A Biomanufacturing Outreach Module for Middle School Students Using Lego-Based Desktop-Factory Concepts (Evaluation)

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Tyler Brown is a junior (2017) at Rensselaer Polytechnic Institute, pursuing a dual degree in Computer & Systems Engineering and Computer Science. His research work includes development of software for a selective laser sintering (SLS) 3-D printer that provides greater user feedback control than current systems. He is enthusiastic about inspiring students to pursue careers in STEM fields, with a focus on advanced manufacturing.

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Ms. Herkenham is the K-13 Education Outreach Director of the School of Engineering (SoE) at Rensselaer Polytechnic Institute. Her responsibilities include managing the Pre-College educational programs for the NSF-funded Lighting Enabled Systems & Applications Engineering Research Center (LESA ERC), CURENT ERC, and faculty-driven Broader Impact initiatives. Under Ms. Herkenham's leadership, the RPI Engineering Ambassadors undergraduate program was established in Spring 2011. This unique program has been an effective approach for disseminating cutting edge research concepts into today's 4- 12 grade classrooms whereby over 20,000 students have been engaged in engineering related activities. The Advanced Bio-Manufacturing Lego-Machines are outstanding examples of outreach modules designed and implemented within the framework of the RPI Engineering Ambassador program and under the technical guidance of faculty support.

Dr. Johnson Samuel, Rensselaer Polytechnic Institute

Dr. Samuel has been serving as an assistant professor in the mechanical, aerospace and nuclear engineering department of Rensselaer Polytechnic Institute (RPI) since the spring of 2011. As director of the Nano/Micro-scale Manufacturing and Material Design Lab at Rensselaer, he leads research and education efforts in the areas of advanced manufacturing and material design. Besides research, Johnson is also passionate about training and developing the next generation of manufacturing engineers in the US. He is the 2014 recipient of the National Science Foundation CAREER Award. He was also awarded the 2014 - Rensselaer Class of 1951 Outstanding Teaching Award and the 2015-Rensselaer School of Engineering Education Innovation Award in recognition of his manufacturing education innovation efforts at RPI.

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1. Introduction

In 2011, the President's Council of Advisors on Science and Technology (PCAST) Report on advanced manufacturing identified biomanufacturing as one of the key pathways to revitalize the economy in the United States (US) [1]. While the field of biomanufacturing has seen significant research growth over the years, the fact remains that student interest in manufacturing-centered careers has been on the decline in the US [2-4]. This trend has been primarily attributed to their view of manufacturing as a "*dirty, dark, dangerous, and declining*" field, which is the wrong perception of the advanced manufacturing sector in the US [4]. In order to address this critical human resource shortage faced by the Nation, there is a need to design middle/high-school outreach activities that paint a more realistic picture of the US manufacturing sector. Biomanufacturing provides an ideal platform for such activities because of its combination of high-tech industrial processes and perceived societal impact.

In this paper, we report the design and implementation of a biomanufacturing outreach module for middle-school students that uses Lego^{TM}-based desktop-factory concepts. This module leverages the power of Lego^{TM}-based instructional techniques to convey the biomedical impact of the advanced manufacturing sector in the US. The module comprises of a suite of three Lego machines that replicate the metrology, subtractive manufacturing, and additive manufacturing, processes, respectively. These Lego^{TM} machines are combined into a single desktop factory whose stations correspond to the *inspection, excavation, and filling* processes required for the treatment of dental caries (cavities) in clinical dentistry. The module comprises of an engaging presentation followed by the students performing a simulated procedure to remove carie shape equivalents from a dental analog workpiece and subsequently filling it with cake icing. The evaluation data suggests that the module is successful in painting a positive view of advanced manufacturing, even within the female demographic.

The remainder of the paper is organized as follows. Section 2 presents the candidate biomedical process that lies at the core of the module. Section 3 presents the design of the Lego^{TM} desktop factory and its individual components followed by Section 4, which presents the classroom implementation details. Section 5 presents the evaluation data collected from the schools and finally, Section 6 summarizes the findings of this work.

2. Candidate Biomedical Procedure: Treatment of Dental Caries

According to the National Institutes of Health (NIH) dental caries (cavities) are one of the most prevalent oral diseases present in both children and adults in the US [5-6]. The middle-school student demographic is well acquainted with this dental procedure, which makes it a great avenue to explain manufacturing principles. Caries form due to the demineralization of different layers of the tooth in the presence of bacteria. Left untreated, cavities will grow and can even pass through the enamel and dentin of the tooth and reach the root, causing great discomfort and requiring a more invasive procedure [6]. As described in Fig. 1, (a), the treatment of dental caries starts with a dentist visually inspecting the tooth for any cavities in the outer enamel layer. Then the inspection process is completed using an x-ray scan to detect caries in the inner enamel and dentin layers. After detecting the presence of dental caries in the enamel, the dentist proceeds to use a dental handpiece that rotates a tungsten-carbide dental bur at high speeds to remove the enamel and dentin located in the affected region of the tooth. After removing the decay and surrounding tooth material, the dentist uses a ceramic paste to fill the area in which the tooth material was removed. The paste is cured and solidifies to complete the treatment process.

3. Lego™ –based Desktop Factory

To create the Lego™-based desktop factory analog of the dental carie removal process, two existing Lego™ machine tools[10,11] were implemented side by side (schematic shown in Fig. 1 (b)) with the students performing the operations on a floral foam workpiece. Additional modifications, including a custom built graphical user interface, and electronic controls, were made to allow for remote operation of the desktop factory. The details associated with each of the machine tool components used in the Lego™ desktop factory are described in the following sub-sections. Figure 1 (c) shows the workpiece flow through the desktop factory with the steps of *inspection, excavation and filling* being handled by the three specific stations.

