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Teaching High-School Students Innovative Topics Related to Advanced Manufacturing and 3D-Printing

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Abstract:

3D printing is considered to be one of the most innovative technologies of the current century, with diverse applications in education, engineering, art, and design.

We conducted a summer teaching class about advanced manufacturing and 3D printing. The project is financed by NNSA (National Nuclear Security Administration), and the Department of Energy DOE. With our summer program, our objective is to serve advanced manufacturing, as evolving technology and to improve STEM education and prepare the new generation of high-school students (future engineers) by the use of the existing tools.

Through the use of programs, such as CREO and Autodesk Inventor, as well as 3D printing concepts, we include both technology and basic traditional STEM knowledge, such as math and science. 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.

The purpose of this paper is to demonstrate the design and implementation of an experiment, from basic parts. In particular, we will discuss several activities performed during this summer camp. This methodology is based on the understanding of the physical phenomena, perform experimentation, and the use of software, such as Autodesk Inventor. Our approach is based on active learning strategies, that emphasis comprehensive understanding, avoiding as possible all the complications of numerical and analytical mathematics needed for such level of study.

Collaborations with high school instructors have been carried out and a methodology has been developed, based on a step by step learning method. At this moment, only two high-school instructors are involved. They enthusiastically help with the process, and at the same time, they are learning with the students, since they never had been exposed to such projects. Their presence was very useful in terms of addressing the appropriate pedagogy, communicating with high-school students, and controlling them in certain circumstances. Their presence is also available for the second explanation, where usually the first explanation from a university faculty is not completely appropriate with their level.

Most importantly, the project methodology will be discussed. We discuss the project design program from 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 terms of learning outcomes is also described. In this paper, we focus only on the second year of the summer camp.

Introduction:

With the support of the United States' Department of Energy (DoE), North Carolina A&T State University has been hosting for many summers years hosting every summer high school students from various Guilford County Schools for a two-week workshop (June 20 to July 3rd, 2019). The aim of the workshop is to introduce these students to engineering-based computer graphics and Additive Manufacturing (3D printing) among other activities. This 2019 summer year, twelve high school students were invited from the following high schools: Eastern Guilford, South East Guilford, High Point Central, Northern Guilford, and NCAT A&T State University STEM Early College. A high school teacher is also invited as an instructor who also actively participates in designing the activities for the workshop.

In the past 4 years, Ms. Michelle Wallace, who is the Architectural and Engineering Drafting teacher at Northern Guilford High School has been working with us. This year Mr. Marvin Morgan who is the Architectural and Engineering Drafting teacher at Eastern Guilford High School also participated in the workshop for a week. Dr. AC Megri who is an associate professor in the Department of Civil, Architectural and Environmental Engineering at NC A&T State University participated in organizing the workshop activities and instructed the students on a number of engineering topics as detailed below. The program usually starts by introducing the students to the main tools in Autodesk Inventor that students use in their designs. This year the students also learned the Tinkercad program. Then the students are given design projects to work on. These projects are either individual or team projects.

During this year's workshop, Dr. Chris Wetteland from the University of Tennessee (Knoxville) spent two days with the students where he did several activities such as using a sputter coater to coat plastic with a layer of gold and how to make filaments for 3D printers using 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.

Ms. Michelle Wallace, as well as Dr. AC Megri, taught the students the basic tools of the Inventor program and developed several lessons to expound the students' understanding of Autodesk Inventor. Students researched and designed tool holders for standard household tools. They also design and virtual assembled a weathervane prototype.

To have a better understanding of Additive Manufacturing, students watched various videos on the history and projected outlook of using 3D printing. Also, students researched various concepts surrounding Additive Manufacturing. Dr. Megri taught the students to stress analysis and, along with Ms. Wallace trained the students on constructing and presenting their work at the end of the workshop. Mr. Morgan worked with the students on several projects: 1) designing and 3D printing tools holder; 2) designing safe children playground equipment. On the last day of the workshop, the students gave PowerPoint presentations on their designs and 3D prints. Parents were invited to the presentations.

Workshop objectives and general description:

The two-week camp is part of a consortium project that includes research, education and outreach programs. More specifically, this program has several objectives:

1) Train high-school students to use the Autodesk Inventor™ 3D CAD computer program, to create technical designs, and teach them how to print designs in 3D using 3D printers.

