The Development of a Framework for 3D Printing, Casting, and Entrepreneurship

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1. Abstract

Casting is one of the oldest manufacturing processes. 3D Printing is known as one of the newest technologies used in the manufacturing field, and it is almost thirty years old. Although both technologies are commonly used in various fields of industry and daily life, this research study reports a unique implementation of both technologies in a new entrepreneurial environment. The entire study had been performed in Summer 2016 as part of the Research Experiences for Teachers (RET) Supplement of a National Science foundation (NSF) funded project. In ten weeks of extensive design, 3D Printing, and casting studies, several best practices between the P16 educators and students have been established. As a follow-up, a local high school also received an equipment grant to establish similar design and 3D Printing practices for its students. This current paper will report the accomplishments of the summer RET project and its reflections from the teacher's side.

2. Introduction

Manufacturing and Techno-Entrepreneurship Program is one of the two NSF funded Research Experiences for Undergraduates (REU) Site at Tennessee Tech University[1]. Each year, about ten undergraduate students perform cutting-edge manufacturing research related to techno-entrepreneurship with intensive programs in facility tours, a lean launch pad course, and guest lectures. In 2016, one high school teacher was added into the program as part of an RET Supplement provided by NSF. The three primary focuses of the RET supplemental research were: 1) To study the viability of the sand casting process in the 21st century; 2) To test the efficiency and effectiveness of rapid prototyping, combining the modern technologies of 3D Printing with the sand casting process; and 3) To assist a Tennessee Tech engineering student, who has already started a personal casting and smithing business, with his entrepreneurial endeavors.

3. Process Overview

In this project, prototypes of various designs were printed with 3D printers and then cast in three metals. Before the prototype tool or object could be printed, it had to be designed. The prototypes were designed with a variety of programs. Dassault Systèm's SolidWorks and Autodesk's AutoCAD, both of which are industry standard 3D modeling software programs, were used to create the majority of the prototype models. SketchUp, a free, yet powerful 3D modeling program, marketed based on its ease of use, was also used to create prototypes.

4. 3D Printing Prototypes

"3D printing is a unique technique that prints complex 3D structures that cannot be produced by other means, especially for rapid prototype purposes."[2] 3D printing in itself has been a revolutionary concept for those who desire to develop a prototype quickly, but sometimes plastic is not enough to meet a product's design needs. Matt Stultz, founder of both 3D Printing Providence and Hack Pittsburgh, specifies that although the capability of 3D printing filaments is incredible, due to the ability of modern printers to "print in strong, flexible, glowing, and dissolvable plastics," sometimes a part must be made out of metal.[3] Traditional pattern prototyping is both time intensive and expensive. Due to this fact, foundries, for some time, have shown interest in using 3D printers for prototype creation, "This results in substantial savings in cost, labor and time, ultimately speeding new product development."[4] This emerging technology is so advantageous, that it potentially could "up-end the last two centuries of approaches to design and manufacturing with profound geopolitical, economic, social, demographic, environmental, and security implications."[5] "The incentive for a business to adopt a 3D printer for casting applications is to reduce waste associated with traditional manufacturing; additionally, it requires no retooling of a 3D printer as is required by a CNC mill/lathe. Retooling takes time and money."[6]

In this project, three printers were utilized for creating the prototypes: the MakerBot Replicator Z18,[7] Printrbot Simple Metal,[8] and Ultimaker 2 Extended +[9]. Out of the three printers, the Ultimaker 2 Extended + performed the best, as illustrated by *figure 1*. The data presented has been collected from various parts' printing in different machines. Ultimaker 2 Extended + was more reliable than the MakerBot Replicator Z18, and just as reliable as the Printrbot Simple Metal. Moreover, the prototypes printed from the Ultimaker were of higher quality than either of the other two printers. The MakerBot Replicator Z18 had the potential to print high quality prototypes; however, its prints often had a warped surface foundation defect. The Printrbot Simple Metal performed well when price is considered, but its significantly lower quality textured finished required more post-processing than the other two printers. A significant amount of post processing was needed to remove the heavily textured finish that it left behind. Of the three printers, the MakerBot Replicator Z18 had by far the largest print area and hence would be able to prototype larger tools. This ability would certainly be advantageous to businesses that needed to be able to prototype larger objects (see *figure 2*).

