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Undergraduate Engineering Design Projects that Involve Inter-Departmental Collaboration

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Abstract:

This paper reports on a collaborative engineering projects involving undergraduate engineering students. The focus of the paper is on an undergraduate freshman-level mechanical engineering graphics course whereby the students had the task of designing and modeling a 3-D printer constructed of standard purchased and fabricated components. The goal of the project is to design a 3-D printer with a total cost of under $150. The graphics class is organized into various engineering groups with specific design functions assigned to each group. The project is led by a Chief Engineer whose task is to perform design reviews and keep the entire group on schedule. The graphics class worked closely with a student led Robotic Development Group, the Computer and Information Science Department (CIS) and the Electrical Engineering Department (EE). Ultimately more than fifty local high school students were able to build a low-cost 3-D printer as part of the student-led group summer STEM program. The design project is extremely valuable in teaching the importance of collaboration with multiple departments, project organization and timing as well as tolerancing, manufacturing techniques, fits and producing detailed engineering drawings. Finally, the design project supported the ABET Student Outcome 5 and 7: ability to function effectively on a team and ability to acquire new knowledge[1]. These outcomes are assessed with an in-class survey and results reported.

1. Introduction

Project collaboration is an essential part of the engineering education in order to help students develop professional and technical communication skills, leadership skills, and conflict resolution skills. This paper presents an interdisciplinary collaborative design project. The project, design of a low-cost 3D-printer, is a collaborative project used to evaluate students in a freshman-level engineering graphics course.

Team member efforts to understand and appreciate the contributions and various disciplinary frameworks of other team members are essential for interdisciplinary collaborations[2]. A study by Ritcher and Parattie[3], explored interdisciplinary learning by conducting a case study in a university class involving students from different disciplines. They discovered two main learning obstacles related to interdisciplinary collaboration. The first obstacle is students fail to recognize the relationship between their own discipline and how it relates to an interdisciplinary project. The second obstacle is students fail to recognize the value that other technical (and non-technical) disciplines may offer. Collaborative projects involving multiple disciplines may present challenges to students. Not only is the learning setting unique but students are exposed to new members with different skill-sets and disciplines while trying to jointly achieve project timelines and goals. Complex engineering projects are especially difficult to manage when there are multiple groups with various tasks. In the professional world, complex engineering projects are usually carried out by different work teams and members with a variety of technical backgrounds across geographically distant locations. Engineers can be better prepared for the challenge of working on interdisciplinary teams in industry if they are exposed to interdisciplinary projects as part of their education.

Institutions have unique ways of presenting this experience to students. Probst and Gerhard[4] provide insight into the education of mechanical engineering design students using product data management (PDM) systems. PDM-software is used extensively to manage large projects involving multiple students from different colleges and different disciplines. All files (CAD, drawings, design specifications and calculatins) are stored and maintained with the PDM system. All members of the large design team have access to all the information through the PDM system. The PDM system offers a great solution to keep large projects organized and on schedule. Martinez et al., describes using a Collaborative Web environment to manage a complex engineering project carried out by the assimilation of various work teams[5]. Finally, Oden et al, describes Rice University's efforts to implement and evaluate outcomes from collaboratively teaching capstone design and assigning interdisciplinary teams to solve real-world design challenges[6]. Rice University Brown School of Engineering opened a facility, the Oshman Engineering Design Kitchen (OEDK) which is dedicated to undergraduate engineering design efforts. The facility has space for all 8 engineering department with the goal of offering interdisciplinary design opportunities to the students.

2. Design of Low-Cost 3D Printer

The design of a low cost 3D printer was a collaborative project between a freshman level mechanical engineering graphics class and GUBotDev[7]. GUBotDev, short for the Gannon University Robotic Development Group, produced an initial "rough" prototype of the low-cost 3D printer by using off-the-shelf and fabricated components. The printer was too expensive and unreliable to be used for outreach purposes.

