An Outreach Program Focusing on Design Process and 3-D-printing

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Dr. Mufeed Basti is currently chemistry Professor at NC A&T State University. He received his PhD in physical chemistry from Northern Illinois University in 1988. He did two postdoctoral fellowships at the University of California at Davis and at NC State University. He has earned over $4.5 million in research awards. For CAM, Dr. Basti's research includes use of nanoparticles to densify binder-jetting 3D parts. He serves as chair of the CAM's Outreach subcommittee.

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Abstract:

3D-printing is going to be one of the most innovative technologies of the current century, with diverse applications in education, engineering, art, and design. Over two summers, we conducted a teaching class about advanced manufacturing and 3D printing, in the framework of a project funded by the DOE Office for Nuclear Security/National Nuclear Security Administration (DOE-NNSA).

The objective of our summer program is to serve advance manufacturing, as an evolving technology and to improve STEM education to prepare the new generation of high-school students (future engineers) through the use of the existing tools.

Through the use of programs, such as CREO and Autodesk Inventor, as well as 3D printing concepts, both technology and basic traditional STEM knowledge, such as math and science were served in this program. These tools allow the students to reach their objectives without going through complex mathematics and engineering concepts and methods. This way, these projects will mostly focus on critical thinking and the development of creative solutions to problems.

Without deep mathematics knowledge, students were able to conceptualize, customize and prototype their design. The visual nature of these tools (CREO and Inventor), and the 3D-printing technology enabled high-school students to grasp the technology and concepts very quickly.

The purpose of this paper is to demonstrate the design and implementation of an experiment, from basic parts. In particular, we will discuss the lesson learned, such as:

- Instead of going through the program chapter by chapter, we encouraged collaboration and integrated work through a set of projects. The students selected only five project that fit their needs and curiosity.

- Going through the design process, step-by-step: define the problem, background research, specify the requirements, brainstorm solutions, development work, prepare the prototype, and finally assessment and analysis. Students have the ability to create their own designs using tools to reach a creative design and concrete outcomes.

Most importantly, project methodology will be discussed. We discuss the project design program from the students' point of view, and the experience earned in design, integration, and also in written and oral communication skills. The methodology used to evaluate the effectiveness of this design program in term of learning outcomes is also described. In this paper, we focus only on the second year of the summer camp.

Introduction:

To expose some high school students in Guilford County to the importance of computer engineering design, modeling and 3D printing, twenty high school students (10th and 11th grade) were invited to participate in a two-week summer camp at North Carolina A&T State University (NC&AT) campus. A graphic design high school teacher was also invited to be part of the instructors' team. The team that conducted the workshop is composed of two NCAT faculty members, one undergraduate student and the high school teacher. The workshop started at 9 AM, and ended at 5 PM. The lunch break was at 12 noon (lunch was provided). The main objective of the workshop was to initiate the students on advanced manufacturing and 3D-printing.

In particular the objective is to teach the students how to use Autodesk Inventor™ 3D CAD software which is a computer-aided design application for creating 3D digital prototypes that are used in the design, visualization and simulation of parts and assemblies. During the first three days, the students did learn the basic tools and utilities of the program. Each student then worked on four projects that they chose from twelve projects suggested by the instructors.

When working on the design, the students began from sketching the design and discussing it with one of the instructors. The discussion included the math skills that the students utilized in making such designs. At least one of every student's designs were be 3D-printed. This year, we used Fortus 400mc 3D printer, which is a professional grade fused deposition modeling (FDM) printer, to print the students' designs.

At the start of the second week, a representative from Oak Ridge National Lab conducted a short series of talks about 3D-printing methods that use metal powder. The lectures aimed to inform the students about the great interest that the Department of Energy (DOE) has in advancing engineering graphic design and advanced manufacturing (AM) in its facilities (Shahi, 2016), **(**Tibbits, 2017)**.** The lectures also exposed the students to the specific applications of AM that DOE is using in these facilities. Such exposure has as objective to spark the students' interest in these topics and motivate them to pursue college education that would prepare them for careers in AM. The camp also included a half-day visit to a facility on campus that uses computer graphics designs and 3D-printing. The afternoon of the last day of the workshop was dedicated to students' presentations where each student gave a twenty to thirty minute presentation about his/her design. The presentations are aimed to improve students' communication skills. Also, parents were invited to attend the presentations.