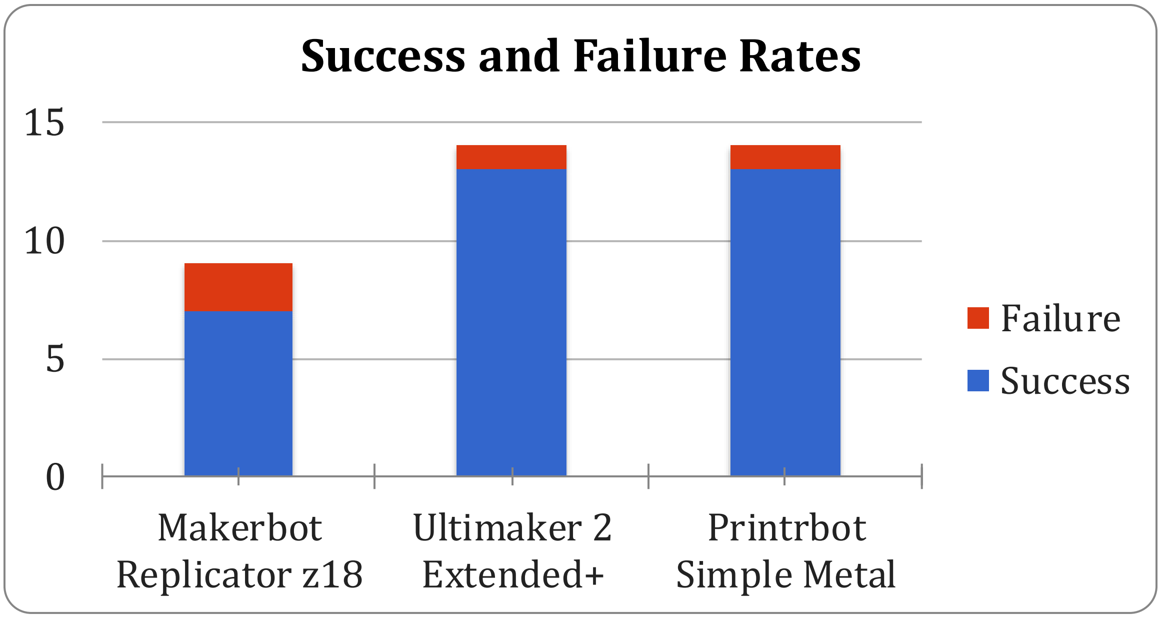

Figure 1: Success and Failure Rates of the 3D Printers Utilized for Prototyping

3D Printers for Prototyping					
MakerBot Replicator Z18		**Printrbot Simple Metal**		**Ultimaker 2 Extended +**	
Pros	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
Relatively high quality prints. Up to 200 microns. Largest print area 2,592 cubic inches 30.0 L x 30.5 W x 45.7 H cm	Less portable Slower print times Print speed: 90mm/sec Warped surface defects Most expensive. Retails at $6,499 Least reliable. 2 misprints out of 7 prints.	Incredibly affordable. Retails for only $599. Portable. Reliable. Only 1 misprints out of 14 prints.	Slower print times Print speed: 80mm/sec Lower quality, textured finish. Print resolution: 50 microns Smallest print area. Build Volume: 6″ x 6″ x 6″ | 216 cubic inches	Highest quality prints. Fewest print defects Fast print times Print speed: Up to 300mm/sec Reliable. Only 1 misprints out of 14 prints. Highest potential resolution. Up to 600 microns.	Less portable More expensive. Retails at $2,999.

Figure 2: 3D Printers Utilized for Prototyping

5. Sand Casting Process

All items were cast at the foundry at Tennessee Tech University. In sand casting, the flask refers to a two-part mold, with cope being the top part of the mold, and the drag being the bottom part of the mold. First, the prototypes are placed into the drag, dusted with a parting compound, and packed tightly in a silica sand molding mixture. The sand is packed tight with a tool called a hand rammer. Second, the cope part of the flask is placed on top of the prototype, the prototype is dusted with the parting compound, and the sand is packed tightly in the cope. Before the two sections of the flask can be put together, a runner bar and gating system must be cut into the sand, creating a pathway for the molten metal to fill the cavity. Additionally, a sprue is drilled into cope using a sprue cutter to create a hole for the metal to be poured in.

