Work in Progress: Development of a 3D Printing Curriculum for K-12 STEM After-school Outreach Programs

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Abstract

As part of our ongoing efforts to stimulate interest in Science, Technology, Engineering and Mathematics (STEM) among young female students, Cummins Inc. has partnered with Girls Inc. in North America to develop and execute an after-school STEM outreach program in which Cummins employees volunteer to mentor and coach said students on STEM concepts by using Project-based Learning (PBL) activities. One such module that we developed was that of 3D printing to expose manufacturing to kindergarten to 4th grade students in the Franklin, Indiana School District. As a technology, 3D printing has emerged as a manufacturing method that allows rapid changes to detailed parts with low investment costs, especially with the advancements in 3D printing technology that has significantly reduced the purchase cost and improved availability of 3D printers to the public. With raw materials, i.e., filament that are readily available and the compatibility of 3D printers with easily accessible online open-source/freeware Computer Aided Design (CAD) applications, 3D printing offers tremendous potential for educators to expose students to the fundamentals of design and manufacturing at an age-appropriate level without getting too complicated. Moreover, with K-12 students being given laptops and tablets in school for homework, the relatively ready availability and low cost of procuring 3D printers can potentially help educators in quickly putting together lesson plans for introduction design and manufacturing without having to spend too much effort in resources and logistics. Design, designing and manufacturing of sculptures and figurines via 3D printing also allows integration of engineering with art, a subject many school-going students are familiar with, thereby helping to reinforce concepts to a real-world application in a fun way. This work-in-progress paper will describe in detail the motivation behind developing a 3D printing curriculum for the Cummins-Girls Inc. after-school STEM outreach program for the Franklin Indiana Schools District, the curriculum development strategy and outlines our future plans to evaluate the outcomes of the lesson plans conceived and executed to encourage young women to gain basic design and manufacturing concepts while simultaneously attempting to increase interest in STEM careers among them.

Introduction

In order for the United States to continue to remain competitive in Science and Engineering, it is necessary to establish and maintain a steady pipeline of scientists and engineers with the technical prowess and expertise to contribute to the development of technological solutions that will improve society's quality of life. Although the number of Americans graduating from college has increased, employers find it difficult to recruit graduates for jobs in the Science, Technology, Engineering and Mathematics (STEM) domain due to a shortage in highly skilled and competitive applicants [1,2]. This shortage can be attributed to the decrease in proficiency of students in mathematics and science as they progress to higher grades [3], and a dwindling number of students graduating high school interested in pursuing STEM degrees in college, with about 33% of those pursuing engineering planning to switch to non-Engineering before graduating [4]. This shortage becomes even more acute among underrepresented minorities such as women, who only make up 20% of the total number of this already small number of STEM

graduates, especially in physics, engineering and computer science [5]. Researchers have tried to understand the low proportion of women in STEM fields, and a major factor appears to be a lack of exposure to STEM concepts at an early age [6]. Some studies also demonstrate that STEM education starting from the elementary school level has an impact in student decisions to pursue STEM majors in college [7-10]. K-12 STEM Outreach programs, especially those that incorporate the Project-based Learning Method (PBLM) [11-13], have demonstrated success in teaching students to actively apply skills and techniques from diverse disciplines.
Drawing from lessons learnt by other K-12 STEM Outreach Programs, Cummins Inc., one of the US' and the world's leading automotive manufacturing companies, has partnered up with Girls Inc. North America through the "Cummins Powers Women" (CPW) initiative to develop PBLM-based educational programs to help bridge the achievement gap in STEM fields. A specific program under this initiative is the STEM after-school outreach curriculum that Cummins employees have developed in partnership with the Franklin, Indiana affiliate of Girls Inc. to mentor Kindergarten - 4th grade students from the Franklin, Indiana School District on STEM concepts through science and technology projects. One of the modules developed as part of this curriculum is 3D printing. This work-in-progress paper will discuss about our motivation in developing the 3D printing module for Kindergarten-4th grade female students, the module development process, as well as future plans to assess the effectiveness of teaching 3D printing on stimulating STEM interest in young girls.

The paper starts with a background on the current curriculum and attempts to explain why the 3D printing module was incorporated as one of the activities in the curriculum, followed by a description of the tasks and concepts that we put together to develop the module and deliver the module as weekly lessons over a period of 8 weeks.

