



## **BYOE: Using 3D Pens for Enhancement and Rework of 3D-Printed Parts**

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## Abstract

While inexpensive 3D printers are allowing designers to quickly see their work without enlisting expensive machine shop personnel and without experiencing long turn-around times, they have limitations such as small build volumes, warping of thin objects, relatively low-precision, etc. This work demonstrates a new device, a 3D pen, which can be used for (1) repairing 3D-printed parts by adding material, (2) for “welding” the ABS or PLA plastic parts together, (3) for personalizing and decorating 3D printed objects, or (4) for creating free-hand 3D plastic objects. For each one of these processes, an appropriate example with instructions is provided. During the demonstration, three 3D pens from three different manufacturers are used on appropriate 3D-printed objects to show the above-mentioned processes. Creation of free-hand 3D plastic objects is also illustrated. Two laboratory exercises using 3D pens for welding plastic and for personalizing 3D-printed objects are described.

## Introduction

Experimenting with physical models is a well-documented advantage of engineering education as justified by the Kolb’s Experiential Learning Cycle Theory<sup>1</sup>. The 3D-printing technology based on inexpensive 3D printers and inexpensive plastic materials is at a stage of enabling student designers in creating quick, inexpensive, and functional design iterations in support of experimentation in engineering education<sup>2,3</sup>. However, more complicated designs and/or assemblies sometimes fail to print correctly<sup>4</sup>. Also, an object may be just too large to fit in the 3D-printer’s build volume and thus it must be redesigned to include multiple parts that require assembly.

There is scant literature on post-processing of 3D-printed objects<sup>4,5</sup> created by inexpensive 3D printers. Griffin<sup>5</sup> describes “friction welding” and riveting using a high-speed rotary tool like Dremel, sanding, surface reheating, and gluing/filling (for ABS parts only) with ABS slurry. A 3D pen manufactured by Nanjing Yahong Electrical Technology Company<sup>6</sup> used here for “after-printing touch-ups and rework” is also addressed previously<sup>4</sup>.

Even though 3D pens are designed for free-hand 3D-drawings using plastic, in this work, 3D pens are used for

- Repairing 3D-printed parts by adding material,
- Welding ABS or PLA plastic parts together,
- Personalizing and decorating 3D printed objects, and/or

- Creating free-hand 3D plastic objects.

Curricular context in which 3D pens are used is addressed next. In the section that follows, three 3D pens from three different manufacturers are compared. Specific operating instructions for each of the 3D pens are provided and differences between them are noted. Then, 3D-printing post-processing 3D-pen applications stated above are described in detail. Finally, descriptions of two lab exercises are provided for possible adoption by others.

### **Curricular Context**

Our institution offers two undergraduate engineering degrees: Bachelor of Science in Engineering with specialization in Mechatronics and Bachelor of Science in Industrial Engineering. The two programs use inexpensive 3D printers in a number of courses. A newly-established 3D-printing lab includes: nine inexpensive 3D printers (two MakerBot Replicator 2, three MakerBot Replicator 2X, two UP Plus, one Thing-O-Matic, and one Replicator Z18) based on Fused Deposition Modeling technology, one inexpensive 3D laser scanner (Next Engine 3D scanner HD), one 3D printer filament extruder (Extrusionbot EB), one plastic shredder (FilaMaker mini XXL shredder), and 3D pens from three different manufacturers. During the last two years students logged over 3,000 3D-printing hours and printed over 1,000 parts for their classes, senior projects, independent projects, and outreach activities. 3D-printing technology has become a part of our engineering education culture. Students are well-aware of 3D printing capabilities and limitations<sup>4</sup>. However, except for simple post-processing procedures (removing parts from 3D printers, removing rafts and other support material, using soldering irons for shaping and gluing, and supergluing broken parts) most of the students rarely used any other process. Since 3D pens started shipping at the beginning of 2014 there was little student exposure to this technology in the past.

To introduce students to 3D-printing post-processing operations using 3D pens two new laboratory exercises are developed for the Engineering of Manufacturing Processes Lab course (a fifth semester, one credit, required, engineering lab course that accompanies our 3-credit, required, lecture course on engineering of manufacturing processes). The 3D pen lab exercises are scheduled after the topics on joining processes (including welding). Thus, before starting this lab, students are already familiar with welding processes and types of joints and welds<sup>7</sup>. They also had practical experiences with arc welding using continuous wire electrodes and creating continuous welds. A short lecture on post-processing of 3D-printed objects (tools, benefits, and applications) is delivered just before the lab.