The casting process for all of the prototypes designs was attempted in aluminum, bronze, and iron. Due to the inexperience of the researcher, some of the items were not able to be cast due to the pattern not having enough draft for their particular designs. However, the finished product for many of the items turned out to be of excellent quality. As illustrated in *figure 3*, the cheapest metal of three utilized in the research was iron, and the most expensive metal, as well as the heaviest metal, was bronze. Aluminum, as expected, was significantly lighter than the other two metals.

	Bronze Item Weight (oz.)	Bronze Item Cost	Iron Item Weight (oz.)	Iron Item Cost	Aluminum Weight (oz.)	Aluminum Item Cost	Aluminum Item Retail
Dagger	30.3	$8.48	23.3	$0.23	9.1	$0.55	$0.76
Shaving cup			42.7	$0.43	14.2	$0.85	$1.19
Shaving stand	56.4	$15.79	54.4	$0.54	17.9	$1.07	$1.50
Clover pendant	3.1	$0.87	2.4	$0.02	0.8	$0.05	$0.07
Clover earring	0.6	$0.17	0.5	$0.01	0.1	$0.01	$0.01
Sword letter opener	3.2	$0.90	3	$0.03	1	$0.06	$0.08
Macbook stand	29	$8.12	26.7	$0.27	9.6	$0.58	$0.81
Batman paperweight			8.5	$0.09	3.2	$0.19	$0.27
Star pendant	1.2	$0.34	1	$0.01	0.3	$0.02	$0.03
Cross pendant	1.6	$0.45	1.4	$0.01	0.5	$0.03	$0.04
Diamond-shaped pen			0.4	$0.00	0.1	$0.01	$0.01
WIU footprint	2.6	$0.73			0.7	$0.04	$0.06

Figure 3: Cost and Weight of Items Cast in Bronze, Iron, and Aluminum.

As expected, bronze produced the heaviest objects of the three metals utilized and aluminum produced the lightest (see *figure 4*). Items cast in bronze were significantly more expensive than those cast in the other two metals. Iron was the cheapest metal. Items that were cast in iron were still less expensive than those cast in aluminum, even though the aluminum items weighed significantly less than the iron items (see *figure 5*).