Background

In our previous work [14], we had presented about adapting the "A World in Motion" (AWIM) modules developed by the Society of Automotive Engineers (SAE) as part of the after-school STEM outreach curriculum [15,16]. While these modules were initially chosen due to the lesson plans being well-organized and their ease of implementation, the number of modules available in the AWIM curriculum is limited, and the modules themselves only allow a limited level of customization to tailor the lessons to female students in the kindergarten - 4th grade. As a result, the number of concepts taught is constrained to this limited set of modules, and the instructors find it challenging to modify the lessons in such a way that the female students' interests and passions, especially arts and crafts, can be incorporated to engage them better. Moreover, the somewhat rigid structure of these modules makes it challenging for the female students to unleash their creativity and implement challenging and unique solutions to science and engineering problems. It was therefore necessary for us to develop a new module from scratch that could help mitigate some of the drawbacks faced with the AWIM modules.

The new module developed is centered around 3D printing, a recently developed additive manufacturing process that involves creating objects using a device called a 3D printer that adds progressive layers of material until it takes the shape of the object as designed in Computer-aided Design (CAD) software. With continually decreasing cost of portable 3D printers and the wide availability of open-source CAD applications, 3D printing has the potential to become an effective teaching tool that exposes students to the iterative cycle of a typical product development process, which is fundamental to many engineering disciplines [17]. In particular, 3D printing can help inculcate aspects of design thinking and also improve students' spatial reasoning and creativity [18]. Moreover, with students nowadays being given laptops and tablets in school for homework, integration of 3D printing with the IT devices used by the students is relatively seamless and does not require a huge investment in resources by schools and nonprofits. Studies by academics demonstrate that integrating 3D printing into classrooms improved students' technical aptitude and creativity [19], while also developing their capability to visualize, iterate and refine their design concepts, a critical component of design thinking.

Besides inculcating design thinking, 3D printing also allows instructors to incorporate an artistic component to K-12 STEM education, enabling implementation of the STEAM (Science, Technology, Engineering, Arts and Mathematics) pedagogy into the classroom [17], since 3D printing has the potential to allow students to take their arts and crafts concepts and convert them to manufactured objects. As noted by Kijima et al. [21], STEAM education can increase enthusiasm towards STEM among adolescent girls, and a detailed quantitative cum qualitative study performed by Forbes et al. [22] demonstrated that makerspaces incorporating 3D design and printing improved engagement and increased enthusiasm in STEM among students, particularly girls. Forbes et al. also noted that 3D technology-enhanced makerspaces fostered collaboration amongst students to work together and was empowering as the 3D technology encouraged creative freedom, allowing students to stretch their imagination to create any object by themselves (in their own words).

The aforementioned positive aspects of 3D printing, particularly the low cost of materials and resources, the incorporation of STEAM pedagogy and the flexibility in allowing students to unleash their creativity and thereby increase enthusiasm in STEM encouraged us to develop a new 3D printing module for the K-4th grade students at Girls Inc. Franklin. In the next section, details of the 3D printing curriculum will be covered.

3D Printing Curriculum Details

As mentioned earlier, the 3D printing curriculum we developed was focused on an arts and crafts theme so as to incorporate STEAM pedagogy, based on the observations of Kijima et al. that STEAM can increase enthusiasm towards STEM among adolescent females. Before starting any lesson planning, the first decision we had to make was the 3D printer to buy for the module. The printer we chose for our module was the Flashforge Adventurer 3 [23]. This particular make and model was chosen because Flashforge is a well-known brand in the 3D printer space that manufactures printers specifically for school education, and the cost of purchasing one was inexpensive, at $349. This printer was purchased using budget money from the Corporate Responsibility department at Cummins. Inc that was allocated for the Girls Inc. Franklin STEM outreach program. The printer came with 2 spools of filament, which is the raw material used to make the products. Figure 1 shows a picture of the Flashforge Adventurer 3 3D printer.