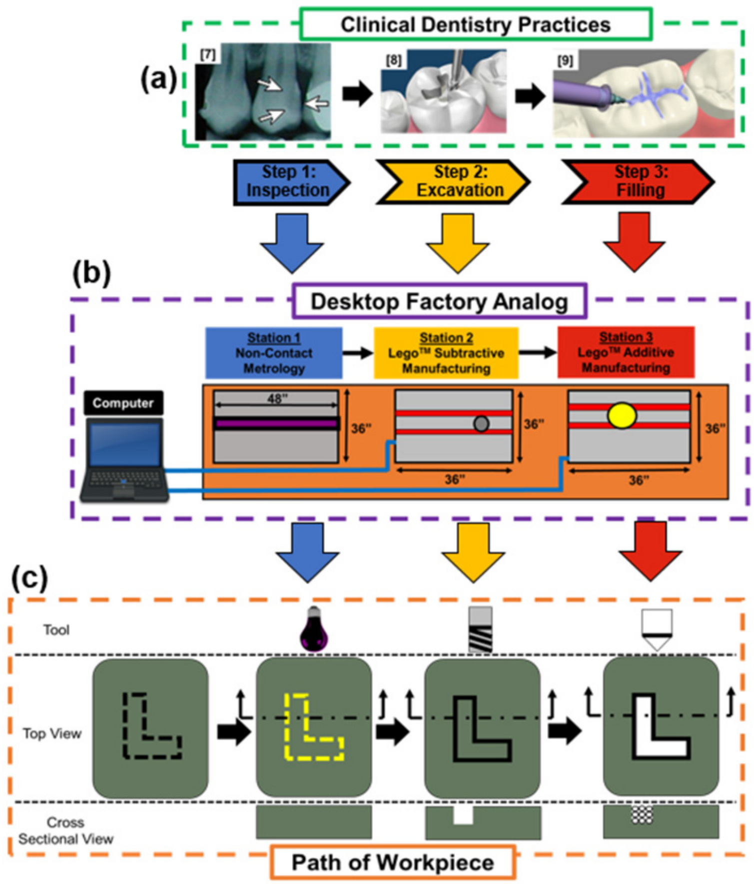

Fig. 1: Conceptualization of Desktop Factory Educational Module for Clinical Treatment of Dental Caries

3.1 Step 1: Inspection of Carie-shaped Equivalents using Black Light

This first step was designed to replicate the x-ray scan used to identify the geometry of the dental caries before their removal. Planar carie shape equivalents (presented ahead in Section 4.2) were first created on the floral foam workpiece by applying a dilute solution of yellow highlighter ink to the top surface of the workpiece using a cotton swab. A blacklight bulb was then turned on to identify the pre-drawn carie shape equivalents. It should be noted here that the shapes were invisible to the naked eye until they were put under the light, which causes the colored pigments to fluoresce.

3.2 Step 2: Excavation of Carie-equivalents using Lego™ Subtractive Manufacturing Machine Tool

For the second step involving the excavation of the dental caries, students used the Lego™ Subtractive Manufacturing Machine Tool (Fig. 2) to remove the necessary material based on the shape that they identified in Step 1. The subtractive manufacturing machine tool replicates the processes seen on a three-axis computer numerical control (CNC) milling machine. The details for the construction and use of this machine tool are described in Nowak et al. [10].

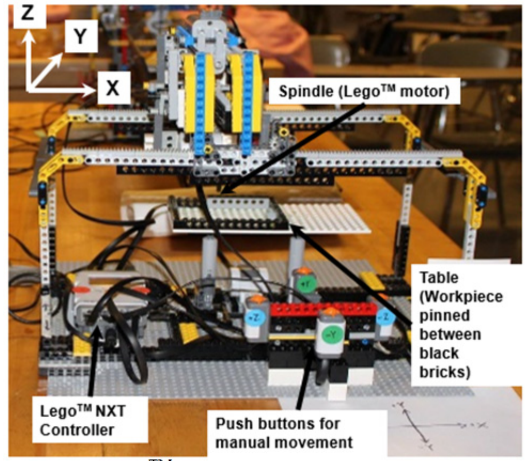

Fig. 2: Lego™ based subtractive manufacturing machine tool used in Lego™ desktop factory analog

3.3 Step 3: Filling of Carie-equivalents using Lego™ Additive Manufacturing Machine Tool

For the third step involving the filling of the cavity, students used the Lego™ Additive Manufacturing Machine Tool (Fig. 3) to add material (cake icing) to the site from where material was excavated in Step 2. The details about the construction and use of this machine tool are described in Almodovar et al. [11]. However, for this implementation the Almodovar et al. [11] machine tool was improved by making the frame completely out of Lego™ components. Furthermore, the original C-shaped frame design was replaced with the gantry-style frame present on the subtractive manufacturing machine tool

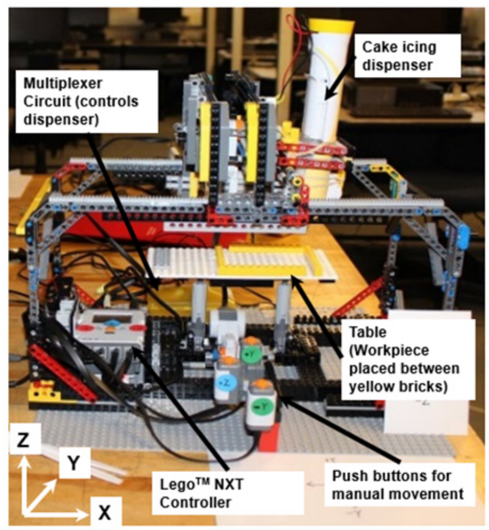

Fig. 3: Lego™ based additive manufacturing machine tool used in Lego™ desktop factory analog

3.4 System Integration: Graphical User Interface (GUI)

One of the features of a desktop factory is its ability to allow for remote operation of all the machine tools present in the system. Therefore, we have implemented a custom graphical user interface (GUI) to allow for the students to control the desired machine tools and perform the necessary operations on their dental carie shape equivalents. The GUI for the additive manufacturing machine tool is shown in Fig. 4. Students load and fixture the floral foam onto the bed of the Lego™ additive manufacturing machine (Fig. 3). Then the "*HOME AXES*" button **(Button #1)** on the GUI lets the students manually set the location of the extruder nozzle to the starting position that they had marked at the inspection station. Next, the appropriate profile option is selected on the GUI **(Button #2)**. Finally, the "*START ADDITIVE*" **(Button #3)** button is pressed, causing the machine to move in the desired path needed to fill the cavity shape. The subtractive manufacturing machine tool has a similar GUI with the exception of not having the "*Extruder Refill*" button located in the **Box 4** (Fig. 4), as well as having the spindle manually activated by the student when they are ready to start their operation.