GUBotDev is a student group formed in 2014 at Gannon University focused on STEM outreach. The group focuses on modern technologies and is open to any engineering student interested in designing automated machines, piloting aerial vehicles, creating artificial intelligence, using 3D printers, or programming robots and drones through modern technology such as artificial intelligence, airborne automatons including multi-rotor and fixed-wing aircraft, 3D printing and other rapid prototyping technologies. GuBotDev has been described as a "playground" for engineering students and occupies a 1,000 sq. ft lab. One of the biggest strengths of GuBotDev is the cross-disciplined composition. GUBotDev boasts members with multiple engineering backgrounds, including electrical, mechanical, biomedical, industrial, and software engineering. An important role (and source of funding) for the group is outreach. The group takes part in dozens of outreach events a year. The 3D printer was designed so the group could teach local high school students how to build and operate their own machine. The added bonus is, due to cost, the students were able to take their 3D printers home with them. Figure 1a shows the initial fabricated prototype and Figure 1b shows the final "production" (kit) version after the collaborative project was completed.

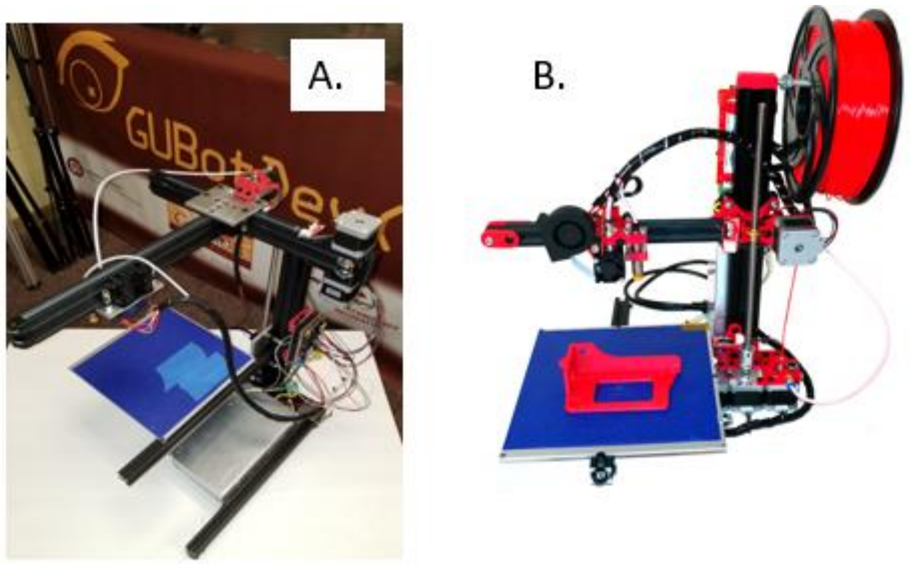


Figure 1: 3D Low-cost printer, a) Initial fabricated design, b) Final production (kit) version

The freshman engineering graphics course is a 16-week course covering fundamentals of engineering graphics. The first four weeks of the course focuses on the basics of sketching, orthographic and isometric projections and dimensioning rules. The next seven weeks consists of intense CAD training with ProEngineer Creo. Students spend approximately 5 hours per week in a lab environment learning fundamentals of solid modeling, subassemblies and assemblies, bill of material and engineering drawing creation. Tutorials and numerous in-class lab exercises are used to teach students proper feature-based modeling techniques, constraints, design intent, etc. At the end of week 11, students are assigned their semester design project. The students have 5 weeks to complete the design project.

In the past, a wide range of design projects were given at the end of week 11. Some years, students were given the same project but had to complete it alone. Other years, students were allowed to pick their own design project (usually related to their hobby or something of interest). Depending on the complexity of the product (# of components, etc.), students worked alone or with a partner. The product or device chosen had to consist of at least 5 components. Regardless of the project, detailed drawings were required for each component; submitted in a well-organized design binder with CAD files at the completion of the project. Figure 2 shows some of the design projects given to students in the past.

These CAD projects are discussed in great detail in reference 8 – a paper on self-directed learning: "Self-directed learning (SDL) is essentially the learner initiating the learning. The learner makes the decisions on how, when and where training occurs. The learner sets his or her own learning goals, objectives and methods. The need for self-directed learning becomes ever more important as the complexity and capability of engineering software increases."