By the way, mechatronics is a complex, highly technical, multidisciplinary subject that involves the design and manufacture of integrated products. In order to teach it properly in a course, student teams have to engage in designing a product. Due to the complicated nature of mechatronic products, such a project further complicates the administration of mechatronics courses. Kolberg and al. (2003) presents a design of a course for non-technical high school students. The design includes elements that motivate students to devote extra hours for technology study; thus leading students to successfully design products through managing a team project with little budget and scarce teaching resources.

Workshop Objectives and General Description:

The two-week camp was part of a larger program that includes research, education and outreach. Specifically, this program has multiple goals:

1) Train the students to use Inventor™ 3D CAD computer program to create engineering designs and teach them how to 3D print the designs using advanced 3D printers.
2) Improve students' math skills
3) Introduce the students to applications of advanced manufacturing (AM) to enhance their interest in pursuing college degrees that would prepare them for careers in AM.
4) Improve students' communication skills.

The camp involved twelve high school students (10th and 11th grade) and a high school teacher in a two-week workshop. The aim of the camp was to provide the students hands-on experience in modeling and generating engineering designs using Autodesk Inventor™ 3D CAD computer program which is one of the programs used for solid modeling. The program is similar to PTC CREO that is used in Honeywell at the Kansas City Plant, and many other auto-companies. One major advantage of the program is that interested students can download a one-month trial copy of the program to their own computers free of charge. The workshop took place in July, high schools principals and guidance counselors in Guilford County were contacted so that the teachers in their schools assisted in choosing the participating students. Students included both genders and at least 70% minority students. The day before starting the workshop, the students and their parents were invited to a meet-and-greet where they met the instructors, visited the computer lab, and were informed about the main activities of the camp.

During the first three days of the camp, students learned hands-on the basic tools of the Inventor program. After that each student chose four out of twelve projects suggested by the instructors. These projects were obtained from multiple sources, and industry, including the Autodesk Design Academy (https://academy.autodesk.com). At least one of each student's design was 3D printed. Some of the designs were printed on the Fortus 400mc 3D printer. The students also had access to the newly acquired handheld ErinScan-Pro 3D scanner. During the last day of camp, each student gave a twenty-minute Power Point presentation about his/her design followed by a ten minute discussion during which the student was expected to defend the use of certain tools or features in his/her design. Parents were also invited to the presentations.

Workshop Activities:

The camp activities were organized to facilitate learning and benefit all categories of students, including those who were novices and those who had some knowledge of the computer program.

Days1, 2 and 3 (July 10-12): Activities started with a brief introduction about the camp and its aims by one of the instructors. The students started learning the basic tools and utilities of the Inventor™ 3D CAD program. Since every student worked on a separate computer in the lab, the students then followed along with the instructor to gain the hands-on experience they need when making their own designs. The instructors demonstrated the use of the program's tools and utilities through making simple designs during which the students were given enough time to go through the same steps of the activity. While one of the faculty demonstrated these tools and utilities, the other faculty, the high school teacher and the undergraduate student were moving around to assist the students so that all of them were working at the same pace. The goal of the sessions was to familiarize the students with the use of all the basic tools and utilities of the program such as sketch (perform some operation on the sketch), creating trajectories, and extrusion. In parallel, students were introduced to basic computer skills that the program requires such as setting the working directory and creating a folder.

Day 4 (July 13) morning: The students were introduced to the twelve projects out of which each student was to choose four.

Day 4 afternoon and Day 5 (July 13 and 14): Students started working on their designs with the supervision of the instructors.

Day 6 (July 17): Short lectures about 3D printing applications in the DoE facilities by a representative from Oak Ridge National Lab.

Days 7, 8 (July 18-19): Students continued working on their projects; and started the 3D printing of their designs.

Day 9 (July 20) morning: Visited a computer and 3D printing facility at NCAT.

Day 9 (July 20) afternoon: Students continued working on their projects and continued the 3D printing of their designs.

Day 10 (July 21) (morning): Students practiced their presentations.