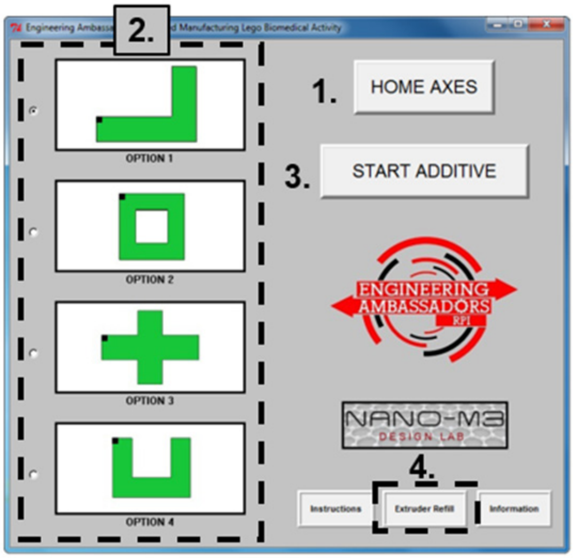

Fig. 4: Developed GUIs to control the Lego™ additive manufacturing machine tool

The GUI was written in *Python 2.7* using the *Tkinter* library. As can be seen in Fig. 5, the structure of the GUI is comprised of three separate regions. A main function was created first. This was followed by the user panel, which was created by initializing and formatting various components. A primary function of any GUI is to handle a wide range of possible inputs from a user at any given moment. *Tkinter* handles this using a built-in function, *mainloop(void)*, which checks for any interaction from the user. The GUI is designed in such a way that when a student presses one of the shape option buttons (**Box #2**, Fig. 4), a pre-compiled, external program downloads and runs on the Lego^{TM} NXT controller. This program contains all the necessary coordinates to reproduce the shape either by removing material using the subtractive manufacturing machine tool, or by dispensing cake icing using the additive manufacturing machine tool. For more information on the specific *Python* GUI program or individual Lego^{TM} NXT programs used to control the machine tool, please see the associated files at http://www.johnsonsamuel.com/outreach.html.

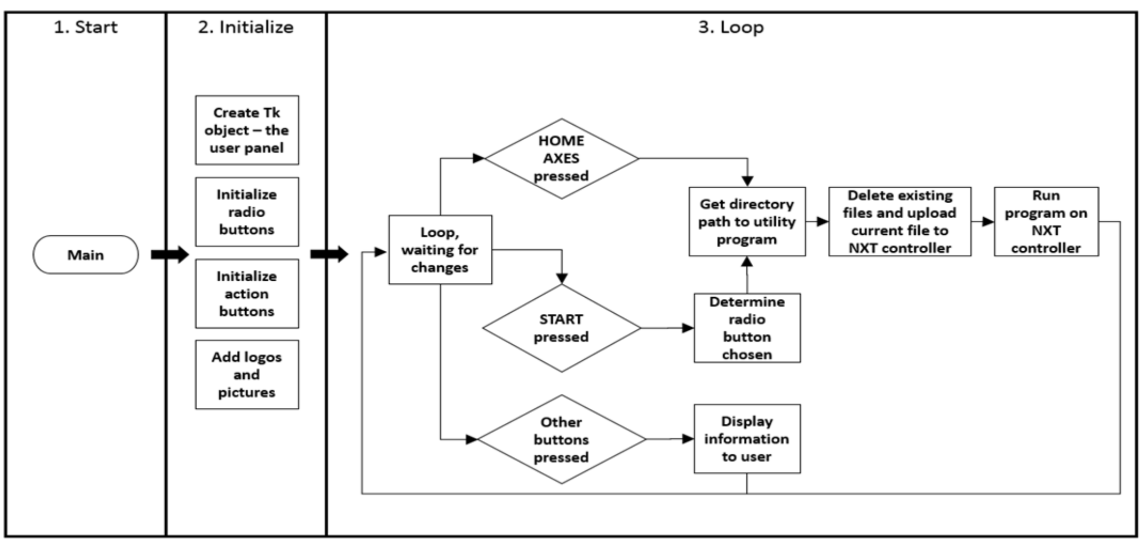

Fig. 5: Flowchart of the code structure for the GUIs implemented

3.5 System Integration: Electronic Controls

One key aspect of additive manufacturing is to match the dispensing of the material with the movement of the stages. This required that the activation of the cake icing dispenser be automated to allow for proper filling of the cavity. To accomplish this, the circuit shown in Fig. 6 was designed and implemented. First, a multiplexer and transistor (*TIP120 NPN* in Fig. 6) was used to extract an additional output from the Lego^{TM} NXT controller to allow for the X, Y, and Z axes as well as the cake icing dispenser to be synchronized. The circuit utilized the pulse width modulation PWM) of the Lego^{TM} NXT controller to turn on an external voltage source that powered the cake icing dispenser. (The toggle switch (*DPDT Switch* in Fig. 6) reversed the current flow through the motor, to allow for reloading the cake icing **(Button #4,** Fig. 4**)** into the additive manufacturing machine tool.

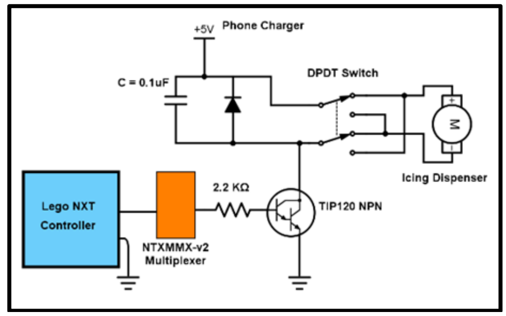

Fig. 6: Circuit schematic of additional hardware added to the Lego^{TM} additive manufacturing machine

4. Module Implementation

As shown in Fig. 7, the module was designed for a 45 minute middle school class period and was facilitated by a group of 2-3 undergraduate engineering students. The middle school students began by entering their classroom and completing a pre-module assessment, described in Section 4.3. Once all students completed the pre-module assessment, an engaging 12 minute assertion-evidence based presentation (Section 4.1) was presented to the students. After the completion of the presentation, students operated the Lego^{TM} –based desktop factory under the guidance of the facilitators. After the desktop factory activity, the facilitators led a concluding discussion on the topic following which the students completed the post-module assessment.