2) Improve students' STEM skills and Improve students' communication skills

3) Bridging the gap in industry and research laboratories in terms of human resources and qualified personnel.

4) Introduce high-school students to advanced manufacturing (AM) applications to increase their interest in pursuing university degrees that would prepare them for careers in AM.

Each year, the camp brought together twelve high school students (grades 10 and 11) and a high school teacher in a two-week workshop. The goal of the camp is to give students practical experience in modeling and generating engineering designs using the 3D CAD program Autodesk Inventor ™, which is one of the programs used for solid modeling. The program is similar to PTC CREO which is used at Honeywell in Kansas City Plant and many other automotive companies. The workshop takes place in summer (mostly in June/July months). High-school principals and guidance counselors from Guilford County have been contacted so that teachers in their schools can help select participating students. Students included both genders and at least 70% of minority students. The day before the start of the workshop, the students and parents were invited to a welcome meeting where they met the instructors, saw the computer lab and learned about the main activities of the camp.

During the first three days of the camp, students learned the basic tools of the Inventor program. After that, each student performs multiple designs and projects proposed by the instructors in a progressive and interactive way. These projects are obtained from multiple sources and the industry, including the Autodesk Design Academy (https://academy.autodesk.com). At least one of each student's creations has been 3D printed. Some of the designs were printed on a Fortus 400mc 3D printer. Students also had access to the newly acquired ErinScan-Pro portable 3D scanner.

Without deep mathematics knowledge, students were able to conceptualize, customize and prototype their design. The visual nature of these tools (Autodesk Inventor) and the 3D printing technology enabled high-school students to grasp the technology and concepts very quickly (figure 1).

On the last day of camp, each group of students gave a twenty-minute PowerPoint presentation on their design, followed by a ten-minute discussion during which the student is expected to advocate the use of certain tools or features in their design. Parents were invited to the presentations (figures 2 &3).

Figure 1 (a): camp activities

Figure 1 (b): camp activities

Figure 2 (a): last day presentation

Figure 2 (b): last day presentation

Figure 3 (a): last day presentation

Figure 3 (b): last day presentation

Workshop Activities:

Camp activities are organized to facilitate progressive learning and benefit all categories of students, using active learning and avoiding any form of boredom through the inclusion of additional activities that promote learning and focus on the goals of the camp.

Realistic projects: the projects given to students are progressive and aims to teach them the functionally of the software as well as the design process. Creativity is also one of the objectives. They start with designing a "Vase" vs. a "Cup" object, where straight and spline lines to form realistic shape has been introduced. Other functions, such as offset, revolve, creating geometric forms in different plans, and sweep are all used in this project.

The second project was mostly related to several types of Legos with different sizes, colors, and functionality. In this project, students learn how to create a composite system using several shapes of Legos, such as cars, planes, robots, or even animals. Later, the students perform 2D and 3D-plans and views representing their projects.

The third project was mostly related to a realistic design project, where the students need to select three to four hooks for separate tools, from a bank of tools brought to the classroom by the instructors. The instructors brought tools from their homes (figure 4), as well as Vernier Calipers to measure tools to determine the dimensions and the shape of the hooks. The students had a quick lesson in Caliper reading. The students are required to have goals and action plans written in their notebooks.

The students need to make 3-4 hooks (figure 5) for a separate tool. Using innovation, where every student needs to make his own design. Then print them to test them out on a real pegboard. Stress analysis (figure 6) to test how strong the hook was to hold the objects has been performed. As well, under this project, each student needs to perform a study related to a challenge, such as "select the appropriate material for the hooks, if such hooks are used under very low temperature".

Other projects (Figure 7), such as weather vane, playground, and name tag, have been developed (figure). The weather vane is made up of 5 main parts and a topper, including the base, the pole, the direction indicator north, east, south, and west, the small end screw top to close the connector and a part to connect the indicators. Lastly, the students had to assemble all the pieces together.