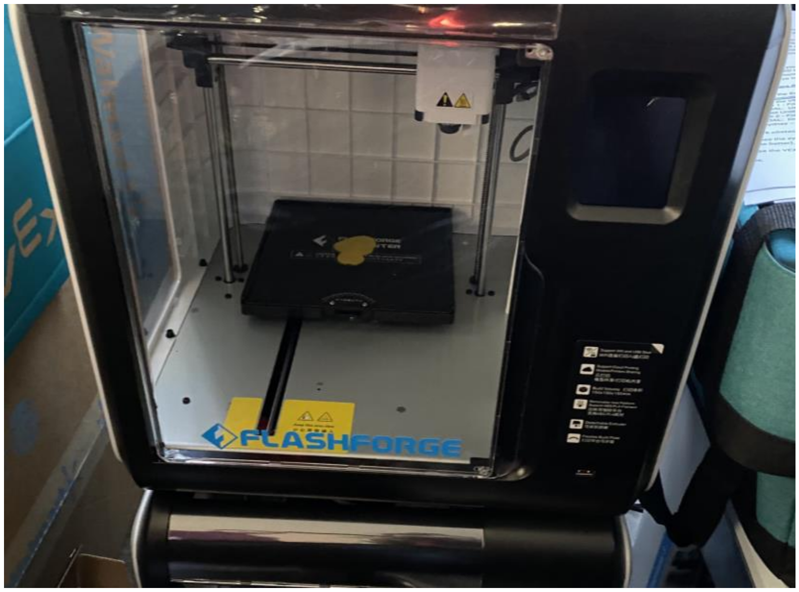

Figure 1: Flashforge Adventurer 3 3D Printer at Girls Inc. Franklin

The module was planned to be covered over a duration of 3 weeks (with an hour-long session each week) as part of an 8-week STEM summer camp held in-person at the Girls Inc. facility in Franklin, Indiana. A shorter duration was chosen initially due to the following reasons:

1. Complexity of Engineering Concepts: Since 3D printing itself is a relatively new process, it requires some planning and preparation to break down the sophisticated concepts of product design and additive manufacturing to be covered at an age-appropriate level tailored to K - 4^{th} grade students. As we were just starting out this program, we had to take a gradual approach to provide a high-level overview so that the K - 4^{th} grade students at Girls Inc. could takeaway key critical concepts over a shorter duration, before going deeper into these concepts in future iterations of the module.

2. Available Preparation Time for Instructors: As Cummins engineering employees running the program and mentoring the students during after-school hours, this was a supplemental activity in addition to our day job as engineers in other engineering fields not necessarily related to design and manufacturing, such as engine performance, product strategy, etc. As a result, we needed to set aside additional time outside of work hours to develop the curriculum from scratch. A gradual approach would therefore be the most effective way to first expose the students to the field of 3D printing and provide them a flavor of this activity, following which we could continue to improve the content over a period of time as we keep holding subsequent sessions of the module.

3. STEM Summer Camp Structure and Objective: The objective of the Girls Inc. STEM summer camp is to expose the students to a wide variety of topics across STEM, not just engineering-specific topics alone. Students would attend workshops about nutrition, biology, computer programming, etc. during the 8-week camp and so it would be challenging to go deep into any one of these topics over just 8 weekly sessions, especially since only a few

weeks out of the 8 were dedicated to any of the topics. Hence it was decided to start the 3D printing module out slow and build upon it after reviewing the outcomes of this 3-week session.

After purchasing the printers, the liaison team brainstormed as to what items/products would drive enthusiasm among the students. We found a website describing instructions to create a flower press along with CAD models for the press and developed figurine CAD models. The goal was to show the students how 3D printing could be used to manufacture tools for arts and crafts activities as well as pieces of art themselves.

Although the end-products of the 3D printing process were figurines and a flower press, we were mindful of linking the creation of these items back to product design and manufacturing concepts during each lesson so that the main objective of inculcating engineering principles in the students was not lost. To do this, we planned the lessons over the three weeks in this manner:

- Week 1: Engineering Drawings – Students were asked to use engineering paper to draw top, lateral and front views of things that they liked, such as flowers and animal figurines. Their goal was to use the preset dimensions of engineering paper grids to determine the sizes of the objects they wanted to create. The desired outcome of this exercise was to inculcate in students the importance of engineering drawings and dimensions to quantify the size of the products/prototypes they had in mind. While the students could be creative and show off their artistic skills, they had to think and quantify the sizes of the objects they desired. This would serve as a segue into how engineers would first start out with sketches and dimensional drawings on paper before moving their ideas to a Computer Aided Design (CAD) software package, where they could extrapolate their ideas in two dimensions to a 3D space. Instructors would then talk about how the information stored in a CAD file could be input into the 3D printer to manufacture the product they desired.

- Week 2: Critiquing the Design of a 3D printed Flower Press: For Week 2, a few flower presses were manufactured by the instructors using 3D printers with detailed instructions and CAD models from the following website: [24]. Instructors then brought the flower presses to the session and instructed the students to use the flower presses to flatten and compact different kinds of flowers that they could then take home. Students were asked to test the flower press kits and critique the designs, in terms of utility and durability. They had to identify any flaws or issues with the designs and suggest improvements.