Day 10 (July 21) (afternoon): Students gave their presentations.

Detailed about Learning Process and Learning Assessment:

The students learned two primary components that are interlinked in the AM course content: the engineering design process, and manufacturing skills. The course is comprised of several project units, scattered with some 3D-printing skills. Most projects in the course require the use of the design process which we did introduce to the students in one lecture (shown in Figure 1). This course focused on using the process in practice and understanding its systematic, iterative nature.

Iterative design is a design methodology where the process is cyclic from sketching, testing, analyzing, and improving the product design or its characteristics.

Students are required to carefully document their ideas, using sketches, and data collected throughout the design process, which is assessed after each project. In addition, students must verbally communicate with their peers and teachers in both formal and informal presentations to justify their design decisions and pitch their final design solutions. The manufacturing and engineering aspects of the course require the students to draw their ideas, through sketches, in two dimensions and, later to build them in three dimensions using a computer program, and 3D-printers. Specifically, they learn to communicate their ideas using both pencil and computer technologies including 3D printers. The sequence of projects is such that there is a consistent progression from 2D to 3D, as well as a progression of sophistication in using the technology. Early in the course, students learned to use 2D drawing sketch. As projects progressed, students moved to 3D CAD packages (Autodesk Inventor) to create blueprints for 3D objects and assemblies or to 3D print their prototypes.

We have multiple levels of 3D-printers, the basic ones and the most advanced ones. The basic ones are easy to use and can be used by the students. The advanced ones need a special training and require advance knowledge. At NCAT University, we have a teacher responsible for such sophisticated printers and he is always available to give information and help different students regarding the use of such printers.

Each of the projects is considered a design problem, and the projects are presented in order of increasing complexity thus, improving the understanding of the use of the software functionality.

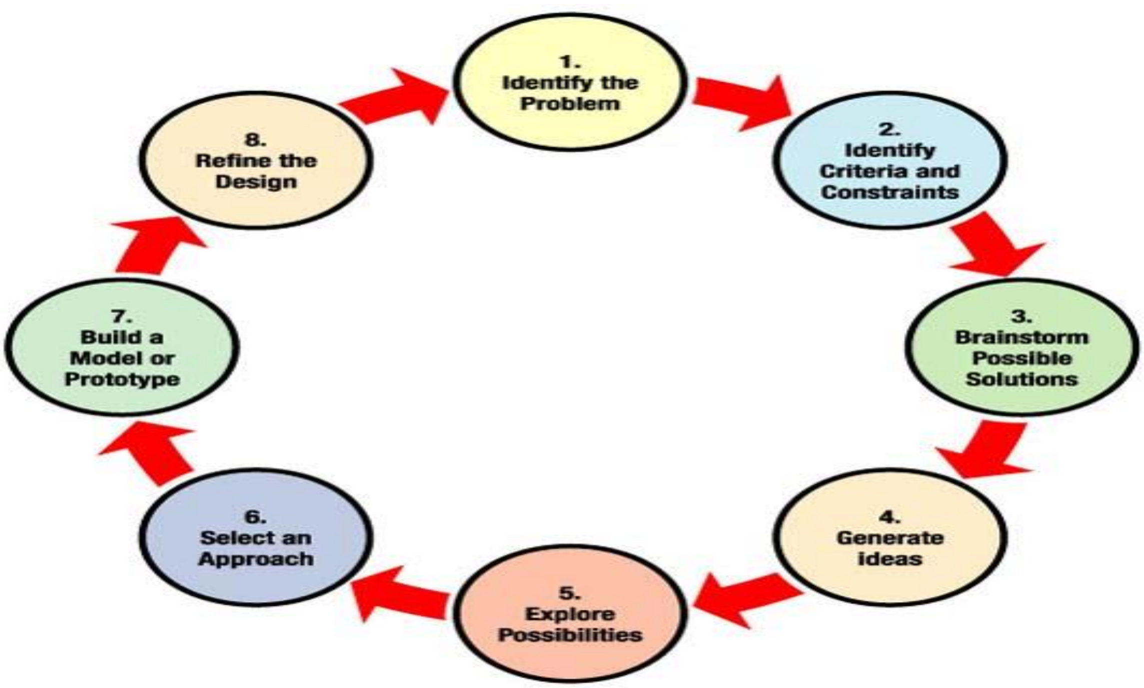


Figure 1: Design Process followed by the students in each project

The importance of understanding the criteria, the requirements of the design, details, and innovation before designing a product is emphasized. As an example, the students must search the bird feeder design (Figure 2) as part of the investigation, research the steps in the design process, and build a house that meets the defined requirements and constraints. As the projects grew more sophisticated, students were paired with other students for whom they will collaborate to reach a final product.