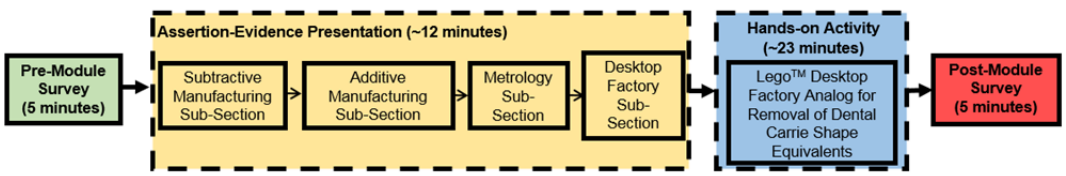

Fig. 7: One-period biomanufacturing module timeline (45 minute class period)

4.1 Assertion-Evidence Presentation

The in-class presentation was primarily developed to explain the concepts associated with the three manufacturing operations used in the Lego^{TM}-based desktop factory, as well as to showcase the impact that biomanufacturing has on our society. Additionally, the presentation also stressed the importance of collaborative endeavors between engineering disciplines such as manufacturing and biomedical. An assertion-evidence format was chosen for this presentation since it has been proven to result in greater retention rates in the audience [12]. This format of presentation reduces the amount of text on the slides, and maximizes the number of images and videos used, thereby allowing the audience to focus on the oral delivery of content [12].

The presentation started with challenging the current student perceptions about manufacturing in the US. Subtractive manufacturing was then introduced as a concept. Examples of subtractive manufactured biomedical devices, as shown in Fig. 8, were presented to the students. The presentation then shifted to additive processes stressing upcoming fields such as 3D printing of tissue and organs (bio-printing). Metrology was then introduced as a method to measure the parts that were produced, as well as a way to measure cell density/activity in order to identify disease. The presentation concluded by taking all three of the previously described processes and combining them together into a desktop factory. The concept of a desktop factory was introduced as a way to **1)** provide variants of a particular product, **2)** reduce the transportation costs and the environmental foot print, and **3)** provide point-of-need manufacturing by de-centralizing the factory to the location it is needed, which in this case would be the dental clinic (Fig. 9).

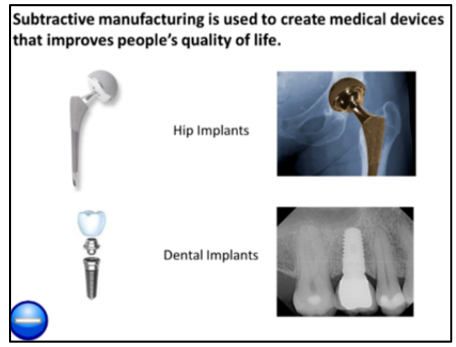

Fig. 8: Examples of biomedical devices created from subtractive manufacturing using Assertion Evidence presentation format

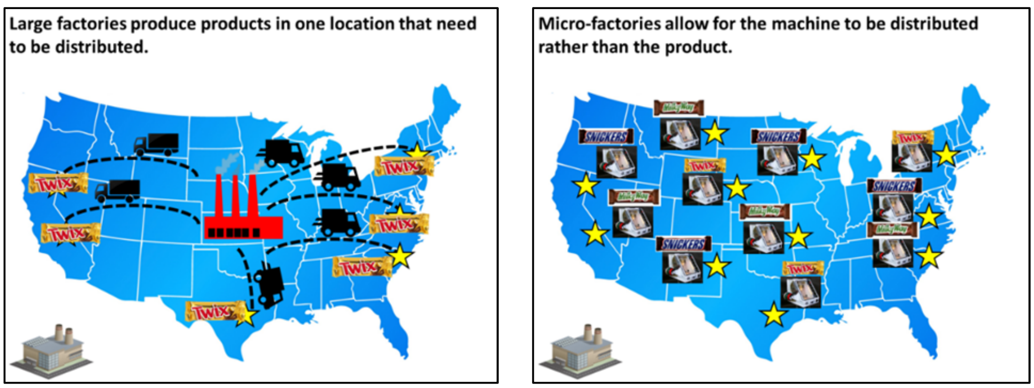

Fig. 9: Shows assertion evidence slides of the distribution scheme for large scale factories (left) and desktop factories (right)

4.2 Hands-on Activity

After completion of the presentation, students use a floral foam workpiece as a dental analog to perform all the manufacturing processes in the Lego™ desktop factory. Students start by using the inspection station, described in Section 3.1, to illuminate one of the pre-made carie shape equivalents on the floral foam workpiece, shown in Fig. 10. Due to the limited time of this one-class period module, and varying skillsets of the students, pre-made shape equivalents were used for this module. The students then proceed to identify the shape of the carie equivalent given to them and set the workpiece origin for their future operations.

After the students have identified the correct shape at the inspection station, they proceed to operate the Lego™ subtractive manufacturing machine tool. Students load and fixture the floral foam onto the bed of the Lego™ subtractive manufacturing machine. The "*HOME AXES*" button on the GUI lets the students manually set the location of the cutting tool to the origin they marked at the inspection station using the manual stage movement buttons. Next, the appropriate profile is selected on the GUI and the "*START SUBTRACTIVE*"

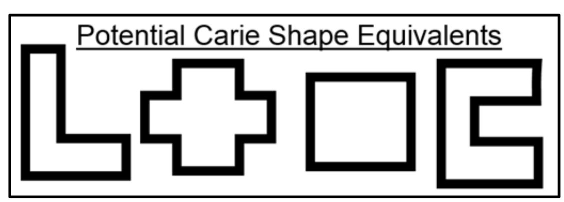

Fig. 10: Potential carie shape equivalents for students to select in desktop factory analog

button is pressed, causing the machine to remove the necessary material of the desired shape. Once the subtractive manufacturing operation is completed, the floral foam workpiece can be loaded on the Lego™ additive manufacturing machine tool. Students follow a similar procedure to the subtractive manufacturing process, to now fill in the shape of the pocket they had cut out.

