

Advanced Manufacturing Online STEM Education Pipeline for Early-College and High School Students

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Abstract— During the summer of 2020, we hosted a virtual summer camp for high school and early-college STEM students. The subject is related to advanced manufacturing (AM) and 3D printing. This outreach is funded by the Department of Energy DOE consortium project. With this summer program, our objective is to prepare a pool of students in the AM area in high demand in industrial and national research laboratories.

The main objective is to teach students to use Autodesk Inventor, use mathematics to solve engineering problems and use 3D printers. Additionally, the application of materials science is introduced to demonstrate the integration between mathematics and science. The progressive level of projects related to producing better parts, assemblies, and drawings mainly focuses on critical thinking and developing creative solutions (problem-solving, writing, visual arts, communication skills, and open-mindedness) to problems.

One goal is to first introduce students to different areas of engineering and how each of these areas is connected to different applications of advanced manufacturing to help students shape their careers and select a discipline program that best suits their goals.

This article aims to discuss the virtual teaching experience from the perspective of students and teachers. We will discuss the virtual activities carried out during this summer camp, as well as the modifications made to this course to make it more suitable for online teaching. Virtual teaching was an opportunity to share knowledge, information, and experiences online with other groups and universities.

Collaborative work between an NCAT faculty and high school instructors and teachers from the AM industry and research labs has been one of the success stories that have helped shape this program. The industrial participation was very helpful in meeting industrial needs, reviewing AM applications, and discussing issues related to research and education, pedagogy, communication with high school students, and keeping them focused on the task.

We discuss the project design program from a student's perspective and experience gained in the AM area, integration, and written and oral communication. The methodology used to assess the effectiveness of this outreach program in terms of learning outcomes is also described.

Index Terms— Advanced Manufacturing, Outreach, Pipeline, STEM Education.

1. Introduction

Advanced manufacturing [1-6] has been at the heart of our technological growth and economic indicators as more manpower is needed in industry and laboratories to advance towards AM applications in several areas. In order to attract more students to careers focused on manufacturing as well as science, technology, engineering, and mathematics (STEM) [7, 8], academic institutions are working with the national laboratories, the energy department, the education department, etc. to prepare a new generation of engineers with the knowledge related to this new technology. Cutting-edge manufacturing programs and programs strive to meet the industry's growing need for high-tech skills, adaptability, and critical thinking to accelerate in their fields.

This effort is reaching all levels [9], starting with elementary [10], middle [11] and high schools and early colleges through outreach programs, new curriculums or undergraduate program changes [12, 13], new certificates [14] and online courses, as well as the research and development [2, 13, 15], through summer internships and graduate programs.

The AM is touching several industries and major applications of AM are building and construction [16], Medical devices [17-20] educations [17, 21-24], aerospace, robotics, pharmaceuticals, rapid prototyping, and much more.

During the summer of 2020, we hosted a virtual summer camp for high school and early-college STEM students. The subject is related to advanced manufacturing (AM) and 3D printing. This outreach is funded by the Department of Energy DOE consortium project. With this summer program, our objective is to prepare a pool of students in the AM area in high demand in industrial and national research laboratories.

High school Architectural and Engineering Drafting teachers from Guilford County participated in the workshop to help with teaching and designing the activities and the program. A University faculty participated in organizing the workshop activities and instructed the students on a number of engineering topics.

The program usually starts by introducing the students to the main tools in Autodesk Inventor that students use in their designs. This year, students also learned about the Tinkercad program, especially for those who have difficulty installing Autodesk Inventor on their computers. Then the students are given design projects to work on. These projects are either individual or team projects.

To keep the program successful and challenging, we invited talented faculty to perform several activities such as using a sputter coater to coat plastic with a layer of gold and produce filaments for 3D printers using an extruder and spooler. The students were also asked to do research on the different methods of 3D printing that the Department of Energy labs are involved in.

The students are taught the basic function of the Autodesk Inventor program and carried out several activities to expound the students' understanding of Autodesk Inventor. Among the projects, the students researched and designed tool holders for standard household tools. They also designed and virtually assembled a weathervane prototype. Several projects have been performed, including 1) designing and 3D printing tools holder; 2) designing safe children playground equipment.