Figure 4: 3D-Printing and tools

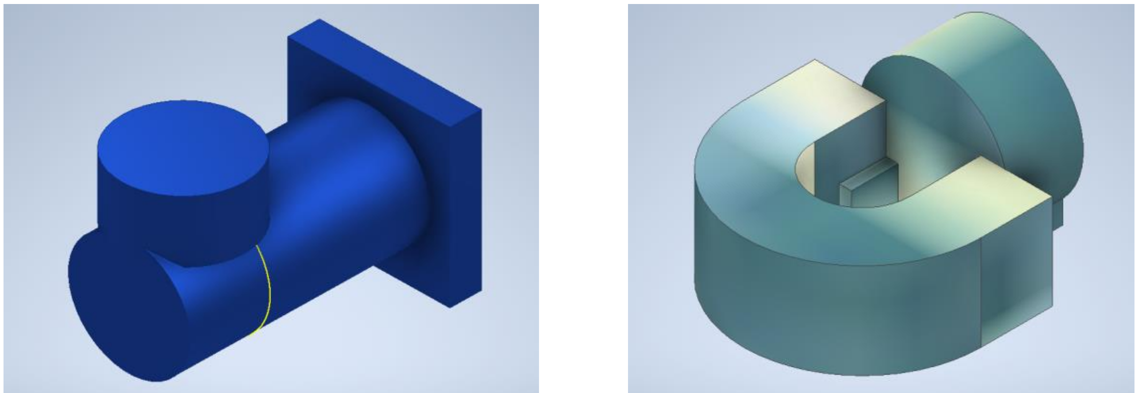
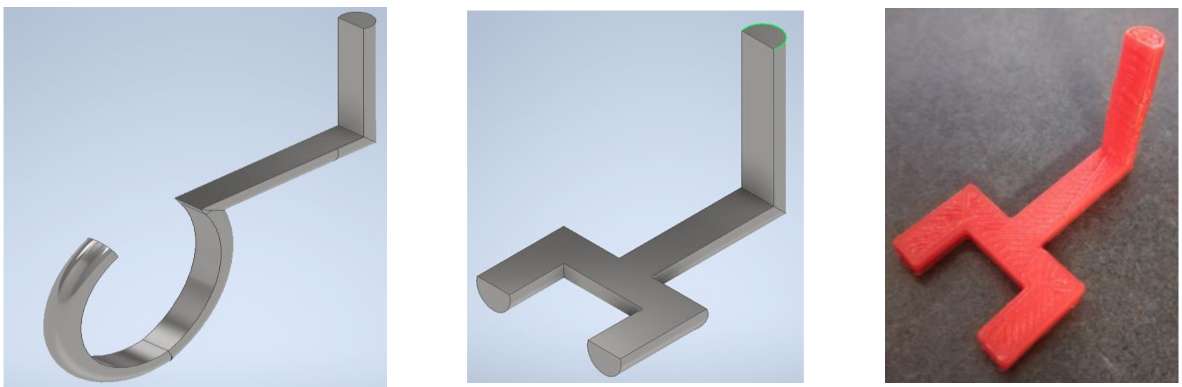


Figure 5: (a) Double Sided Box Head Wrench (b) Adjustable Wrench



(c) Military Flash Light (d) Spline Roller (model and printed version)