### **3D pens - Characteristics and Operating Instructions**

Originally, a 3D pen named 3Doodler was developed as a Kickstart project that started shipping in March 2014. However, a Chinese company, Nanjing Yahong Electrical Technology Co., Ltd. started selling a similar product even earlier (January of 2014). For this study, 3Doodler was not chosen because it uses 3mm diameter filament that is not compatible with the lab 3D printers' 1.75mm diameter filament. While all 3D pens are like hand-held, manually-controlled 3D-printer extruders, they do differ in operating procedures and capabilities. As the first generation products, they are bulky and thus somewhat hard to use. The second generation of 3D pens is planned for release in mid-2015 by another Kickstart project (illustrating the project's popularity is the fact that the project leaders requested \$30,000 and received over \$1.5M). The new 3D pen will be slimmer and will be able to use different diameter nozzles<sup>8</sup>. 3D pens, Ahiro-002A (Ahiro)

by Nanjing Yahong Electrical Technology Co., Ltd. operating on 12 VDC, 3D AirPen<sup>9</sup> operating on 12 VDC, and 3D printing pen (rainsun pen<sup>10</sup>) by Rainsun international, Ltd., operating on 24 VDC, are shown in their original boxes in Figure 1.

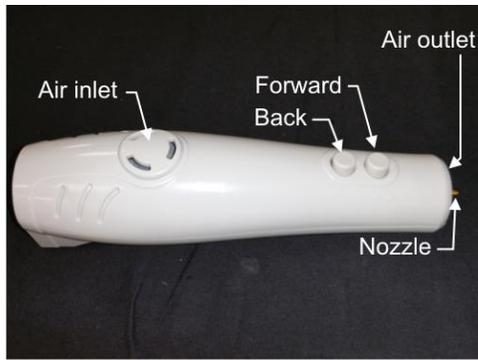
### **Ahiro**

Ahiro 3D pen is depicted in Figure 2. While most of the 3D printers use 0.4mm diameter nozzles 3D pens usually use 1.0mm diameter nozzles. Some features of the Ahiro 3D pen are the temperature display, temperature control, and a Back button for powered unloading of filament. All 3D pens have a small fan that creates airflow around the nozzle for quick cooling and solidification of extruded plastic. Ahiro 3D pen also includes a motor with appropriate bi-directional motor drivers, a mechanism for filament feeding, a heater, and a nozzle – just like basic extruders in 3D printers. Temperature control is a feature that allows extruding ABS and PLA plastics at their optimal temperatures which depend on filament color, environment temperature, humidity, and elevation<sup>3</sup>. The manufacturer suggests an initial setting of 230°C for ABS and 190-200°C for PLA.



Figure 1. 3D pens used in this study

Ahiro 3D pen is easy to use. After it is plugged in for the first time it heats automatically to a factory set temperature of 50°C. Otherwise, the pen heats to the last previously used temperature. Then, if necessary, the heater is adjusted to the desired temperature by pressing an appropriate temperature adjust button. The desired temperature is reached when the temperature display stops flashing (about 5 seconds). Filament is loaded by hand through the filament inlet until it comes to a stop. Then, the Forward button is pressed (engaging the 3D pen's motor) until material starts extruding from the nozzle. At this time, the pen is ready for use. The 3D pen will extrude material as long as the Forward button is pressed. Note that it takes a couple of seconds for filament to stop flowing out of the nozzle after the Forward button is released. This should be taken into consideration when using the 3D pen. When changing filaments, the filament that is already in the pen can be partially unloaded by pressing the Back button. When the motor stops moving the filament, the remaining filament needs to be pulled out by hand the rest of the way.



a



b

Figure 2. Ahiro 3D pen: a) side view, b) rear view

Ahiro was the first 3D pen used in the departments' 3D-printing lab. During the trial run, it stopped extruding material after about five minutes of use. The 3D pen would not feed filament properly. Under closer inspection it was discovered that the mounting screws were too tight. After loosening those screws slightly the 3D pen performed as intended.