- Week 3: Feeding CAD Models into 3D Printer to Manufacture Products: Based on the drawings by the students in week 1, and inputs obtained in week 2, instructors developed CAD models of the objects that were most popularly drawn. These CAD models were then fed into the Flashforge Adventurer 3 printer, where these objects were manufactured using filament material. Students had the opportunity to witness the 3D printer manufacturing products in real time while the instructors explained in detail the additive manufacturing process. At the end of the session, each student took home either a manufactured flower or a cat figurine. Figure 2 shows the CAD models created.

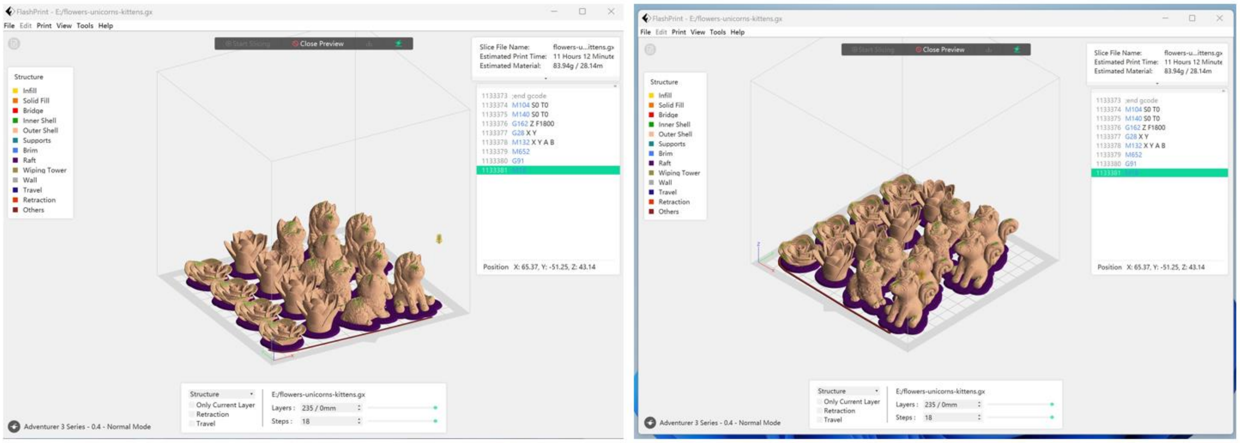

Figure 2: CAD Models of the Flowers and Animal Figurines

Overall, with the limited amount of time we had for this module, we had to tailor the lesson plan to clearly emphasize key concepts behind additive manufacturing to provide a concise yet proper understanding of the product design process and how 3D printing works as a manufacturing method. The short duration, coupled with long manufacturing times of the Flashforge Adventurer 3 (which is an entry-level printer) meant that the students did not get the opportunity to operate a 3D printer, but had to learn by intently observing the processes. As a result, we discovered that a 3D printing module is too short for a summer camp activity, and most likely needs to be spread out over an entire semester, or maybe even an academic year to fully benefit students.

Proposed Plans to Enhance 3D Printing Module & Evaluate Program Effectiveness

For future semesters, we plan to utilize the entire semester or an entire school year, rather than a during a summer camp to teach the 3D printing module. This way, we can investigate each concept of product design and manufacturing in much greater detail. As students are provided their own laptops in school, we can plan sessions to get them familiar with CAD software and creating their own designs, as well as engineering drawings. Once the students develop designs, we can also allow them to operate the 3D printers under instructor supervision so that they can become familiar with using additive manufacturing tools. In the final weeks of the semester or school year, we can divide the students into project teams so that they can work together to design and manufacture a particular product. This will expose them to how engineers collaborate within teams in the real world.

In terms of assessing the 3D printing module effectiveness, it will be necessary to conduct pre- and post-program surveys, such as the Friday Institute's S-STEM Surveys [25, 26] to evaluate students' progress. Surveys also will conducted among the Cummins employee volunteers, and the Girls Inc. program staff to obtain ideas on how to improve the module from an instructor's perspective. Before conducting these surveys, it will be necessary to collaborate with Engineering Education faculty from universities in Central and Southern Indiana to obtain advice on survey techniques and protocols for getting approvals from Institutional Review Boards (IRBs). Once we obtain IRB approval and work with academic partners to develop and conduct surveys, we will use the survey results to improve the 3D printing module.

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