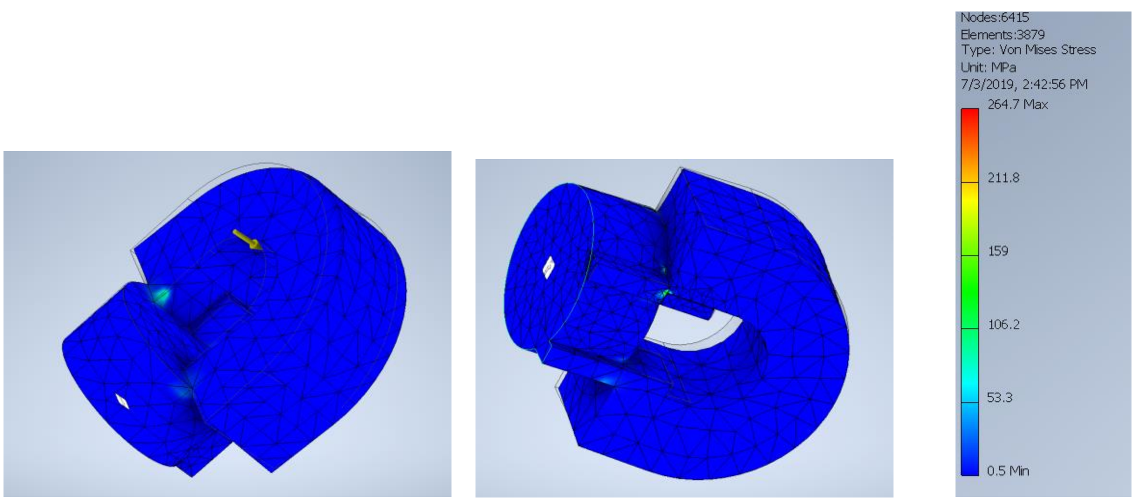


Figure 6: Stresses at the connections

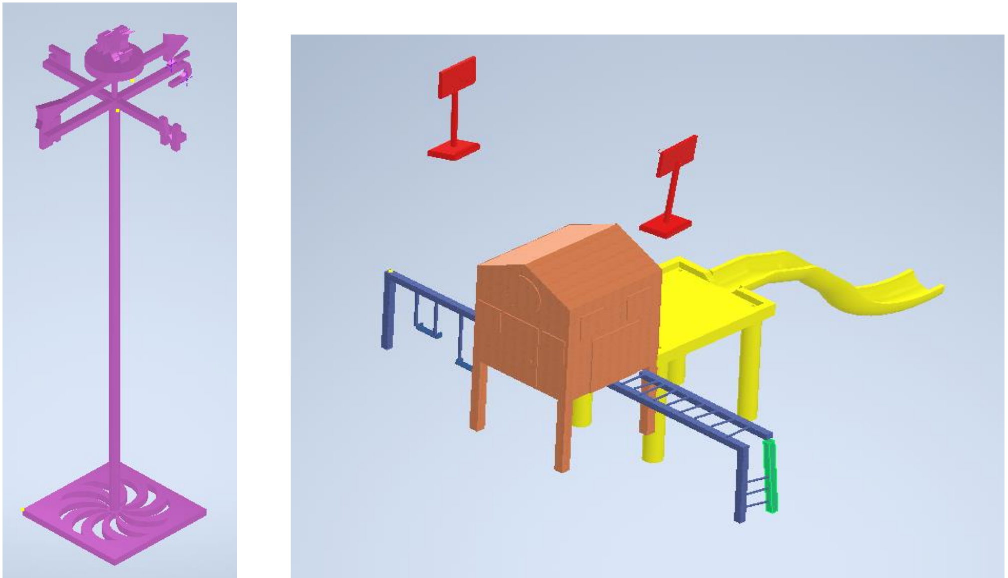


Figure 7: Extra projects performed by the students

One question to address by each group: each group was assigned to perform research about a specific question, such as "what are the benefits of additive manufacturing?"

Extruder: each student has the opportunity to use "A spooler" (Figure 8), which allows them to make their own filament. This machine includes a traverse mechanism that guarantees even filament distribution across the spool. It is variable speed control, so it allows students to adjust the appropriate speed to allow a better filament production that does not broke and without defect.

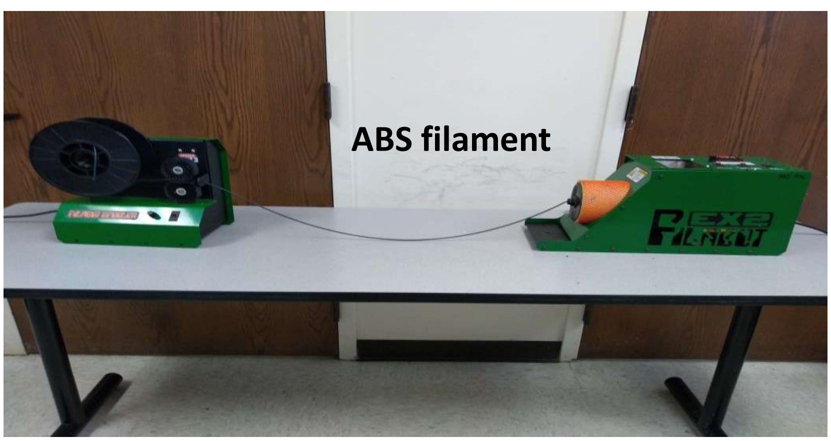


Figure 8: Extruder using raw material

3D-print gold coating: The students used a Sputter deposition (figure 9) is a vacuum deposition technology commonly used to obtain metallic or ceramic coatings. Sputtering deposition exists in many variants, the name of which depends on the spray sources used and on certain technological modifications.