### 3D AirPen

3D AirPen is shown in Figure 3. This 3D pen is slimmer than the Ahiro 3D pen. Also, its nozzle protrudes further than the nozzle of the Ahiro 3D pen. These two features make 3D AirPen easier to hold (it is slimmer) and use (one has unobstructed view of the work surface). Filament loading is somewhat harder even though the filament path inside the 3D AirPen is shorter. When the pen is plugged in, the indicator LED turns red. When the temperature reaches a factory preset level the indicator LED turns blue. Note that the 3D AirPen does not have user adjustable temperature control. At this time filament can be fed to the pen. First, filament is fed by hand until the gears are reached. Then, the Load button is pressed (this button allows two internal gears to separate and accommodate filament) and held while the filament is further advanced by hand. When the filament comes to a stop the Forward button is pressed. This starts the 3D AirPen's motor which feeds the filament further into the 3D AirPen. When plastic starts flowing from the nozzle tip this indicates that the 3D AirPen is ready for use. To unload filament, the Reverse button is pressed and held until filament is removed from the pen. For 3D AirPen, the manufacturer warns users not to pull on filament while unloading or they may damage the motor.

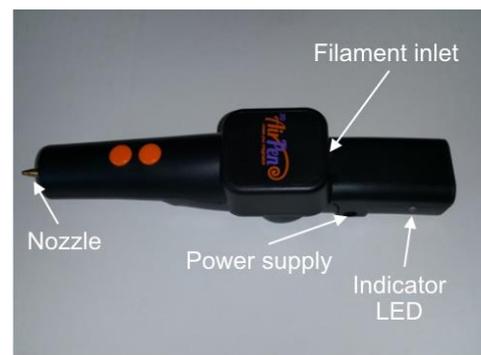
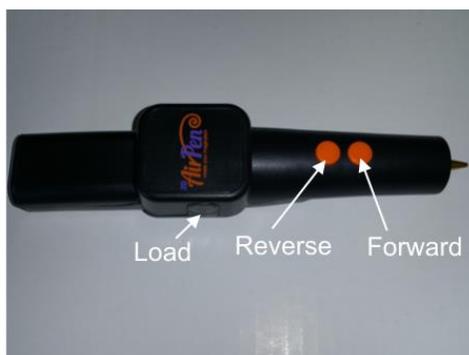


Figure 3. 3D AirPen

### ***Rainsun 3D Pen***

Rainsun 3D pen depicted in Figure 4 is as bulky as Ahiro 3D pen, but it uses a 24 VDC power supply, and it does not have manual temperature control. However, as an advantage, the Rainsun 3D pen has a HI-LOW-OFF switch thus having some control over extrusion speed of plastic. Its nozzle diameter is 0.7mm and its operating temperature is 250°C.

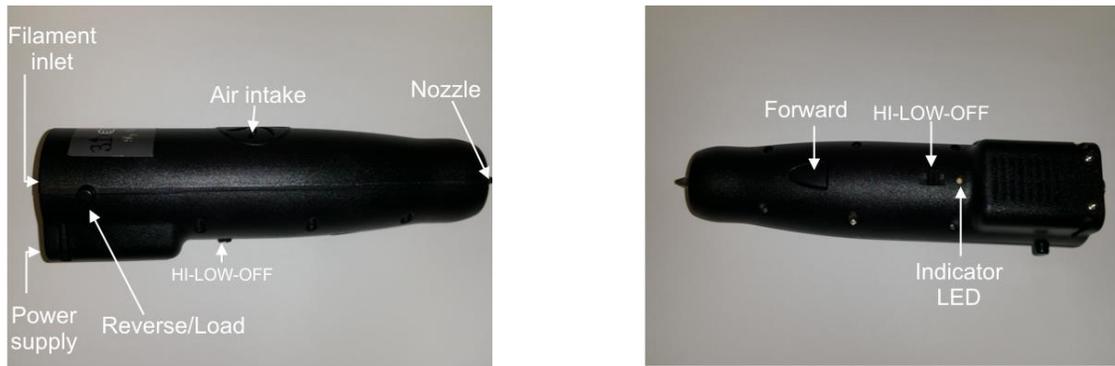


Figure 4. Rainsun 3D pen

When the 3D pen is plugged in and the HI-LOW-OFF switch is turned ON (the switch is moved to either HI or LOW position), the indicator LED turns red while the 3D pen heats up. Then, in about two minutes, when the set temperature is reached (around 230°C) the LED changes color to green. Filament is fed through the filament inlet by hand until it reaches a set of gears (about 3 cm). Then, the Reverse/Load button is pressed and held while the filament is further inserted by hand until it reaches the next stop. Finally, the Forward button is pressed and held (running the 3D pen's extruder motor) until plastic starts extruding. To remove filament, the Reverse/Load button is pressed and held while the filament is quickly pulled out by hand. The extruder motor in the Rainsun 3D pen rotates in only one direction.