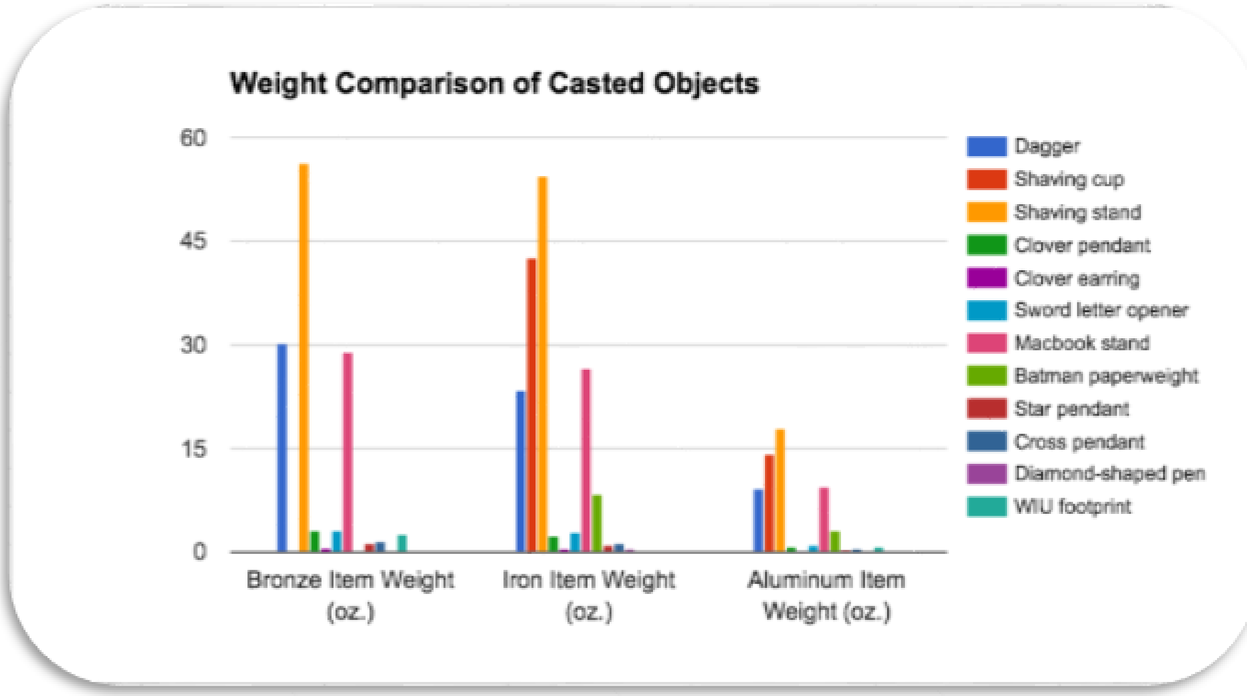

Figure 4: Weight Comparison of Items Cast in Bronze, Iron, and Aluminum

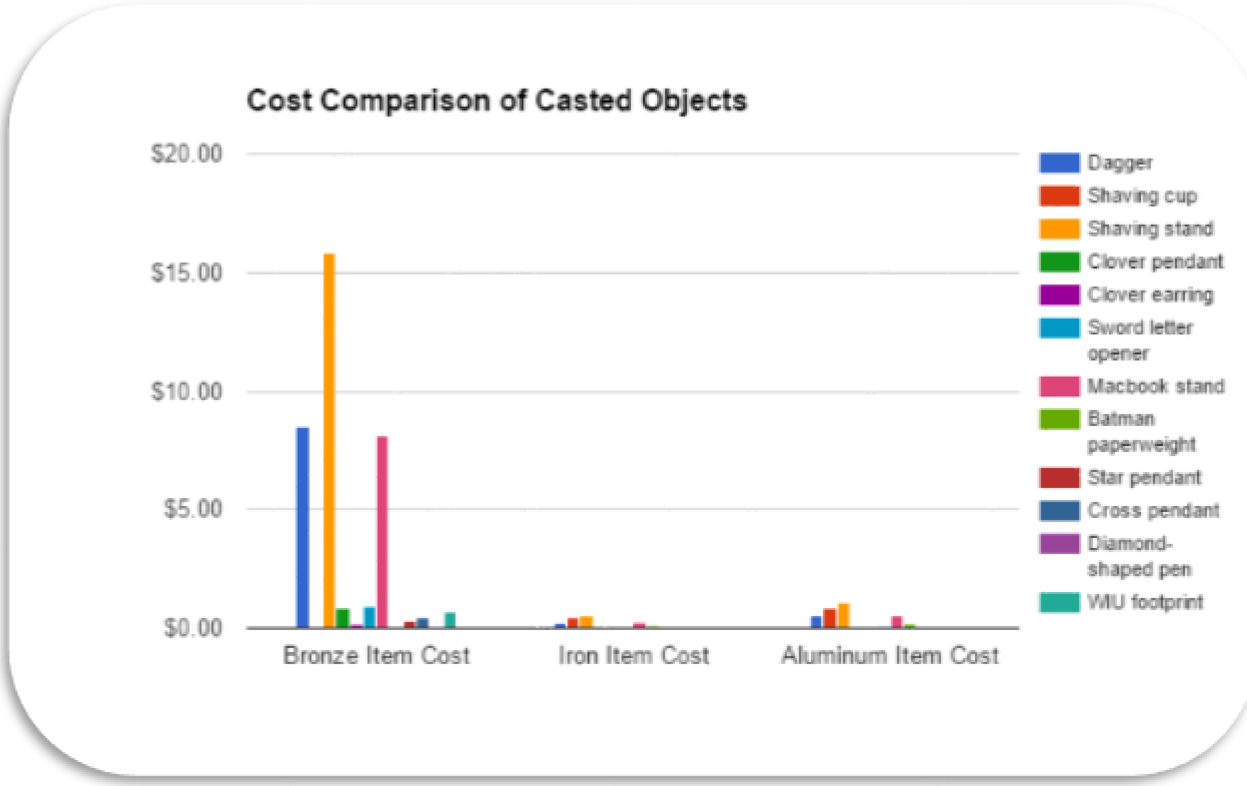

Figure 5: Cost Comparison of Items Cast in Bronze, Iron, and Aluminum

6. Problems faced in Casting Process

For most items, a minimum of five to six degrees of draft is needed for a successful casting project. Other designs require even more draft. For example, a minimum of nine-degree draft is recommended for the casting of a coaster with an extruded design on the top.