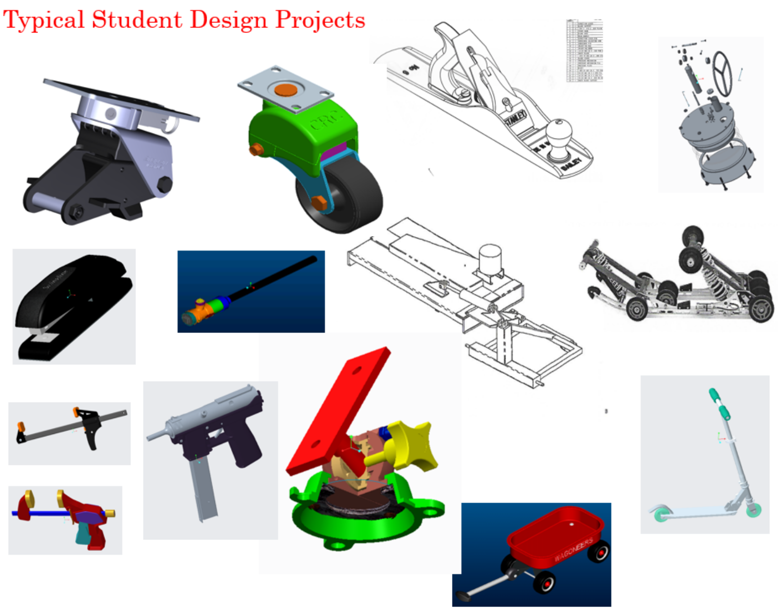


Figure 2: Typical design projects from past years. Students may work alone or with a partner depending on the complexity of product.

The 3D printer design project discussed in this paper was unique in that:

1. The entire class of 13 worked on the same project versus solo or with a partner like past projects.
2. The project was collaborative (13 students working together) and interdisciplinary since the class worked closely with GuBotDev. Again, GUBotDev boasts members with multiple engineering backgrounds, including electrical, mechanical, biomedical, industrial, and software engineering.

Around week 10, members of GuBotDev visited the graphics class and provided an overview of the 3D printer. The group provided a detailed overview of generation 1, the initial "rough" prototype shown in Figure 1.a. GuBotDev then provided the graphics class with a detailed list of design requirements, including:

1. Build volume must be 8" x 8" x 6"
2. Use as many purchased components as possible including printing head, bearings, lead screws, stepper motors, etc.
3. Use standard 3D printing materials and filaments such as poly lactic acid (PLA) and acrylonitrile butadiene styrene (ABS)
4. Make design improvements to improve durability
5. Provide complete CAD design including stereo lithography (.stl) files for ALL fabricated (manufactured) components. Include detailed drawings for all fabricated components.
6. Target cost < $150
7. Provide complete documentation including 3D pdf files for presentation purposes.
8. Create complete Bill of Material (BOM) detailing purchased and fabricated components.

After the initial meeting, members of GuBotDev continued to visit the graphics class on an ongoing weekly basis to monitor progress, answer questions and make suggestions. Electrical and software engineering students from GuBotDev worked closely with the graphics class explaining programming and flashing firmware, wiring and basic operation of the printer.

The graphics class was composed of 13 students. The class was divided into 3 groups of 4 students with one student designated as the Chief Engineer. In terms of logistics, the 3D printer was broken up into 3 main subassemblies: horizontal gantry or y-axis (including the base), vertical gantry or z-axis and lateral gantry or x-axis. Each group was then assigned one of the subassemblies. The group was responsible for the complete design of that subassembly – see Figure 3. Shortly after designating the subassemblies, the entire class created a master Gantt chart (see Figure 4). The Gantt chart shows an aggressive schedule necessary the complete the project in 5 weeks (end of semester).