As described above, all 3D pens' operating procedures are sufficiently distinct that they demand appropriate attention and training.

### **3D Pen Application Examples for Post-Processing of 3D-printed Objects**

#### ***Repairing 3D-printed Parts***

There is a number of occasions when a need arises to repair 3D-printed objects. For example, in Figure 5, a model of the Space Shuttle was created by a student as an assembly of a number of 3D-printed parts. While the smaller parts were assembled into durable subassemblies easily, the final assembly consisting of four larger sub-assemblies was delicate because the sub-assemblies were connected by pins only. Since the pins broke off of two subassemblies on one occasion, the pins were replaced by 3D-pen pins built-onto subassemblies directly. For each pin, the 3D-pen nozzle was brought in contact with the part and held there until the part softened. This was done to bond the part with extruded plastic. Then, plastic was slowly extruded in the shape of a pin by pausing after each deposited layer for a few seconds. The pauses allowed pins to keep their shapes as plastic was extruded.

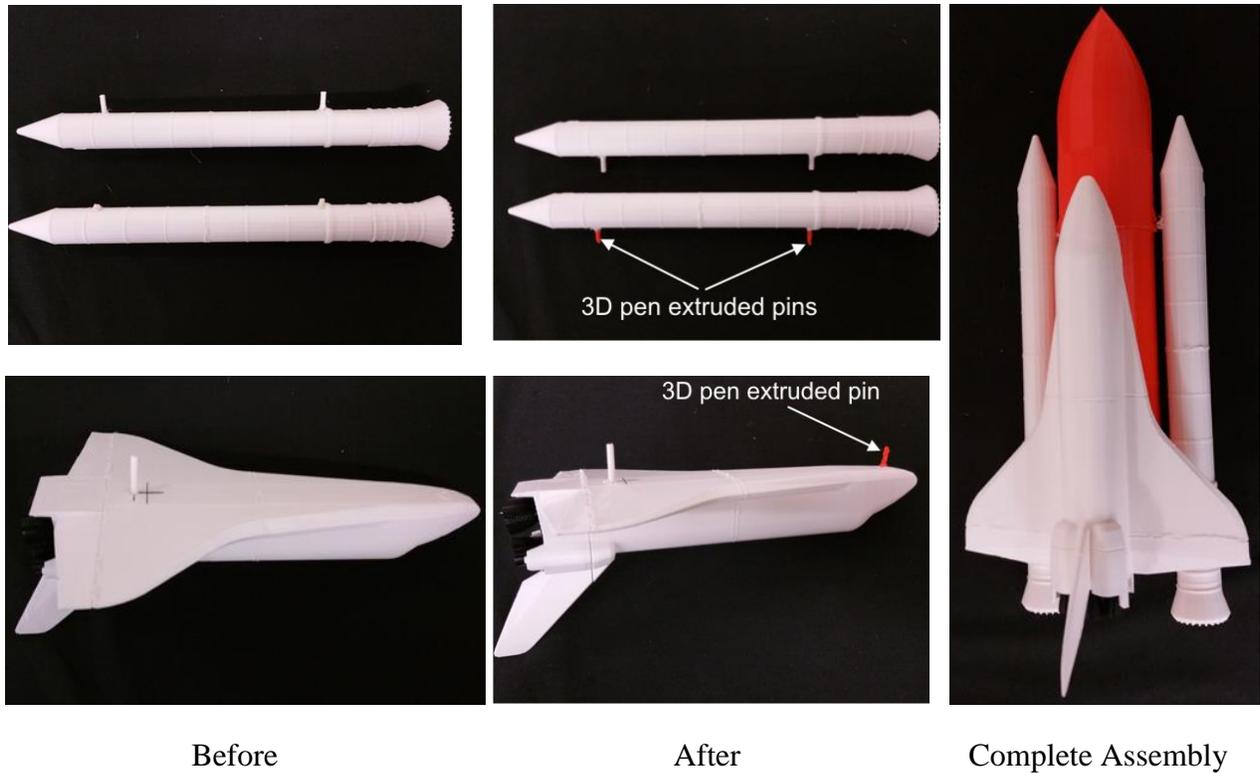


Figure 5. Repaired Space Shuttle model

### ***Welding 3D-printed Plastic Objects***

Figure 6 shows a figurine built with a design flow where the intent was to print the figurine in the picture as one object<sup>4</sup>. However, a 3D printer printed the object from a supplied *.stl* file with figurine legs separated from the body. The figurine was reworked by using a 3D pen. First, the 3D pen was brought into contact with both object surfaces until both became pliable. Then, the gap between the torso and the legs was filled up with plastic extruded from the 3D pen.