4.3 Assessment Instrument

The assessment data was collected using protocols approved by the university's Institutional Review Board (IRB protocol #1313). The pre-module and the post-module assessment surveys were identical so that the results could be compared effectively. The assessment instrument contained both a combination of Likert scale questions measuring students' attitudes and opinions, and polar questions measuring the affective change in the student mindsets.

The first four questions (Fig. 11) measured the change in students' attitudes towards the advanced manufacturing sector using a Likert scale ranging from 0 to 4. The topics for each of these questions are described below:

I. **Career Awareness**, i.e., their knowledge of possible advanced manufacturing careers
II. **Societal Impact,** i.e., their appreciation of the importance of manufacturing in delivering new, innovative products to the masses
III. **Cutting-edge Technology**, i.e., their view that manufacturing uses new technologies and is not regarded as "*dark, dirty, and dangerous*" [4]
IV. **Continued Learning**, i.e., their interest in continued learning of advanced manufacturing

I. Career Awareness
1. Would you want a career in Advanced Manufacturing (3D printers, CNC machines)?

Definitely Not				Yes I Would
0	1	2	3	4

II. Societal Impact
2. How important is Manufacturing to improving society by providing new products?

Not Important				Very Important
0	1	2	3	4

III. Technology Awareness
3. Does Manufacturing involve new technology that is always being upgraded?

No, Disagree				Yes, Agree
0	1	2	3	4

IV. Continued Learning
4. Would you like to learn more on Advanced Manufacturing in class or on a project?

Definitely Not				Yes
0	1	2	3	4

Fig. 11: Likert scale questions to measure change in student's attitudes towards advanced manufacturing sector

The last set of four questions (Fig. 12) were designed to test the affective change of the students' perceptions on advanced manufacturing based on the content presented in the module. This portion of the assessment was evaluated on a binary scale (*correct* or *incorrect*). It should be noted that the response "*I'M NOT SURE*" was recorded as an *incorrect* response when tabulating the data.

I: Awareness of Desktop Factory
5. Manufacturing only takes place in large factories making a single product.

YES	NO	I'M NOT SURE

II: Effect on Household Goods
6. Manufacturing is used to make the products you use at home or at school.

YES	NO	I'M NOT SURE

III: Biomedical Broader Impacts
7. Advanced Manufacturing effects doctors, dentists, surgeons, and nurses.

YES	NO	I'M NOT SURE

IV: Re-shoring of U.S. Manufacturing Jobs
8. Manufacturing is most likely to take place in foreign countries.

YES	NO	I'M NOT SURE

Fig. 12: Polar questions to measure affective change of students based on content in module

5. Assessment Results

The module was presented to a total of 261 students across four different middle schools, *viz.*, **1)** School A, **2)** School B, **3)** School C, and **4)** School D. These schools were selected based on **a)** the demographics of their student body, **b)** admission criteria (public, private, charter), and **c)** distance relative to our Tier-1 university. School A represents a public middle school located 10 miles from the university, School B represents a private, parochial middle school located 20 miles from the university, School C represents an urban, minority-serving public, charter school located 3 miles from the university, and School D represents a suburban, public middle school located in a neighboring state, approximately 150 miles from the university's campus. These different types of schools were selected to be able to test the efficacy of the module in reaching a diverse set of students. Figure 13 (a)-(d) summarizes the student body demographics of the four schools A-D.

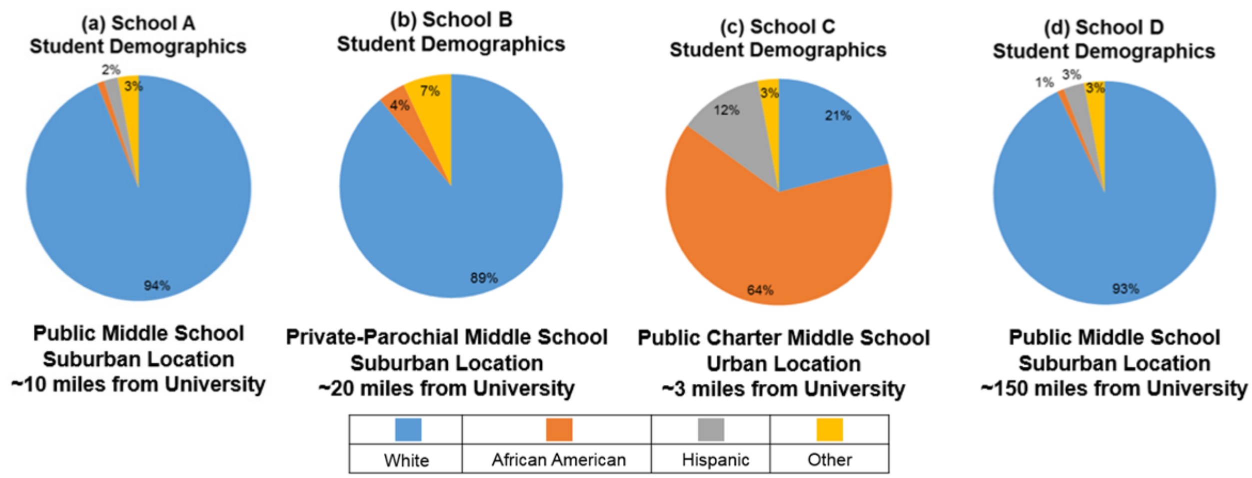

Fig. 13: Student Deomgraphics of Schools A, B, C, and D

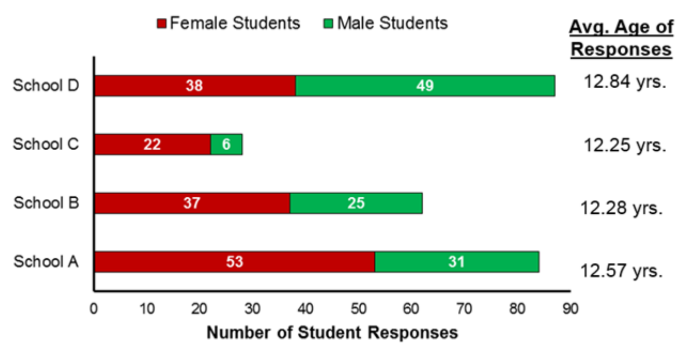

Fig. 14: Number of Student Responses to Pre- and Post-Module Assessment by School

Figure 14 displays the number of students who participated in the module at each school, as well as the number of male and female students from each school. The average age of student participants, across all four schools was 12.6 years old (std. dev. 0.8 years), and 57% of the student participants across all four schools self-identified as female.