Bird Feeder Design
Problem Statement:
The native habitats of birds continue to suffer as man's technology advances. Many species of birds have special needs in their diet and habitat that continue to be destroyed.
Design Statement:
In an effort to counteract this decline you are to design a bird feeder for a species bird that is native to your area. You must research and take into consideration the following
- Most prevalent predator
- Adult body size and wingspan
- Type of food needed (bird seed, bread crumbs, sunflower seeds)

You will use your knowledge of technical drawing to develop:
- Dimensioned drawings of each part
- An assembly drawing
- An exploded assembly drawing with balloons and a BOM
- A full-size mockup using foam core board
- The retail package design
- Design Portfolio
- Formal sales presentation

Constraints:
- The feeder will have a capacity of between 4-5 cups
- Will have a device which will prevent the birds from nesting in the feeder
- Be able to be either hang from a branch or hook or mounted on a post
- Have a roof that sheds water away from the food
- Be able to be opened so that it can be filled with food
- The mockup will be built out of foam core board
- The retail package will include product features, pictures of the product and/or a transparent plastic window
- Final sales presentation

Figure 2: Example of project

In conjunction with the main objective of learning the design process and some elements of Advanced Manufacturing, math and fundamental science skills are also considered and used to improve the quality of the project. For example, overall heat transfer coefficient of the wall designed is calculated, starting from the simplest calculation, such as calculating the areas of the house walls, floor and other components. Later, the basic of heat transfer, such as conduction, convection, and radiation and their simplified equations are introduced and used to predict the overall heat transfer coefficient of the walls, floor, and roof. Tolerance, criteria, and time constraints are proposed to the students. Tolerance in engineering is the allowable limit or limits of variation into a physical dimension, a physical property of a material (thermal conductivity, density, and specific heat), and of the design object developed.

Thus, students are required to use measurement tools, calculators, and estimation in order to satisfy all the criteria and constraints imposed on them by the instructors at the beginning of each project and also to show that their design is feasible, within the time constraints and fulfill the criteria. The integration between the design and the STEM discipline qualify this course to be considered in the future as a STEM course, since the students apply skills from science and math to engineer solutions and apply different technologies to build their models.

The same course content could be offered using any number of different project ideas, leaving room for instructor creativity. The course is about using tools to solve problems with the understanding that flexibility and innovation are key attributes in the work force. The intent of the course is the same as the consortium for advanced manufacturing (CAM), which is to raise innovation, communication, teamwork, foundational math skills, and other skills needed in the case of high-school students, before they join the workforce or higher-level education. The funds of this outreach program are part of CAM financed by the Department of Energy (DOE).

At the end of the summer camp are oral presentations of all projects, describing the ideas, process, and the criteria used. Two types of oral presentations were made: one where the students express themselves through poems and the second is a final oral presentation describing every step of each project developed, in presence of the parents, family, and friends. Figure 3 represents pictures from the camp.

Lessons learned from summer camp:

The activities of the camp and the degree of their success will be shared with other CAM members to determine the possibility that some of the activities would be implemented on other campuses. Knowing that other campuses in CAM plan to have similar summer camps, we also plan to learn from the success of activities from these camps.

During the summer, twelve high school students and a teacher participated in the summer camp. A number of lessons were learned from that program among which were: 1) High school teacher participation was essential to the success of the workshop, since they provide knowledge and experience on how to deal with high-school students in different levels: educational and behavioral 2) Students were emailed data and information every night that prepared them for the next-day activity. This contributed to the success of the workshop as the students knew exactly the activities of the day and had the files they needed to start the activity. 3) Parents were kept involved by: a) inviting them to a short presentation about the camp on Friday afternoon before the start of the workshop (the workshop started the next Monday) and b) inviting them to their children's presentations. One of the success stories of summer camp is that two of the students who participated in the program were accepted into the Mechanical Engineering program and

School of Technology at our University. They started their program in the following fall semester.