To have a better understanding of Additive Manufacturing, students watched various videos on several 3D printing technologies. Also, students researched various concepts surrounding Additive Manufacturing. As advanced topics, stress analysis, the use of 3D-scanner. Students are trained in constructing and presenting their work at the end of the workshop. On the last day of the workshop, the students gave PowerPoint presentations on their designs and 3D prints. Parents were invited to the presentations and were used to judge the work of the students.

2. The Problems of Virtual and Distance Teaching

Due to the coronavirus pandemic, the 2020-summer, we decided to set up virtual classes despite the problems of distance education. Here are the difficulties and problems encountered in distance education:

1. *Quality of teaching*

The first problem for the distance teacher is the ability to adapt face-to-face teaching to distance teaching. Much of the quality of teaching depends on the attitude of the teacher, students, the equipment used, as well as the home environment of the students.

The technology itself is an important factor, however, the technology does not affect significantly the quality of the classroom. Indeed, effective teachers do help to improve distance education. A teacher who can be effective in face-to-face teaching will not perform the same way in a virtual teaching situation.

It is important to use technology to deliver virtual teaching. Too often instructors do not design their lessons to take advantage of the technology presented. This affects the quality of instruction. The effectiveness of distance education depends on preparation, the teacher's understanding of the needs of the students, and an understanding of the target population.

2. *Chances of distraction are high*

In the absence of the faculty of face-to-face interaction and of classmates capable of helping you with constant reminders of pending works and deadlines. The chances of getting sidetracked and losing interest and misunderstanding the teachers' explanation are very high. The teachers play a significant role in motivating students and keeping them focused. Distance learning is not a good idea if you tend to procrastinate and can't meet deadlines.

3. *Hidden costs*

Virtual education comes with hidden costs involved, such as incurring some initial expenses such as setting up a computer and obtaining a reliable Internet connection. You may need to purchase additional resources such as a printer, web camera, etc. Some expenses can be recurring, such as maintenance and electricity costs. In particular, having a good computer that handles demanding software such as Autodesk Inventor is another burden on the shoulder of the parents to make go through this summer camp without difficulties. To solve this problem, few students in difficulties used VMware to connect to university computers, as well as other computer programs were given as an alternative to Autodesk Inventor.

4. *Complicated technology*

Over-reliance on technology can be a major drawback in distance education mode, especially when learning takes place in an online environment. Any faulty software or hardware can block a class in progress and interrupt the class and thus the learning process. Likewise, if a student is better at computers and technology, their learning experience can be unsatisfactory and compromised.

5. *Faculty quality compromised*

Distance education used to be overwhelmed by a lack of good quality teachers. In other cases, even if the instructor is good, he or she may not be comfortable with teaching in an online environment. Sometimes technology may not do full justice to the delivery and design of the course. If the teaching loses in quality, the student will have less good learning. Distance education providers need to realize that it is not technology, but good and effective teachers who teach students.

Let's take a look at some of the benefits of distance education while in lockdown.

There are no limits of distance:

Access to digital education means that different educators will be ready to teach you a unique methodology. Likewise, we have invited high-quality instructors from other states who have participated in the outreach education. Their contribution has been invaluable and has given a significant understanding of new topics, not only to students in our county but also in other states.

More free time:

A real course is not just about explaining theory and practice. You will have seen it with some teachers who start talking about their personal life in class. If you think about it, in a typical classroom, you waste a lot of time because they have to stick to the schedule established by the school. Here it is possible to set the schedules, so you guarantee much more direct teaching.

Several formats:

Since we are talking about virtual education, there will be thousands of formats, through which you can teach and learn. The good thing about it is that they can all complement each other, so a campus can be used to link to

a video on YouTube or attach text documents to reinforce a conference. Many educational institutions only have a blackboard for teaching, but here the possibilities are increasing exponentially.

At the same time, with distance education, students will have the opportunity to review the lessons, since they are recorded, and this can help students understand the lessons better.

3. Workshop Description

The developed workshop model is geared mostly towards minorities to advance their knowledge in the field of 3D printing and advanced manufacturing. Students are selected through an application process, based on their academic performances, as well as their wishes to pursue a career in the AM field.