5.1 Effectiveness of Module: Pooled Average Trends

A statistical paired t-test (95% CI) was performed on the student responses (pooled across all four schools) for all four Likert scale questions, and statistically significant improvements were seen for each of the four questions (Fig. 15). The largest increase was seen for the **Career Awareness** question, where the average Likert scale response increased by approximately 25%.

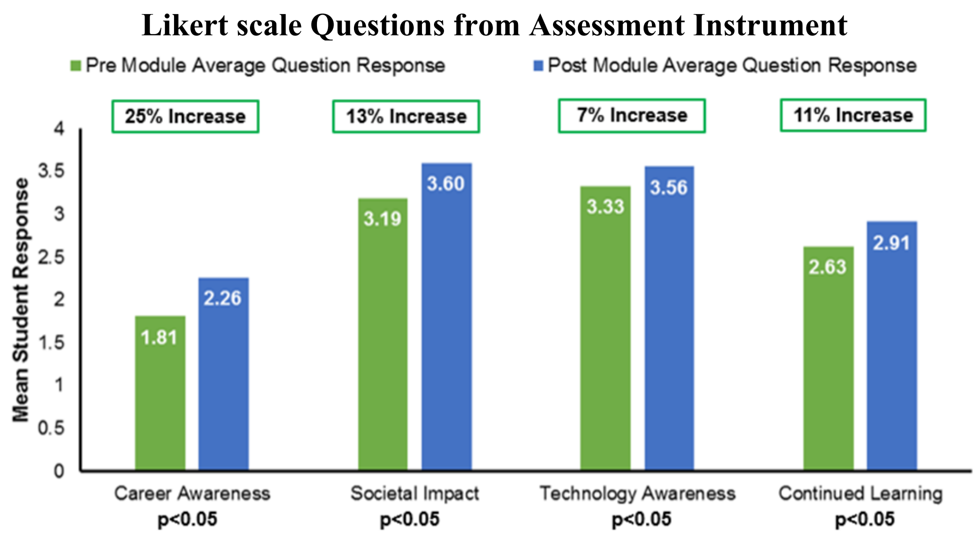

Fig. 15: Pre- and Post-Module Responses to Likert Scale Questions for all students

The number of correct responses, for all of the polar questions (measuring the affective change), was also seen to increase following the exposure to the module (Fig. 16). The question relating to the **Biomedical Broader Impacts** scored the highest percentage of 89% correct responses, which indicates that the module is able to effectively communicate the interplay between manufacturing and biomedical engineering. It should also be noted that correct responses to the **Re-shoring of U.S. Manufacturing Jobs** had the largest increase when compared to the pre-module assessment. This result was promising in that it showed the module was effective at communicating that manufacturing jobs are coming back to America from the factories overseas. The trends in this assessment data are similar to the preliminary work reported by Nowak et al. [10].

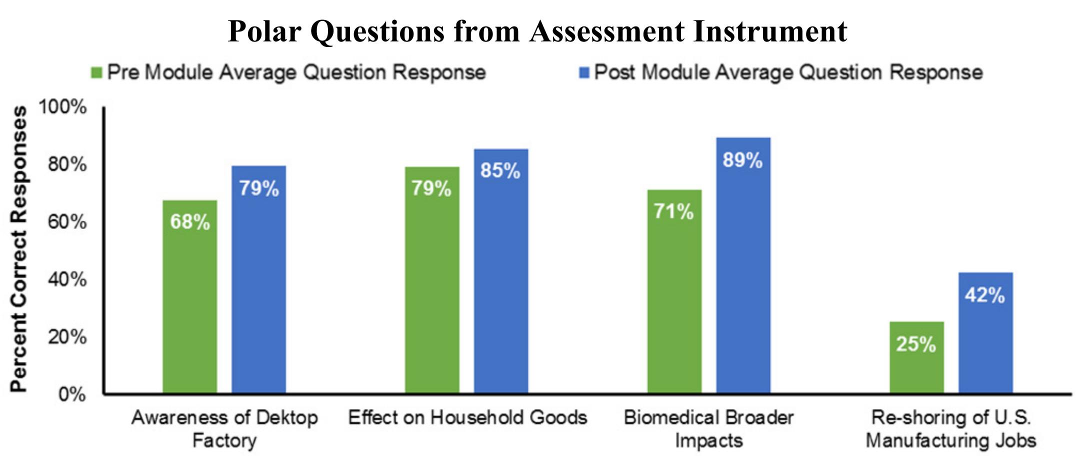

Fig. 16: Pre- and Post-Module Responses to Polar Questions for all students

5.2 Effectiveness of Module based on Age of Student

Two of the Likert scale questions (**Career Awareness** and **Societal Impact**) were analyzed based on the age of the student, pooled across all four schools. It should be noted here that the other responses were not observed to be as sensitive to age. As show in Fig. 17, from this analysis we see that the percent change in the students' views on career awareness increases with an increase in the age of the student, whereas the same metric for their view on the societal impact of manufacturing decreases. This trend may be attributed to the possibility that as students get older, they become more aware of the societal impact of manufacturing and are therefore more interested in the career opportunities offered by the field. Meanwhile, the opposite is true for younger students in middle school who are not as focused on aspects of selecting a career but rather are more inclined to be interested in how the field impacts the society. This information provides crucial feedback to our team to modify the focus of the presentations in the future, based on the age groups of students.

