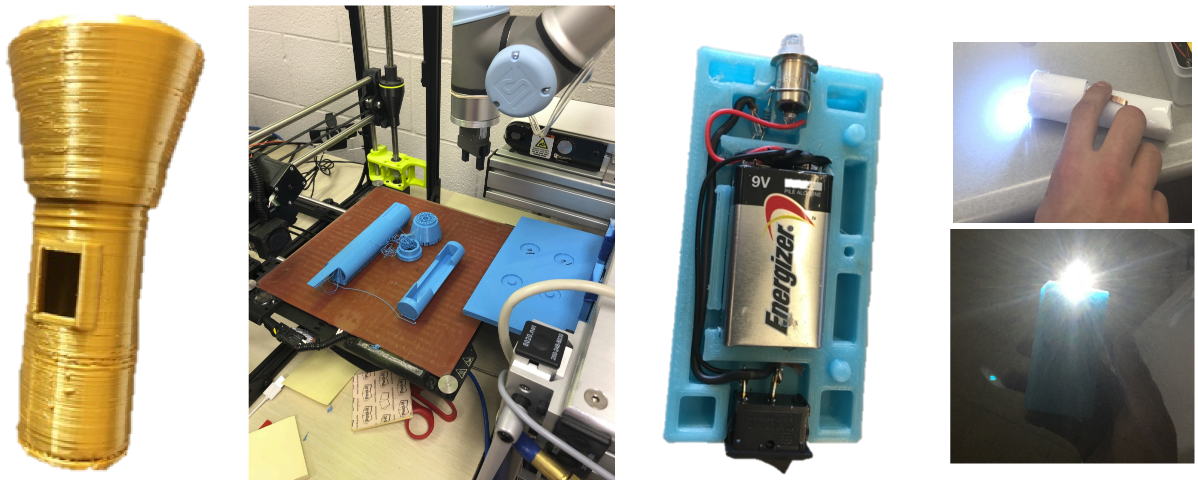

Figure 4. Sample pictures from the additive manufacturing project

3. Program Evaluation

3.1 Post summer program surveys

Data collected from participating teachers in summer 2019 reveals that the RET program is extremely well received across all five aspects, see Figure 5 and 6 below. In addition, the number of people who would recommend the Behrend's RET site for their colleagues also increased from approximately 77% (10 of 13) in the first year to 100% (13 of 13) in the second year.

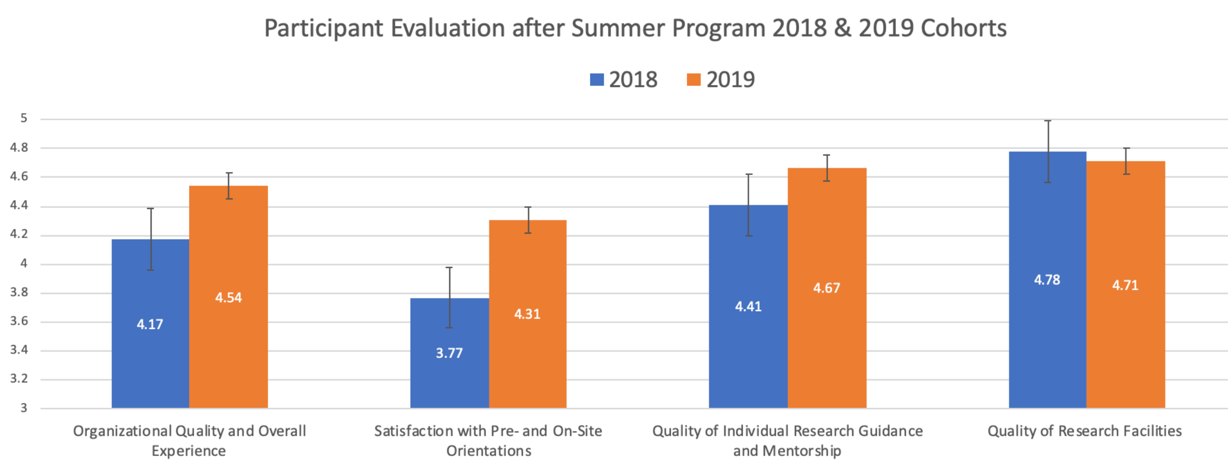

Figure 5. Participant Ratings of 2018 and 19 Summer Program Site (on a 1-5 scale, with 5 being the highest)