Evaluation and Methodology:

The success of the workshop was demonstrated through different outcomes, such as the two of the students who participated in the program and were later accepted in the Mechanical Engineering program and School of Technology at our University. Similarly, camp students participated in at least two different poster competitions (2017 Appalachian Energy summit, and MSIPP Consortium for Advanced Manufacturing 1^{st}, 2^{nd}, and 3^{rd} Annual CAM Scholar Poster Competitors), utilizing the work learned at the summer camp. These competitions are usually designed for undergraduate and graduate university students.

More evaluation research utilizes mixed-methods approach employing both qualitative and quantitative data sources to determine the impact of the workshop on student learning. Mixed methods designs are methodologically superior to simpler designs because of the ability to leverage the strengths of several different methods. Consistent data from both qualitative and quantitative methods increases the trust worthiness of findings.

Using the indirect course evaluation form, students were asked, anonymously, to self-assess their ability in specific areas identified by the instructor in connection with the course learning objectives, as well as the motivations for the program experience. The compilation of the results of the student self-assessment of course learning objectives questions for this short course is presented in Table 1. The students responded with “5” (Extremely Competent) through “1” (Not Very Competent). In this way, an equivalent class was obtained for each question. The results of the students’ assessments show that for all the questions, students generally felt like they were able to perform the tasks requested. The next step is to check if the assignments performed by the students showed the same positive answers.

The instructor also conducted an evaluation of the performance of students in the course as part of the Program Objectives (PO) and outcome assessment process. A summary report on the performance of students (to meet the program objectives) and compliance with the program outcomes was prepared and submitted to the funding agency (DOE). A more rigorous process in assessing the learning outcomes of this capstone course will be implemented, which are in parallel with the program outcomes. The following outlines the process that will be used for this course assessment:

- Individual instructor evaluation of the degree of learning achievement of individual students on a team, which includes consideration of the collective achievements of the team.

- Peer evaluation (optional by instructor)

- Grading of deliverables by the instructors (projects evaluation, oral presentation, team minutes, and web site if applicable)

- Teamwork survey

- Self-assessment

- Final presentation judging (with evaluation criteria explicitly indexed to the learning objectives and articulated via rubrics for all measures)

The survey assessment of the competence and motivations before and after the class learning objectives show clearly that improvement in terms of competence of the students' modeling, data collection and analysis, and problem-solving. The improvement touched all aspects.

Conclusions and Future Work:

Teaching the engineering design process to high-school students to encourage them toward a career in this area was a successful story, especially since DOE funded us to repeat this experience in the coming years. Our objective is to include both elementary and middle school students.

The main objective is to familiarize students with both advanced manufacturing, 3D-printing and how we can use these topics to design, and solve the new century challenges.

Our objective is to take advantage of all the lessons learned and the experience gained during the first trial to improve the coming camps.

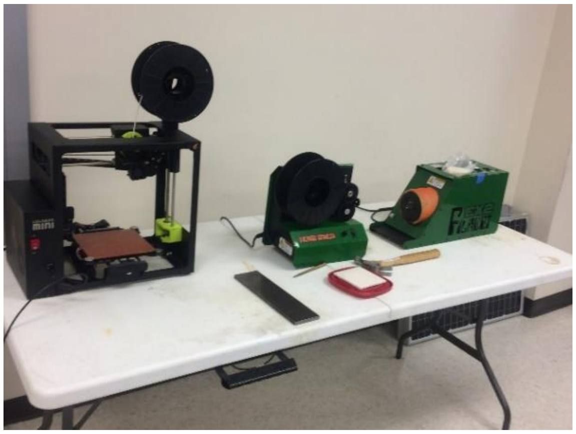
Our purpose for the coming years is to overcome shortcomings and to use the strengths of diverse outreach programs developed during the last year at NCAT (DOE-sponsored). Our objective is to contribute to improving the performance of the students to match the advanced technology in the US.