The gold layers obtained by spraying can be added so as to obtain multilayer coatings. This is particularly useful if we are looking to combine the advantages of these different materials, such as hardness, resistance to oxidation, and temperature resistance. In industry, the most effective mechanical anti-wear coatings are designed in this way.

Ice cream using liquid nitrogen: one of the extra activities is the use of nitrogen and solar-panel to make ice cream for each student after a busy day of work (figure 10).

3D-scanner / lab visit: The students did visit a structural lab, where experimentation performed on beams using a robot for NDT (non-destructive testing) experimentation (figure 11). Two Ph.D. students did perform the presentation to the students about NDT and its use in civil engineering.

Other activities are related to the use of a scanner, the use of an extruder to prepare 3D-printer filament, lab visit, prepare a poem on a subject related to 3D-printing, and answer a question related to advanced manufacturing.

Poem related to 3D printing: Each group of the student asked to prepare a poem to describe a story related to 3D-printing.

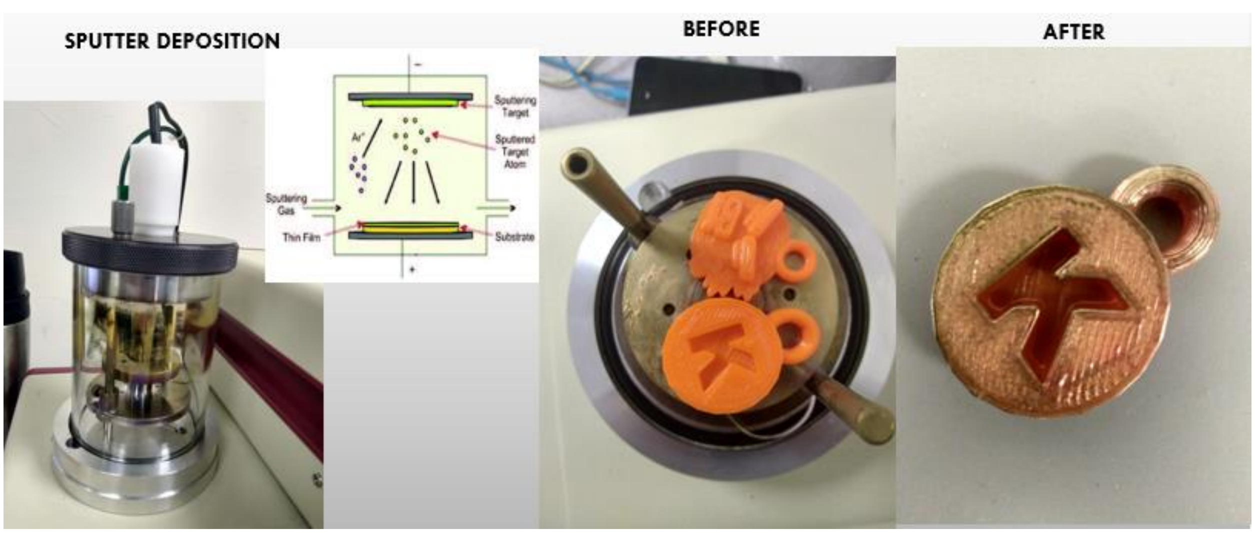


Figure 9: 3D-print Gold coating

Figure 10: Ice Cream preparation

Figure 11: NDT (non-destructive Testing) Robot to scan the concrete surface.

PowerPoint presentation and poem (6 groups): The 12 students were divided into 6 groups to prepare and present their work, to reduce the time of presentations and allow students to collaborate and learn how to work in a team. The groups are selected randomly and the preparation of the PowerPoint presentation were done under the supervision of the faculty and high-school instructors.

Oral Communication Learning Goal**:** A goal of the summer camp is the development of oral communication skills. An oral presentation is performed on the last day of the camp. The students are prepared for effective communication (figure 2 and 3).

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 later accepted in the mechanical engineering program and school of technology at our University. Other than that, the participation of the camp students to at least two different poster competitions (Appalachian Energy summit, 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.

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-evaluation, as well as parents' evaluation of course learning objectives questions for this summer camp are presented in figure 12 and 13 (Outcome 3 from ABET).

Conclusions:

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.