3.1. The workshop Objectives

The ten-day camp is part of the outreach program oriented toward high-school and early college students. The outreach program is part of the consortium DOE project. This program has several objectives:

- 1) Through active teaching early college, as well as high-school students the modeling and models development and production using computer programs, as well as 3D-printing.
- 2) Contribute to the success of existing STEM programs by giving them case studies and applications that improve students' learning and communication skills.
- 3) Preparing skilled and qualified technicians that industry and research laboratories are in huge need, after this revolution created by 3D-printing and new manufacturing.
- 4) Make the early-college and high-school students aware of what is happening in advanced manufacturing (AM) applications to increase their awareness and interest in tracking university degrees that give them career paths in AM.

In the last year, the outreach program conveyed a dozen junior early-college and high-school students and two high school teachers in a ten-day program, full of activities and active learning related to advanced manufacturing and 3D printing. The main objective of this summer camp is to give a limited number of students unique experiences in both designing models and generating the 3D-print out of these models. 3D CAD solid modeling program Inventor™ is used for the training, since available for NCAT engineering students, and considered among the best programs available. The program is similar to PTC CREO and SOLIDWORKS, which is used by the automotive industry. The workshop takes place in the middle of the summer to avoid conflicts with the other students' activities. During the spring semester, early-college and high-school counselors, as well as Engineering Drafting teachers from Guilford County are contributing effectively to inform students, as well as advertising for the program. The parents' contribution is very essential since they were involved since the early stage of this program. Students included both genders and composed in majority from minority students. The students and parents are invited to a welcome meeting, one day before the starting of the program. Both students and parents met the instructors, visited the computer labs, and learned about the main

activities, the camp rules related to absence, parking, and other auxiliary items.

The teaching is progressive, from learning the basics of the computer Inventor program and developing the first models during the first three to four days. Later on, each student performed multiple relatively advanced designs and projects proposed by the instructors with an increasing level of difficulty. Each student is exposed to a challenging project, where more research and study are needed. The projects are obtained from multiple sources and the industry, competitions, and personal suggestions. At least one of each student's creations was 3D printed. Some of the designs were printed on a larger 3D printer available at NCAT, Fortus 400mc 3D printer.

At the beginning of the workshop, our approach is based on active learning of the use of the Inventor software without relying on deep mathematics knowledge. The main objective is to teach students conceptual and prototyping design. The visual nature of the Inventor software and the attraction of the 3D printing technology enabled high-school students to comprehend the concepts related to the use of the software very quickly. Later, more concepts and more challenges are introduced, with more mathematics and the use of equations, materials concepts, a search of material properties, and unit conversion to perform calculation, estimation, as well as analysis and judgment to come up with conclusions of solutions to the challenges proposed.

On the last day of camp, the morning is spent preparing the students for the last activity of the camp, which is to present their work to a non-specialized audience, composed mainly of the parents and close family. Each group of students gave a twenty-minute PowerPoint presentation to communicate their design and contribution to the summer camp, followed by a ten-minute discussion during which the student is expected to promote their ideas and defend the use of certain features in their design. Parents and close family were invited to the presentations. This year, all meetings were conducted using zoom.

3.2. Workshop important aspects

Application to the summer camp

The application is very important and needs to include information relating to students and their parents. Summer camp for high school students needs parental approval and support for many reasons, e.g., summer camp time can be in the middle of summer and may disrupt the summer schedule for the whole family. In addition, in the summer, faculty and high-school teachers have their own summer agenda. All of this needs to be discussed and prepared to find the best time for summer camp.

Schedule

The schedule of the summer camp should be planned carefully, especially in the case of virtual education. The aim is to keep the student focused on his activities, to make the presentation clear and complete enough to make it clear and adaptable for all students.

Type of students

Our goal in this summer camp is to focus on minorities and women, as well as low-income families. At the moment, we are focusing on high school. The involvement of middle school students was only for the purpose of experimentation. For this category, our focus

was on the best middle school students to be sure that their level can correspond to the level of the high school.

Preparation for the summer camp

The preparation of the camp focused on several points.

- (1) The parent's responsibility to guide, supervise and help students who are learning to be successful.
- (2) Recruit more teaching assistants to help with the students' supervision.
- (3) Help install software on personal computers and offer solutions in case of difficulties.
- (4) Remind students and parents to make students available from 9 a.m. to 5 p.m. daily for two weeks.
- (5) Organization of pre-summer camp meetings.
- (6) Preparation of the university computer lab.
- (7) digital survey preparation: students have undergone multiple surveys, and part of these surveys has been digitally prepared to make communication easier and faster.