For business, a potential solution for creating complex designs would be to utilize investment casting. Traditional investment casting involves creating a wax pattern, typically utilizing injection molding. However, 3D printers now have the capability of printing using wax filament. "For prototypes and short production runs, creating wax patterns from 3D printed molds offers substantial time and cost savings over traditional tooling methods. Plus, 3D printing can produce molds with greater complexity without driving up costs."[10]

7. Post Processing

After the objects were cast, they were then ground to a smoother finish. Of course, the area in which the gating system allowed the metal to flow required more grinding, along with other casting imperfections. Objects that were cast using prototypes from the Printrbot Simple Metal required more post-processing than casts from the other printers, due to the lower resolution of the printer (see *figure 6*). Objects were then sanded and dremeled down to an even finer finish. Depending upon the object and the desired aesthetics, this process could take as little as fifteen minutes, to as much as two hours. Finally, objects were polished. A buffer brush was attached to an electric drill. Metal polish was placed on the brush and objects were given a shiny finish.

Figure 6: Prototype printed with Printrbot Simple Metal and aluminum casting of prototype.

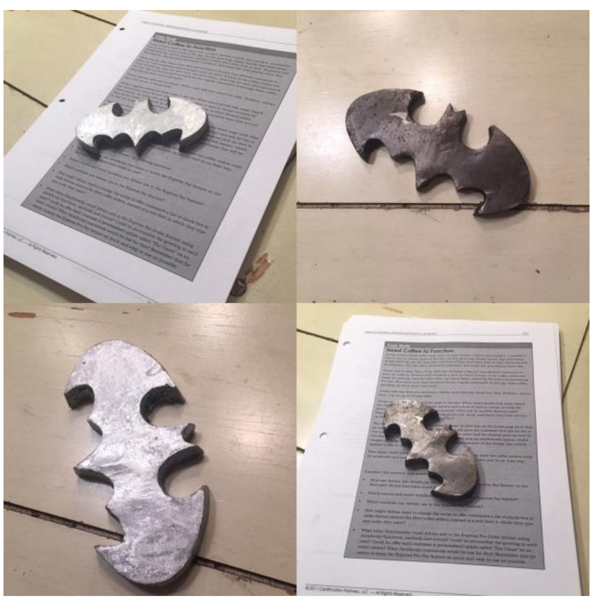

Figure 7: Finished cast objects, in aluminum, bronze, and iron, from left to right.

8. Discussion on the Educational Impact of the RET Project

Due to the relatively low cost of 3D printers and the sand casting process, it is feasible for many individuals to create a business centered on the development and creation of both existing and unique products and tools. For industries, this process is both a fast and affordable mechanism for replacing a broken tool and developing new products. At the conclusion of this project, the finished items (see *figure 7*) were given to an entrepreneurial-spirited TTU student. This student already possesses significant experience with the prototyping, casting and smithing processes; and currently has an online storefront. Each of the prototypes that were successfully cast and finished into an attractive product has been placed on that student's ecommerce website. Some objects are quite unique and would likely be successfully marketed toward young professionals who desires higher end, distinguished products (see *figure 8*).

This project was an educational research experience for the participating teacher. There were several aspects of the project that were outside his areas of expertise. For example, before the project started, he did not have experience with any type of 3D modeling software. Additionally, he was unaware of the procedures of the various sand casting processes and had little experience with 3D printers. Much of the early research was simply spent on education, especially on learning how to effectively use SolidWorks and SketchUp software tools. With that noted, this opportunity was an incredibly enriching activity. Although he lacked formal engineering training, he has significant experience with information technology and coding, and teaches these topics at a local high school. This foundational knowledge assisted him in learning many of the new concepts with which this project required mastery. Finally, and most importantly, this research opportunity will eventually allow him to enhance his classroom, both with his experience and newfound knowledge, and a 3D printer and 3D scanner. In previous Information

Technology classes, he has only been able to provide a surface introduction to STEM topics, such as 3D modeling and 3D printing, along with how these new technologies impact our current society. Now, he will be able to provide a significantly more in-depth, hands-on, exciting experience for his students.