Our target this time will be elementary and middle school students and their teachers, since it is known that students' attitudes towards mathematics and science develop at a young age and become embedded by middle school. In order to encourage young students to pursue careers in science, technology, engineering, and mathematics, NCAT will develop a program for K-5 students and their teachers. This engineering outreach program will be implemented in predominately minority elementary schools in the Guilford school area. This work will aim to improve students' attitudes towards mathematics and science at a very young age.

The workshop will include multiple interactive activities (active learning) connected to math and sciences and related to 3D-printing, and advanced manufacturing. However, the students will not be exposed to any lectures. The workshop topics include activities related to the use of elementary functions of Autodesk Inventor Software, Energy, Solar panels, Sustainable Manufacturing, Materials, 3D Printing, Electrical Circuits, and Computer-aided Design/ Engineering. The main instructors will be an Elementary school teacher, and NCAT instructors, and industrial representatives. One or two high school students participating in the previous advanced manufacturing workshops and summer camps will also be involved.

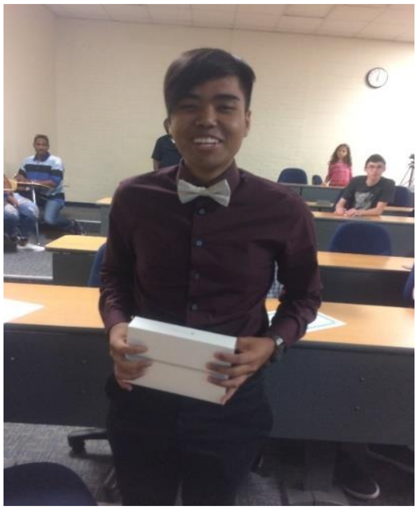
(a) Presentation during the camp

(b) Active learning



(c) Small 3D-printer

(d) Student Presentation



(e) Student Presentation (f) Student with an iPad price for best presentation

(g) Sample of student work

(h) Sample of student work

Figure 3: Pictures from the Summer Camp

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Table 1: Pre-Survey: Results of Indirect Assessment for this short course (12 students in the course)

Indirect Assessment						
Student Self-Assessment of Course Learning Objectives	Extremely Competent (5)	Very Competent (4)	Competent (3)	Becoming Competent (2)	Not Very Competent (1)	Equivalent
The extent to which you feel competent in the following areas:						
Computer Modeling	1	4	6	1		3.42
Laboratory Science	1	1	6	4		2.92
Collecting/Analyzing Data	3	6	3			4
Hypothesis Development	2	4	6			3.67
Problem Solving	3	6	3			4
Motivations for program experience						
Contributes significantly to field of interest	2	5	5			3.75
Desire to improve my skills working with people from diverse backgrounds	2	4	5	1		3.58
My academic advisor of faculty mentor	4	2	6			3.83
To be competitive for college	3	5	3	1		3.83
To be more competitive for the 21st century workforce	5	5	1	1		4.17
To enhance my analytical and research skills	3	7	2			4.08
Desire to learn more about the world	4	5	1	2		3.92
Prior interest	1	10	1			4
Personal Growth	4	4	4			4

Table 2: Post-Survey: Results of Indirect Assessment for this short course (12 students in the course)

Indirect Assessment						
Student Self-Assessment of Course Learning Objectives	Extremely Competent (5)	Very Competent (4)	Competent (3)	Becoming Competent (2)	Not Very Competent (1)	Equivalent
The extent to which you feel competent in the following areas:						
Computer Modeling	5	5	2			4.25
Laboratory Science	3	3	6			3.75
Collecting/Analyzing Data	3	6	1			4.33
Hypothesis Development	2	5	5			3.75
Problem Solving	5	6	1			4.33
Motivations for program experience						
Contributes significantly to field of interest	4	6	2			4.17
Desire to improve my skills working with people from diverse backgrounds	3	6	2	1		3.92
My academic advisor of faculty mentor	4	2	6			3.83
To be competitive for college	4	6	2			4.17
To be more competitive for the 21st century workforce	6	6				4.50
To enhance my analytical and research skills	4	7	1			4.25
Desire to learn more about the world	4	5	1	2		3.92
Prior interest	2	10				4.17
Personal Growth	5	6	1			4.33