3.3. Activities of the virtual summer camp

Due to the corona pandemic, many activities that used to take place are being replaced by others, in particular:

- (1) High quality visiting professors with knowledge of advanced manufacturing and 3D printing:

These applications focused on the seven 3D printing methods and techniques. The fundamentals were explained, and the application of 3D printing at the industry level was introduced to arouse the curiosity of students to pursue engineering careers, since the applications cut across all engineering disciplines, including building construction and architecture, electricity, mechanics, chemistry, as well as industrial and biological.

A specialized presentation related to current research topics and the involvement of national laboratories in this research was also at the center of these presentations.

- (2) Add new lectures related to engineering, materials science, and the use of mathematics to solve engineering problems: the extension of the summer camp is not only 3D printing and advanced manufacturing. This summer camp was an opportunity to answer questions from high school students related to career selection, understanding the difference between engineering disciplines, and the importance of material selection, behavior, and applications to the various projects carried out by national laboratories.

- (3) Share important elements with other universities and collaborators: virtual education was an opportunity not only to share knowledge and experiences but also to share conferences and presentations between different universities, research groups, students, and faculties.

- (4) NCAT Computer Lab as a central focus: To resolve all technical issues related to the camp, one faculty used a computer lab at the university as a central point to teach, organize, and resolve any technical issues that may arise during the camp summer, such as a lost connection to the university server or software problems.

4. Program Evaluation and Methodology

The success of the workshop was demonstrated through different outcomes, such as the multiple students who

participated in the program and later accepted in the mechanical engineering program and school of technology at our University. Other than that, the camp students participated in at least two different poster competitions (Appalachian Energy summit (2017 & 2018) and MSIPP Consortium for Advanced Manufacturing 1st, 2nd, and 3rd Annual CAM Scholar Poster Competitors), using the work learned at the summer camp, knowing that these competitions are usually designed for undergraduate and graduate university students.

This evaluation research utilizes quantitative approach data sources to determine the overall experience of the students regarding virtual education. The questions relate to several aspects of virtual learning, including how much time students spend while taking a virtual course, and determine if they are allocating some time to other activities, such as sports and social interactions. Students' personality plays a major role in whether they prefer virtual learning or classroom interaction. NCAT team offers comprehensive technical support to students in terms of access to NCAT computers and accessibility to Inventor Software to make distance education comfortable and effective.

Studying virtually and especially during a pandemic can be quite stressful, especially if you have a problem accessing a good computer and fast internet. Measuring students' stress levels and identifying ways to reduce it is an important aspect of this virtual learning.

Understanding whether students enjoy virtual learning or do so under pressure from parents is essential for a teacher to adopt different teaching techniques. Find out how you can improve distance education and make it interesting for them.

Virtual learning lacks interaction and presents its own unique challenges. Some students may have difficulty learning a subject and take longer to understand. Measure the extent to which students find their teachers useful is essential to improve distance learning.

Using the course's indirect assessment form, students were asked, anonymously, to self-assess the specific areas identified by the instructor in relation to the course's learning objectives, as well as the motivations for the program experience (the questionnaire is displayed in the appendix).

The compilation of the results of the course learning objective self-assessment questions for this short course is shown in Tables 1 and 2. Student responses from "5" being extremely well and "1" being not at all.

The results of the students' assessment show that for all the questions, students generally feel like virtual learning is a good experience and are interested in distance education. The assignments and performance of the students over the summer camp show the same positive answers.

The instructor also performed an assessment of student performance in the course as part of the process of evaluating program objectives (POs) and outcomes. A summary report on student performance (to achieve program objectives) and compliance with program outcomes are prepared and submitted to the funding agency (DOE). A more rigorous process for evaluating the learning outcomes of this summer camp will be implemented alongside the outcomes of the program.

More evaluation research utilizing a mixed-methods approach employing both qualitative and quantitative data sources to determine the impact of the workshop on student learning were used during the final presentation. The compilation of the results of the student-self-evaluation, as well as parents' evaluation of the summer camp oral presentation questions, are presented in Figures 1 to 3.