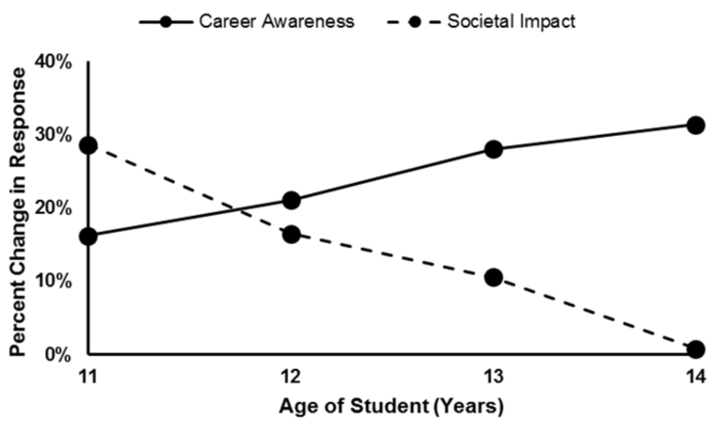

Fig. 17: Percentage Change in Student Responses post-module to Career Awareness and Societal Impact questions, separated by age of student

5.3 Effectiveness of Module based on Gender

Table 1 depicts the gender-based response obtained for the Likert scale questions. The responses indicate that the module is more effective with female students for all of the Likert scale questions measuring their attitudes towards the advanced manufacturing sector. It is important to note that the module was particularly effective in increasing the female students' view on **Career Awareness** and **Continued Learning**. The positive trend in the attitudes of the female students towards biomanufacturing indicate that they are more inclined to have a greater interest in the module due to the perceived societal benefit that they see from the applications of biomanufacturing. This is also shown in their responses to the question regarding **Societal Impact**. This behavior has been described in previous studies that have shown that female students tend to gravitate towards fields that have a higher societal benefit, such as biological, health, and medical fields [13].

Table 2 depicts the gender-based response for the polar questions measuring affective change. From this data it can be seen that the female students had more correct responses for questions regarding the **Awareness of Desktop Factories** and **Effect on Household Goods**. The other two questions were approximately equal and did not vary by a significant margin based on gender.

Table 1: Likert Scale Question Responses Separated by Gender of Student

Likert Scale Questions from Assessment Instrument						
	Female Student Responses			Male Student Responses		
Question Description	**Average pre-module response**	**Average post-module response**	**Percent Change**	**Average pre-module response**	**Average post-module response**	**Percent Change**
Career Awareness	1.55	2.00	28.5%	2.13	2.61	22.5%
Societal Impact	3.11	3.65	17.4%	3.29	3.54	7.4%
Technology Awareness	3.37	3.61	7.3%	3.34	3.49	4.5%
Continued Learning	2.49	2.92	13.2%	2.86	3.04	6.3%

Table 2: Polar Question Responses Separated by Gender of Student

Polar Questions from Assessment Instrument		
	Female Student Responses	**Male Student Responses**
Question Number	**Percent Increase after Module**	**Percent Increase after Module**
Awareness of Desktop Factories	15.4%	6.9%
Effect on Household Goods	8.2%	3.6%
Biomedical Broader Impacts	17.6%	18.8%
Re-shoring of U.S. Manufacturing Jobs	17.1%	17.2%

5.4 Effectiveness of Module based on School

Figure 18 (a)-(d) depicts the responses to the Likert scale questions but now separated according to the schools. School B had the highest increase in average response for questions targeting **Career Awareness** and **Societal Impact**. Figure 19 (a)-(d) depicts the responses to the polar questions separated according to the schools. It can again be seen that School B exhibited greater improvement on the question regarding **Effect on Household Goods** and **Re-shoring of U.S. Manufacturing Jobs**. School B also had the highest percentage of correct answers for three of the four questions, after being exposed to the module.

While the reasons for the high levels of improvements seen in the students at School B need further investigation, it can be partially explained by the fact that the average age of the students in School B who were exposed to the module was 12.3 years, of which, 23% were 11 years old. This is the highest percentage of 11 year old students of any of the schools in which the module was presented. This younger age could indicate that this module may have been their first exposure to these technologies in either their courses or extra-curricular experiences. School B also had the smallest total enrollment of students at the school with a total of 62 students enrolled in grades 6 through 8, while School A, C, and D, had 685, 147, and 714 students enrolled in these grades, respectively.

In three out of the four schools, the **Awareness of Desktop Factories** showed the largest increase in correct responses. Given the recent emergence of this technology, more educational outreach work should be aimed at the development of desktop factory-based modules. In comparing School A and School D, it can be seen that the effect of geography and curriculum in these different states is evident in the question regarding **Awareness of Desktop Factories** and **Biomedical Broader Impacts**. Both of these rapidly developing topics are on the cutting edge of