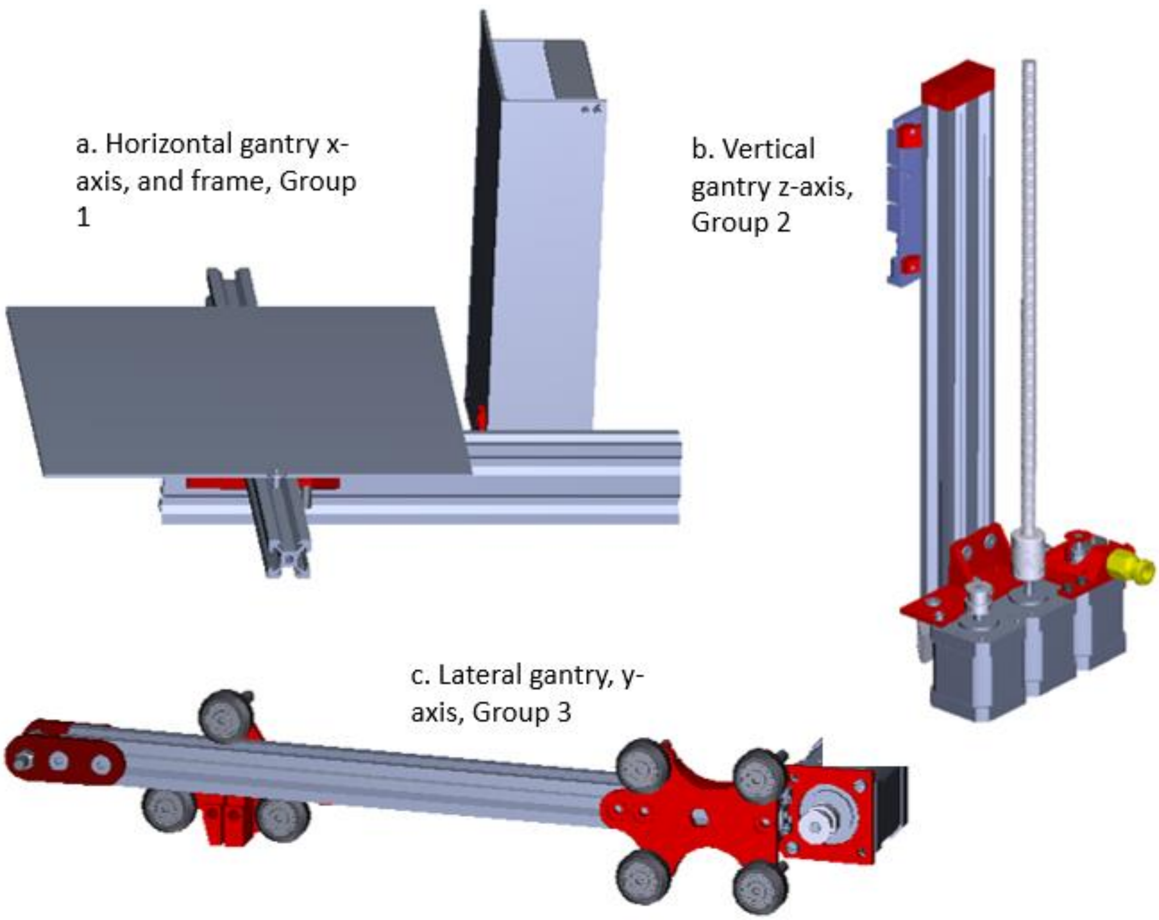