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

What is most significant about this summer camp is its comprehensiveness, since we developed a learning program around the design process, during which students developed sketches and then used software to design them and print them. After all, they learn to make a clear and professional presentation and to defend their ideas and works.

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), and to contribute to improving the performance of the students to match the advanced technology in the US.

The workshop did include multiple interactive activities (active learning) connected to math and sciences and related to 3D-printing, and advanced manufacturing. 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.

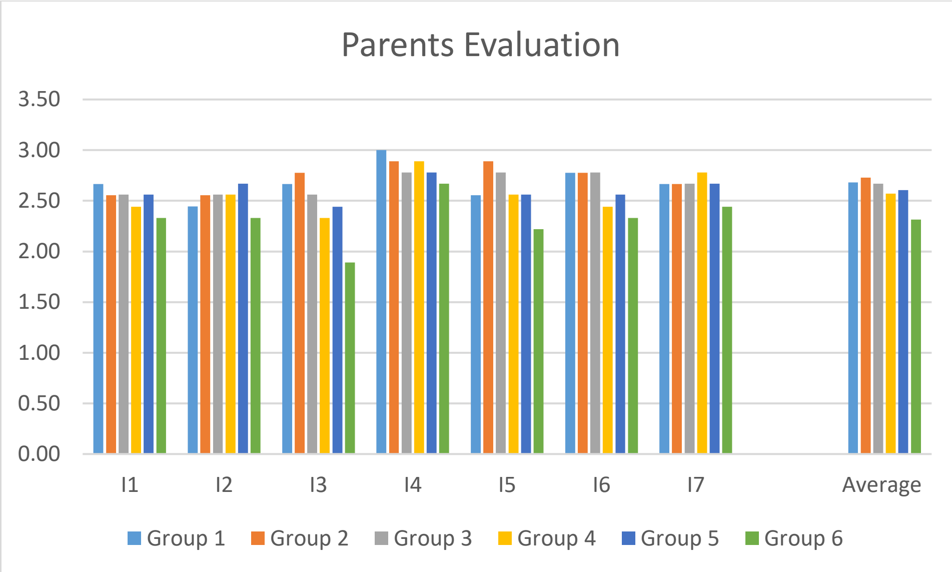


Figure 12: Parents' evaluation of the oral presentation (0 is the worse and 3 is the best), according to ABET criteria 3 (the students are divided in six groups).

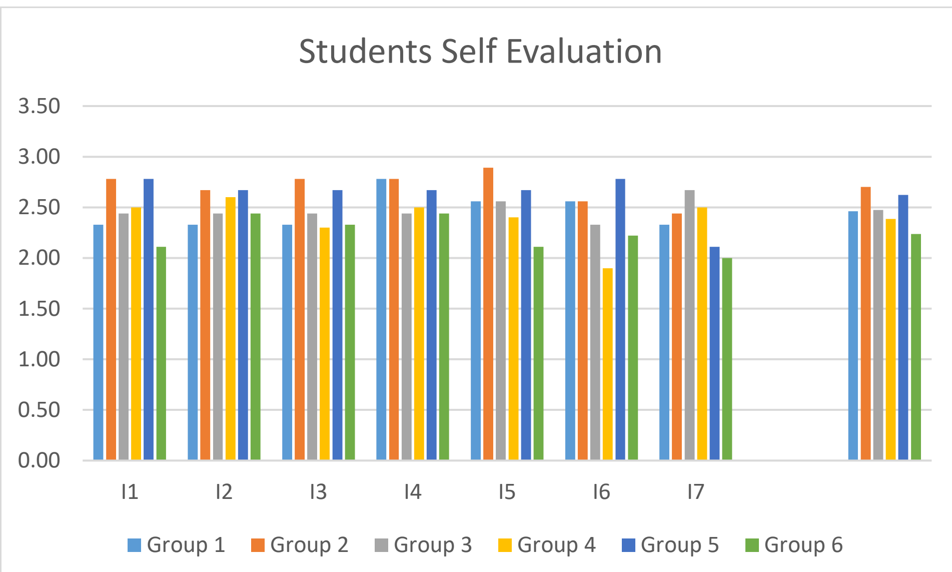


Figure 13: Students' self-evaluation of the oral presentation (0 is the worse and 3 is the best), according to ABET criteria 3 (the students are divided in six groups).

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