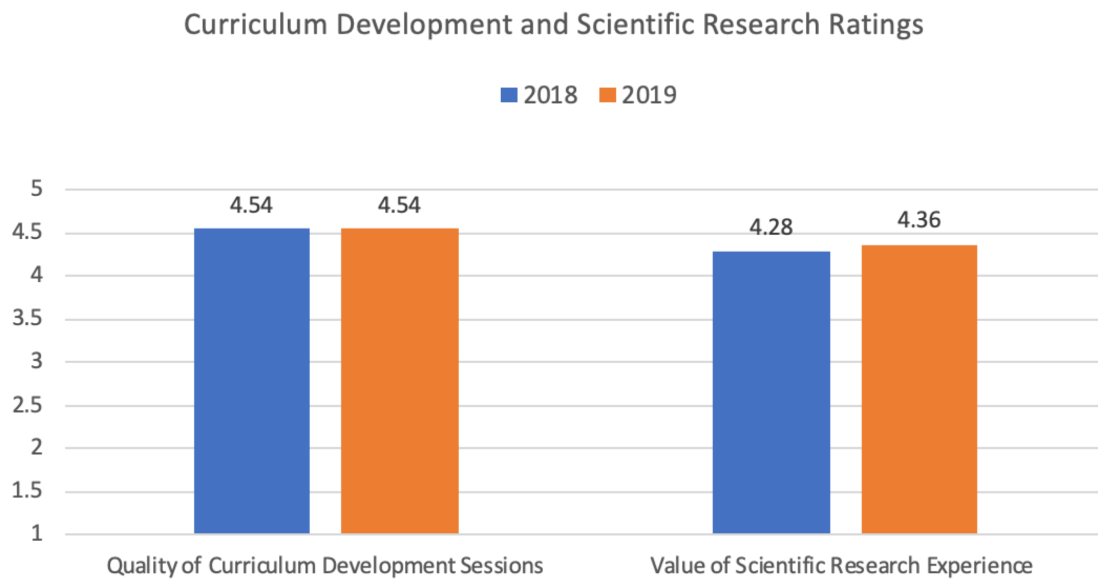

Figure 6. Participant Ratings of 2018 and 19 Summer Program Site (on a 1-5 scale, with 5 being the highest)

It is worth noting that at the end of summer 2019 program, 9 out of the 13 participating teachers reported they developed a new perception of manufacturing or learned something new, even though only 5 of them had no industry experience. Several participants wrote that they used to think of "a dark dreary filthy work environment for low skilled labor" when they think of manufacturing, but the tours had showed them that modern manufacturing is "clean, pristine," and "workers are highly skilled." In addition, participants recognized the amount of "work and research being done to optimize processes in the industry," and "was surprised at the facilities and opportunities available in the region." This perception change has inspired several teachers to "take students to field trips," and "expose students to manufacturing" as it is "a good career choice."

The protocol for the RET program was reviewed and approved by The Pennsylvania State University's Office for Research Protections (IRB #: STUDY00010371).

3.2 Curriculum Implementation

Across the 6 schools and 7 teachers visited in the 2018 cohort, at least 171 students were in the class sections where the curricula designed in the previous summer were implemented. Among the teachers visited, 5 of them felt "very confident" or "very well prepared" prior to delivering the curriculum. One of the self-reflection questions asks the teachers to rate the learner-centeredness of the instructional unit they designed and taught. On a 1 to 4 scale with 4 being the highest, the average of "Learners are engaged by scientifically oriented questions" is 3.83. The evaluator did observe high level of attentiveness and engagement when students were given a hands-on activity to explore the engineering solution to a challenge. Along the same line, the teachers self-rated 3.00 on "Learners formulate explanations and conclusions from evidence to address scientifically oriented questions," 3.17 on "Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding," and 3.33 on "Learners communicate and justify their proposed explanations."

Among the 2019 cohort, 12 out of the 13 participants have committed to implementing the curriculum between fall 2019 and spring 2020. At the time this draft is submitted, 5 teachers have completed delivering their instructional unit or are in the process of curriculum implementation. At least 72 students are in these classes. The remaining teachers had to put their unit on hold due to a nation-wide COVID19 disruption.

4. Sample Implementation Efforts at High Schools

This section presents a sample implementation of one simulation project at a local high school. The simulations were developed by two high school teachers as part of the RET summer program. The developed simulation games were used to teach high school students the concepts of manufacturing systems. This simulation requires two teams of 11 graders to compete on productivity prompted by customer needs. Each team has 7 students who play the roles of customer, part supplier, assembly workers at different stations, inspector, and the shipping department. All students work together in an assembly line to produce toy cars. Figure 7 shows samples pictures from the hands-on simulation activities. The research team developed dedicated kits of plastic bricks for the simulations. The simulation activities were conducted as part of the pre-engineering course (CTE Course Number: Engineering Technologies CIP-15.9999). Figure 7 shows sample pictures from the simulation implementation.