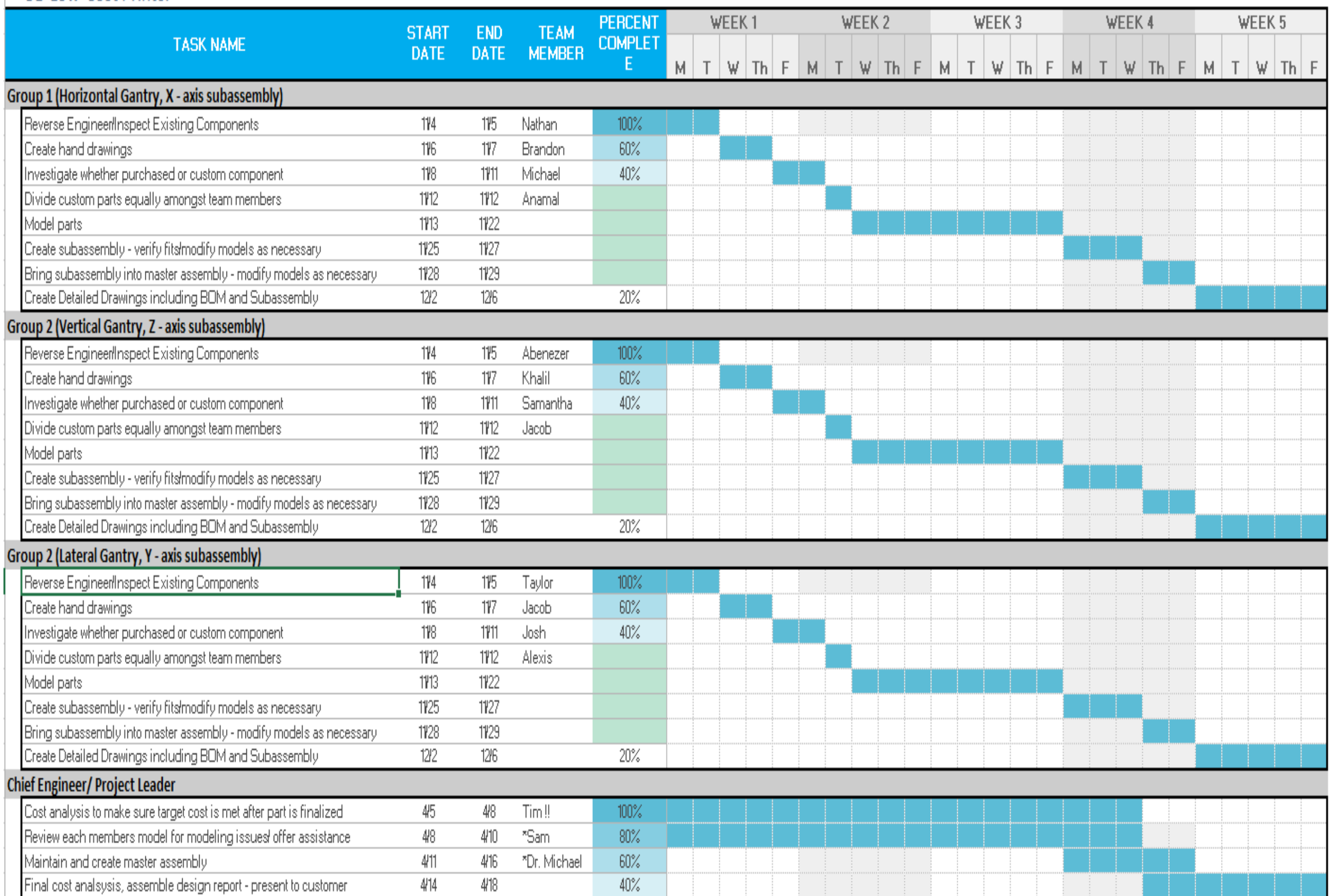