TABLE 1.
INDIRECT ASSESSMENT

Indirect Assessment (Consider 5 being extremely well and 1 being not at all)						
Student Self-Assessment of Course Learning Objectives	(5)	(4)	(3)	(2)	(1)	Average
1. How do you feel overall about virtual summer camp?	5	5	1	1	0	4.17
2. How much time do you spend each day on an average on distance virtual summer camp?	6	6	0	0	0	4.25
3. How effective has virtual learning been for you?	4	6	2	0	0	4.17
4. How helpful NCAT (during the summer camp) has been in offering you the resources to learn from home?	5	6	1	0	0	4.17
5. How stressful is distance learning for you during the COVID-19 pandemic?	5	5	2	0	0	4.25
6. How well could you manage time while learning remotely?	6	5	1	0	0	4.25
7. Do you enjoy learning virtually?	4	4	4	0	0	4.00
8. How helpful are your teachers while studying virtually?	6	6	0	0	0	4.33

TABLE 2.
INDIRECT ASSESSMENT (OTHER QUESTIONS)

Indirect Assessment (Consider 5 being extremely well and 1 being not at all)				
Student Self-Assessment of Course Learning Objectives	(a)	(b)	(c)	(d)
9. Do you have access to a device for learning virtually?	6	6	0	0

WHO IS COMPLETING THIS SURVEY?

183 responses

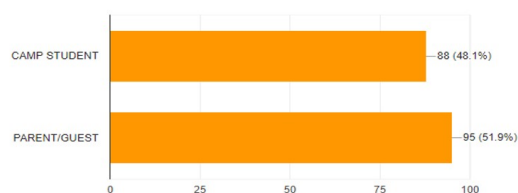


Figure 1. The participant of the survey (parents and students)

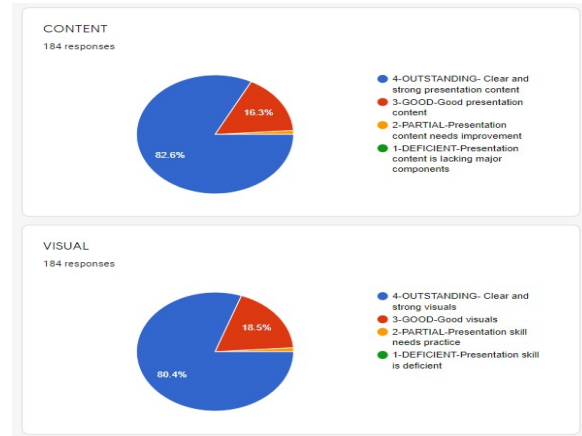


Figure 2. Presentation survey (content and visual) responses

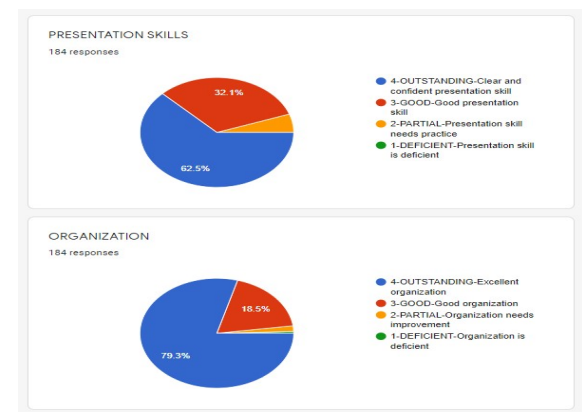


Figure 3. Presentation survey (presentation skills and organization) responses

5. Conclusions

The summer camp took place virtually, due to the COVID pandemic. Our goal is not only to prepare for a successful summer camp but to create a summer camp model that will be shared with other universities and organizations. This template should be comprehensive and cover all aspects of summer camps, including preparation, organization, planning, recruiting, and delivery.

This summer camp was an opportunity for students not only to learn about 3D printing and advanced manufacturing and to help high school students select an engineering discipline for their career but also to help them make the appropriate decision in the choice of engineering discipline or even other disciplines, such as management or business, especially for minority students, who are often not supervised by their own families.

Another achievement of this outreach program was the digitization of the application process, as well as the expansion of participation not only to students from Guilford County but also to students from different states and counties.

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