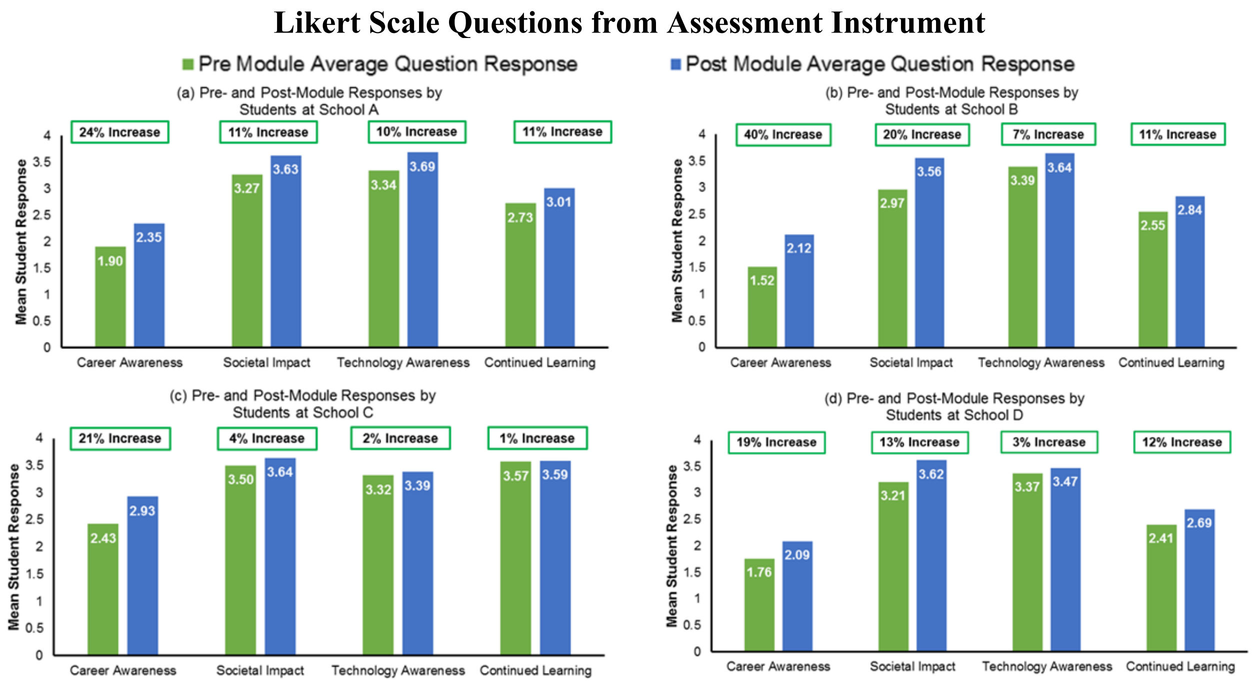

Fig. 18: Pre- and Post-Module Responses to Likert Scale Questions for Students at (a) School A, (b) School B, (c) School C, and (d) School D

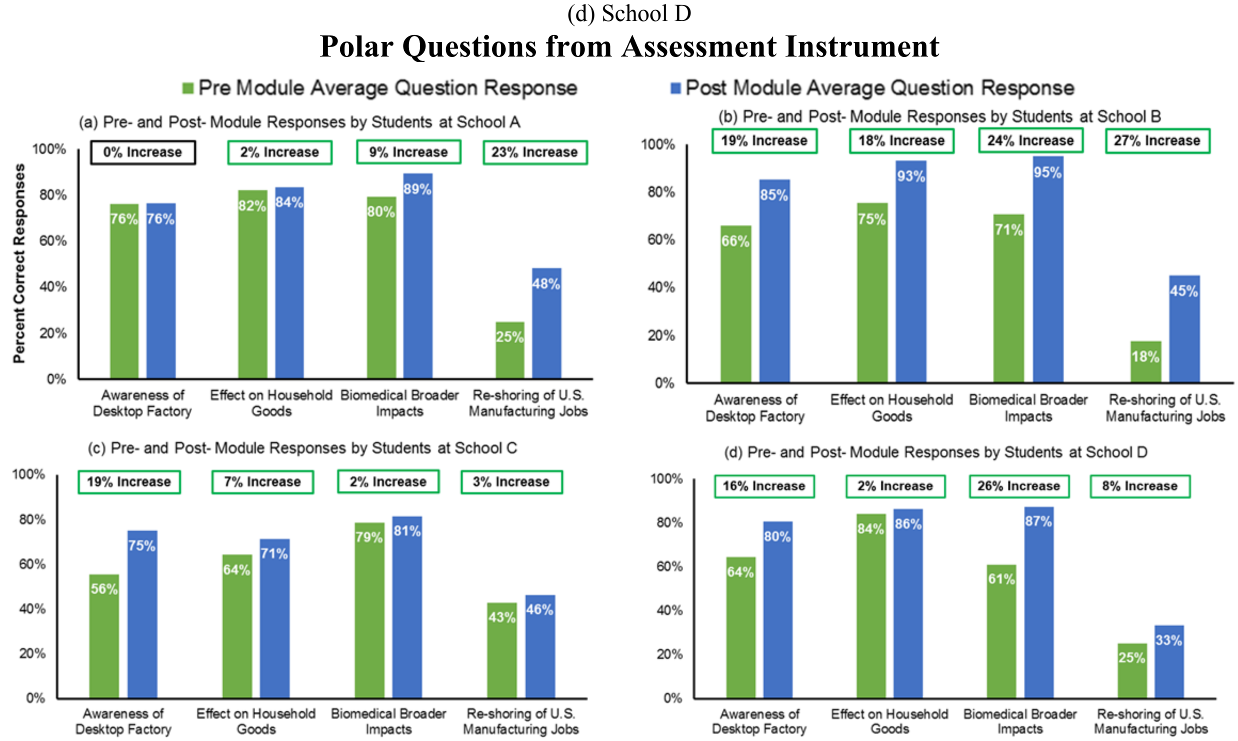

Fig. 19: Pre- and Post-Module Responses to Polar Questions for Students at (a) School A, (b) School B, (c) School C, and (d) School D

research conducted at Tier-1 research universities. School D, (located out of state), had higher gains in these categories after exposure to the module. This is despite having similar student ethnic backgrounds and school size when compared to School A, indicating that the proximity of the middle school to a Tier-1 research university may be significant in the dissemination of these cutting-edge technologies. As a note, the closest Tier-1 research university to School D is 55-70 miles away, while Schools A, B and C are all within 20 miles of multiple Tier-1 research universities.

6. Summary

A Lego^{TM}-based desktop factory was built around the inspection, excavation, and filling steps analogous with the treatment of dental caries. The desktop factory was paired with an assertion-evidence presentation as part of a one-class period module that was deployed in local middle schools (261 students) through the use of undergraduate engineering student facilitators. The module was shown to be effective in changing the students' perceptions about the advanced manufacturing industry, most notably in the *Career Awareness* and *Biomedical Broader Impacts* categories. The age-specific assessment data indicates that the module content for younger students should be more focused on the *Societal Impacts* of advanced manufacturing, whereas for the older students the focus should be on *Career Awareness*. This biomanufacturing module was seen to be more effective in promoting advanced manufacturing to the female students. While further investigations are needed to ascertain the reasons behind the differences between the schools, geographical proximity to a Tier-1 research institution appears to be beneficial in terms of the students being exposed to new technologies.

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