Figure 3: Subassemblies by group, a) horizontal gantry assigned to group 1, b) vertical gantry assigned to group 2, c) lateral gantry assigned to group 3



3D Low-Cost Printer

TASK NAME	START DATE	END DATE	TEAM MEMBER	PERCENT COMPLETE
Group 1 (Horizontal Gantry, X - axis subassembly)				
Reverse Engineer/Inspect Existing Components	11/4	11/5	Nathan	100%
Create hand drawings	11/6	11/7	Brandon	60%
Investigate whether purchased or custom component	11/8	11/11	Michael	40%
Divide custom parts equally amongst team members	11/12	11/12	Anamal	
Model parts	11/13	11/22		
Create subassembly - verify fits/modify models as necessary	11/25	11/27		
Bring subassembly into master assembly - modify models as necessary	11/28	11/29		
Create Detailed Drawings including BOM and Subassembly	12/2	12/6		20%
Group 2 (Vertical Gantry, Z - axis subassembly)				
Reverse Engineer/Inspect Existing Components	11/4	11/5	Abenezer	100%
Create hand drawings	11/6	11/7	Khalil	60%
Investigate whether purchased or custom component	11/8	11/11	Samantha	40%
Divide custom parts equally amongst team members	11/12	11/12	Jacob	
Model parts	11/13	11/22		
Create subassembly - verify fits/modify models as necessary	11/25	11/27		
Bring subassembly into master assembly - modify models as necessary	11/28	11/29		
Create Detailed Drawings including BOM and Subassembly	12/2	12/6		20%
Group 2 (Lateral Gantry, Y - axis subassembly)				
Reverse Engineer/Inspect Existing Components	11/4	11/5	Taylor	100%
Create hand drawings	11/6	11/7	Jacob	60%
Investigate whether purchased or custom component	11/8	11/11	Josh	40%
Divide custom parts equally amongst team members	11/12	11/12	Alexis	
Model parts	11/13	11/22		
Create subassembly - verify fits/modify models as necessary	11/25	11/27		
Bring subassembly into master assembly - modify models as necessary	11/28	11/29		
Create Detailed Drawings including BOM and Subassembly	12/2	12/6		20%
Chief Engineer/ Project Leader				
Cost analysis to make sure target cost is met after part is finalized	4/5	4/8	Tim !!	100%
Review each members model for modeling issues/ offer assistance	4/8	4/10	*Sam	80%
Maintain and create master assembly	4/11	4/16	*Dr. Michael	60%
Final cost analsysis, assemble design report - present to customer	4/14	4/18		40%

*Sam = lab assistant, Dr. Michael = course instructor, primarily helped with item 2, modeling issues. Also, occassionaly reviewed drawings to make sure proper dimensioning standards were used.

Figure 4: Master Gantt chart for low-cost 3D printer showing 5-week completion date.

Week 1 was spent reverse engineering existing components and creating hand sketches. At this point it was determined if components could be purchased or had to be fabricated as custom components. For fabricated components, mini design reviews were held with the instructor and lab manager (an experienced machinist) to make sure parts were designed as cost-effectively as possible. Each student within the group was expected to create CAD models and detailed drawings using Pro/E Creo parametric software. A Group Leader was assigned for each group. The number of parts for each subassembly were totaled and divided equally among the student group members and assigned within the group. The exact number of parts each team member was responsible for may vary based on part complexity. This was done to try to balance workload. Parts used in multiple assemblies such as the v-rails and the wheels for the extruder and slide rail were shared amongst all 3 groups. Each group member spent approximately 3 weeks creating their individual parts and drawings. The Group Leader from each of the 3 groups was responsible for reviewing and collecting the CAD models and drawings from group members. Tolerances were established to yield necessary fits between parts.

Finally, once parts were finalized, a subassembly was created with a detailed assembly drawing and BOM. This information was then forwarded to the Chief Engineer.

The Chief Engineer had multiple responsibilities and roles. He was responsible for making sure the team was on schedule per the Gantt chart. Additionally, he worked closely with each team member and group leader to make sure parts were modeled properly and drawings were dimensioned properly. The Chief Engineer was responsible for creating the master assembly which consisted of all of the group's subassemblies. The Chief Engineer created a design binder and submitted the final complete assembly along with each of the CAD drawings from the students to the instructor for the final grade. The Chief Engineer was also responsible for maintaining cost spreadsheets and making sure the target cost of $150 was met. The Chief Engineer worked closely with the instructor and GuBotDev to make sure all the project requirements were met.

Ultimately all the design objectives established by GuBotDev were achieved. The final submitted model is shown in Figure 5. The final 3D fabricated printer is shown in Figure 1.b.