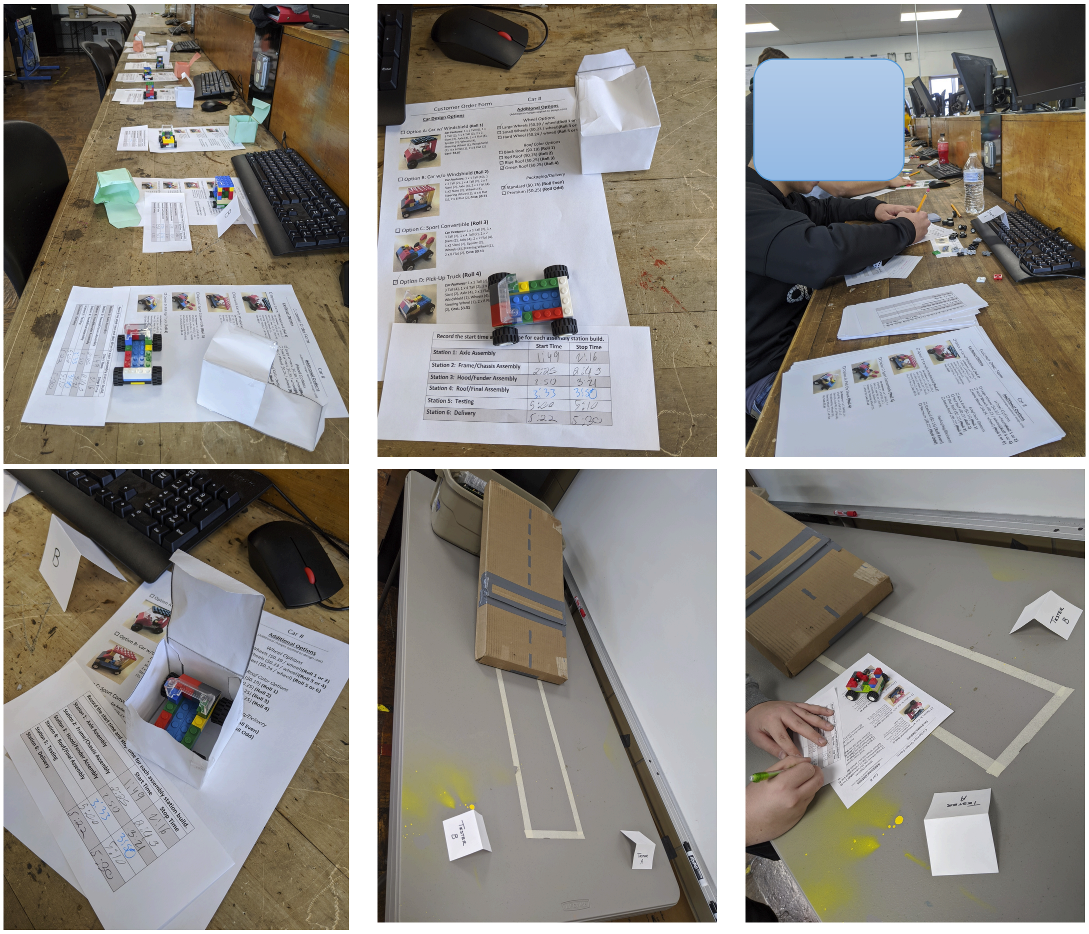

Figure 7. Simulation implementation with high school students

5. Lessons Learned

As we synthesize the qualitative data from the surveys, focus group, and post-implementation reflection, we recognize a couple of common challenges [29]. Firstly, it is difficult to introduce a lengthy curriculum unit while teachers navigate through time constraints, state standards, testing requirements, facility constraints, and student preparedness in order to deliver instruction. While it is not uncommon to see students from mixed grades in the same class, students' academic readiness may pose a challenge if they did not have the same prerequisite knowledge. Therefore, it is better to consider these constraints at the time when participants decide which topic to use for designing the curriculum unit. It is easier for a short unit (e.g. can be accomplished between 5 to 7 lessons) covering a concept required by a particular group of students (e.g. pre-engineering students, 10 graders) to find a niche in the busy schedule of an academic semester. Secondly, the connections between the teachers' research experience and the instructional unit they design must be clear. The curriculum should serve as a conduit to revealing interesting research topics and industrial applications so that students can make meaningful connections with the subject matter. Such integration requires an alignment between participants' professional background, areas of teaching, and the topic of their research. Strong alignment is the key to cultivating student interest in STEM and manufacturing.

To meet these challenges, we have initiated the following changes in the 2019 program: 1. Recruit teachers whose area of teaching is directly related to engineering applications especially in the manufacturing sector; 2. Allow teachers to design a smaller curriculum unit so it is easier to fit in their teaching assignment; 3. Encourage teachers to inspire intrinsic motivation among students to learn the power of STEM subjects through real-world applications in manufacturing industry; 4. Highlight the educator connection between the teachers and research mentors (college professors) who play a dual role in both teaching and research. Since the ultimate success of the program is to attract more students to manufacturing, going forward, we plan to build a stronger presence for the local industries to provide practical advice to the teachers' research and curriculum design projects.

6. Conclusions and Future Work

This paper presents an ongoing NSF RET site and focused specifically on the second year implementation of the program. The program has been successful in providing professional development to high school and community college educators on manufacturing related research and designing instructions for STEM education. A growing network of high school and community college educators is emerging in the region to bring research and industry into simulation-based manufacturing education.

Future work will focus on continuous improvement of the program in year 3 based on the feedback from RET teachers and our industry advisory board members.

Acknowledgement

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