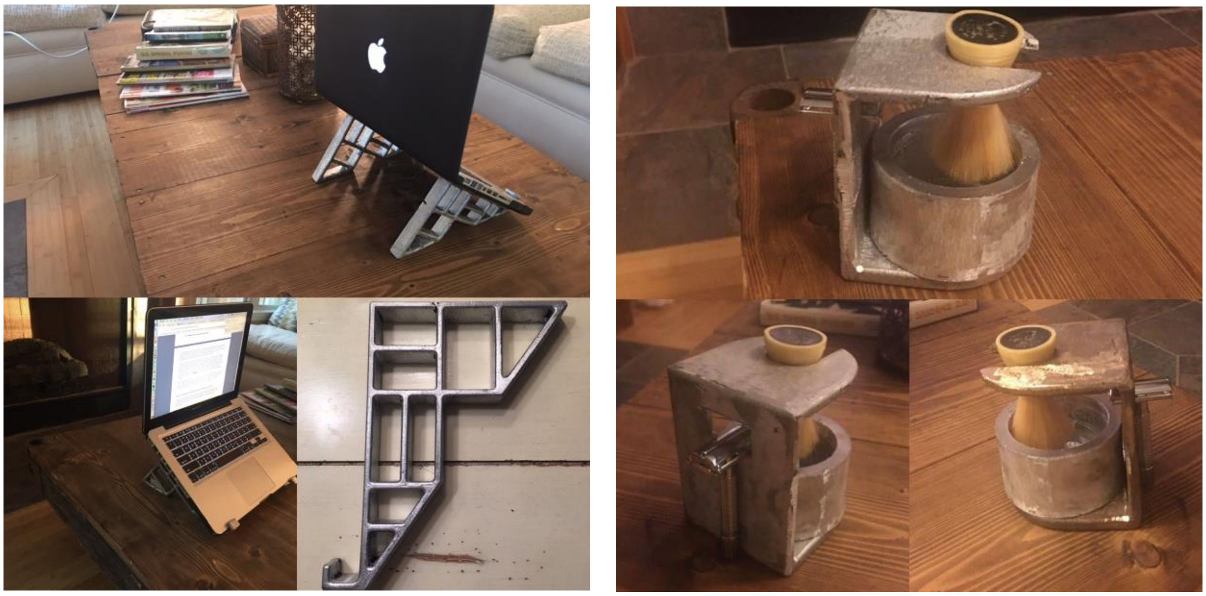

Figure 8: Aluminum MacBook stand, aluminum shaving cup stand with shaving cup, and bronze shaving stand.

In the 21st century, it is believed that creating a mindset with the knowledge of innovation and techno-entrepreneurship is important for a STEM educator. Eventually, he can easily translate his knowledge to his students with various lectures and laboratory practices. In this summer project, the objective was to train the instructor with a pathway provided through Solid Modeling, 3D Printing, Casting, and E-Commerce. The project will continue with the collaboration of students, high school educators, and the College of Engineering.

9. Conclusions

The process of creating a tool prototype with 3D modeling software, printing said prototype, then sand casting the final part, is a viable and affordable option for the rapid manufacturing of many tools. However, several factors must be considered if a business or individual would like to make use of said model. First, the size of the tool should be considered. Even the MakerBot Replicator, the printer with the largest print area of the three printers, would not have a large enough area for many prototype designs that businesses would need to develop. With that noted, it is entirely feasible to design an item in one piece and then use a program such as AutoDesk MeshMixer to split into sections small enough to print. Second, the type of metal needed for the tool or object should be considered. The Tennessee Tech Foundry only casts objects in three types of metal. Similarly, other foundries are limited to various alloys. Finally, the design needed for the manufacturing of many items and tools often does not lend itself to the sand casting process due to the draft requirements of that process. Overall, it is proven that the integration of Solid Modeling, 3D Printing, Casting and E-Commerce practiced in this study is a viable pathway to establish a profitable business for any STEM graduate.

10. Acknowledgements

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