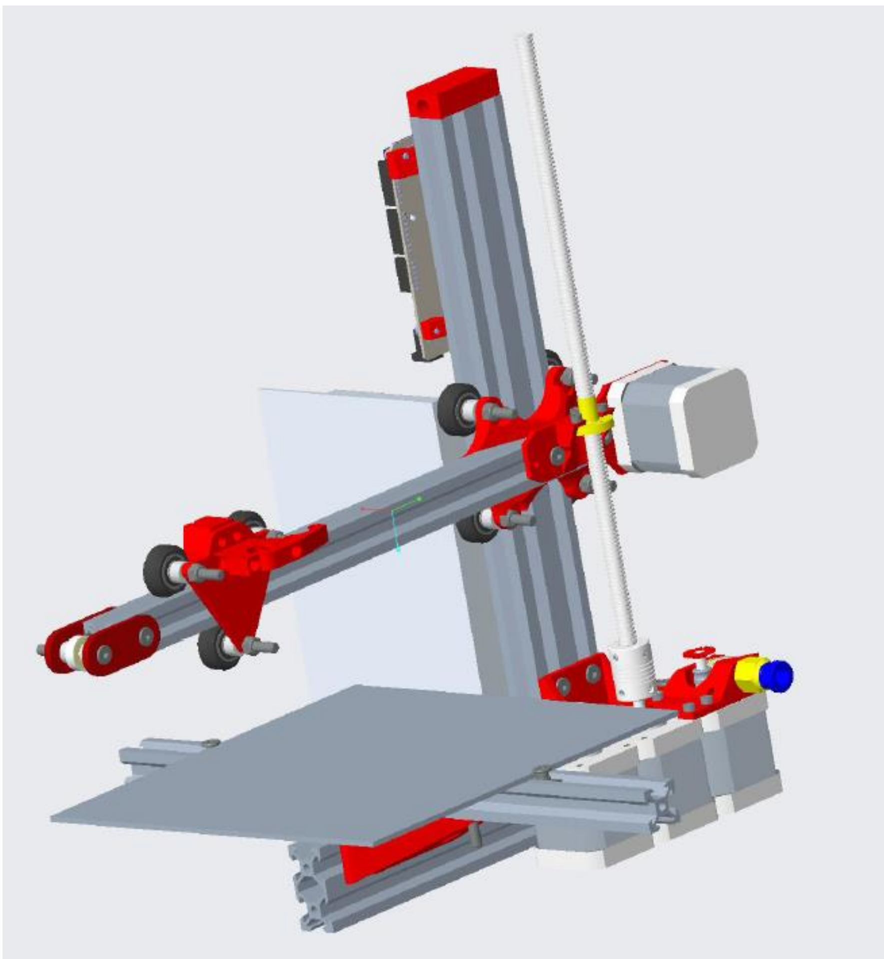


Figure 5: Final CAD assembly of 3-D low cost printer meeting all design requirements.

3. Assessment

An 11-question survey was given to the class for assessment purposes. Some of the questions (1 – 7) were assessed at both the initiation and completion of project. These questions are listed below:

Assessment Questions:

1. Ability to create solid CAD models.
2. Ability to create assemblies and sub-assemblies.
3. Ability to create detailed engineering drawings.
4. Ability to understand tolerances and fits and how they impact assembled parts.
5. Ability to use measuring instruments to inspect and reverse engineer parts.
6. Ability to understand how electronic design and mechanical design are integrated to produce complex machines.
7. Ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
8. Every group in class participated equally.
9. Every person in my group participated equally.
10. As a result of this project, I have a better understanding of the amount of work involved to design a complex machine.
11. Having the entire class work on a single collaborative project is a better learning experience vs. every person working on individual projects.

Students rated the questions above on a scale from 1 – 5 where a 1 was *strongly disagree* and a 5 was *strongly agree*. Results from the assessment survey are shown in Figure 6 below:

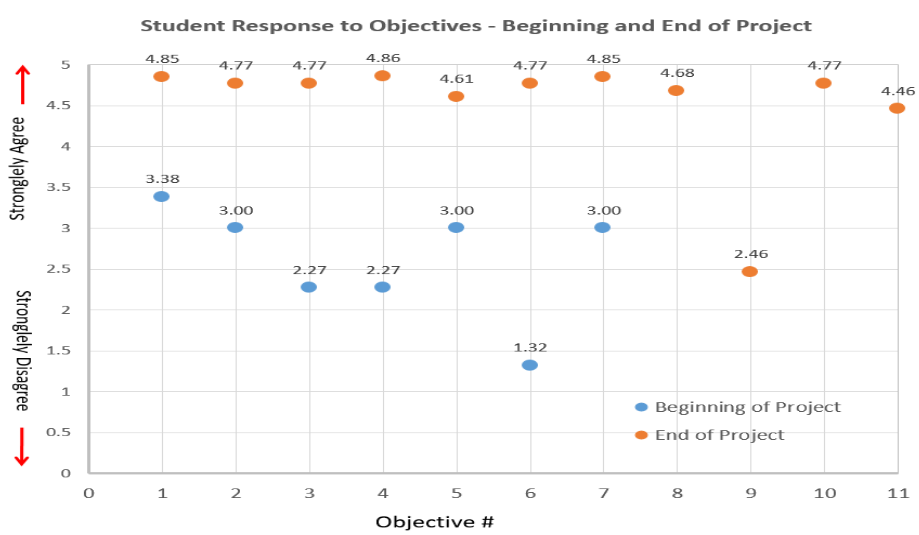


Figure 6: Course survey, before (blue) and after (orange) project

The survey results shown in Figure 6 support the following conclusions:

1. Without exception, students report an improvement in CAD related skills after completing the project. From questions 1 – 7, all CAD related skills increase when results at the beginning of the project are compared to results after project completion.
2. The biggest improvement reported is with Objective 6: Ability to understand how electronic design and mechanical design are integrated to produce complex machines. At the start of the project, the average response was 1.32. After completion of the project, the average response was 4.77 – an increase of 3.45.
3. Objective 7: "Ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" received an average response of 4.85. This is an important survey question as it directly relates to ABET student outcome 5: "ability to function on a team."[1]
4. Objective 9 had a low rating of 2.46 suggesting students felt that member(s) in their own group did not equally share in the workload. Written comments suggested that this may be due to the complexity of the parts. Some students had design responsibility for parts that were significantly more complicated which is just the nature of the design.
5. Interestingly though in contrast to Objective 9, Objective 10 had a high rating of 4.77 which suggests that students felt that design responsibility was equally shared amongst all three groups.
6. Objective 11 suggests that the students support having the entire class work on a large collaborative project versus individual projects as detailed in reference 8.
7. One written comment that consistently appeared on at least half of the surveys was the unfair workload the project placed on the Chief Engineer. As mentioned above, the Chief Engineer had multiple responsibilities and roles. He was responsible for reviewing all the part files and drawings, maintaining the schedule, interacting with the customer (GuBotDev), meeting price target (<$150), creating the master assembly and BOM, etc. A tremendous workload was placed on this individual. If a large collaborative project is given again, the role of the Chief Engineer will have to be modified to reduce his/her responsibilities.

4. Conclusions:

This project not only showcased the skills students acquired within the Engineering Graphics Course; this project also taught students the value of effectively working in a large team environment, collaborating with multiple disciplines, meeting deadlines, and completing a 3D printer to design specifications. Ultimately, the customer (GUBotDev), received an improvement upon their original design with proper documentation for all the parts used within the printer. Drawings, models and .stl files were provide which enables GuBotDev to fabricate parts to specifications or in some cases simply 3D print parts with the .stl files. The cost target of $150 was met.

The survey (assessment) showed strong agreement for all the Objectives related to improvements in CAD skills. The assessment also suggested one notable challenge of this project was the unequal distribution of individual part difficulty. Some parts were as simple as a plate with a few holes, while other parts such as the head of the 3D printer was more difficult. A solution to this problem is classifying parts by the number of features required within the model tree on the CAD software. Each student would then be asked to complete at least one part with an easy, intermediate, and advanced difficulty level. An easy part would have 5 features or less. An intermediate part could have between 5 and 10 features. An advanced part would have greater than 10 features. This is just a sample scale and could be adjusted based on the product and complexity. Another challenge for a large group project was the amount of work required by the Chief Engineer. Managing the entire project turned out to be quite stressful for this individual. In the future, the role of the Chief Engineer will be redefined to include fewer responsibilities (i.e. task a subcommittee for tracking and meeting cost target).

Ultimately fifty high school students from Erie County built the low-cost 3-D printers with help from Gannon University engineering students.[9] The Gannon engineering students through their GuBotDev organization, extended their expertise beyond their own classroom and into the community.

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