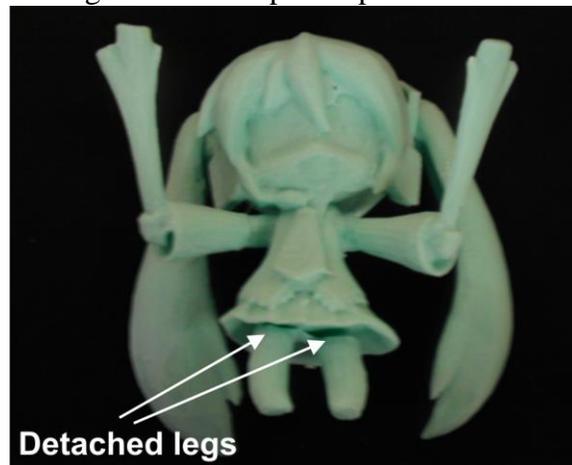


Figure 6. Design flaw in a 3D-printed figurine<sup>4</sup>

Sometimes, desired objects are too large to fit in the build volume of a 3D printer. Other times, desired objects may be too complicated or complex to be printed successfully as single objects.

In such instances, objects are separated into printable parts and then assembled after printing. One of the advantages of 3D-printed parts is that screws can be replaced by other joining methods. Figure 7 depicts the Space Shuttle subassembly, again. Note that the subassembly is printed as three separate parts that were joined together after printing. Here, a 3D pen was used to reinforce the two seams. Same filament is used for the 3D printer used to build the three pieces and for the 3D pen used to weld the pieces together.

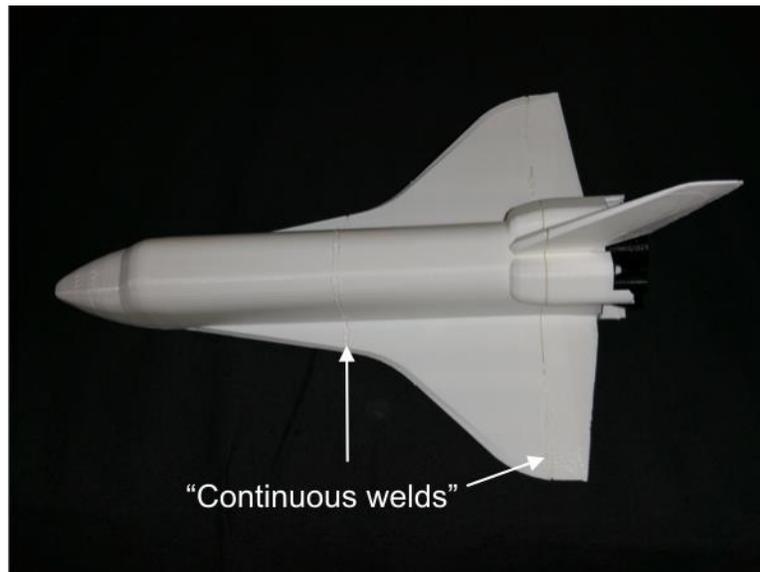


Figure 7. Welds of Space Shuttle model subassembly

### ***Personalizing 3D-printed Objects***

Since 3D printers can print one object at a time it is not hard to personalize such objects at the time of printing. A signature, a logo, a company name, etc. can be designed and built using a 3D printer without an increase in production cost. However, sometimes it is easier to create multiple objects and personalize them as needed. Figure 8 shows multiple personalized objects. A comb and four small key chains were personalized using a 3D pen. These are some of the early attempts in personalizing 3D-printed objects. The success depends widely on operators' skills. At this time, 3D-pen nozzles are too large (1mm or 0.7mm diameter) for fine writing in plastic. This may soon change when 3Doodler 2 becomes available. This 3D pen will be able to use 0.4mm diameter nozzles, the same diameter nozzles as the ones used in many inexpensive 3D printers.

### ***Creating free-hand 3D plastic objects***

3D pens are designed to create free-hand 3D objects. There are many examples that can be found on the Web including race cars, bicycles, quadcopters, butterflies, roses, skeletons, etc. In Figure 9, an example of a free-hand 3D sculpture, created by using one of the lab's 3D pens, is shown. Person's legs are 3D springs, which are hard to build using 3D printers.

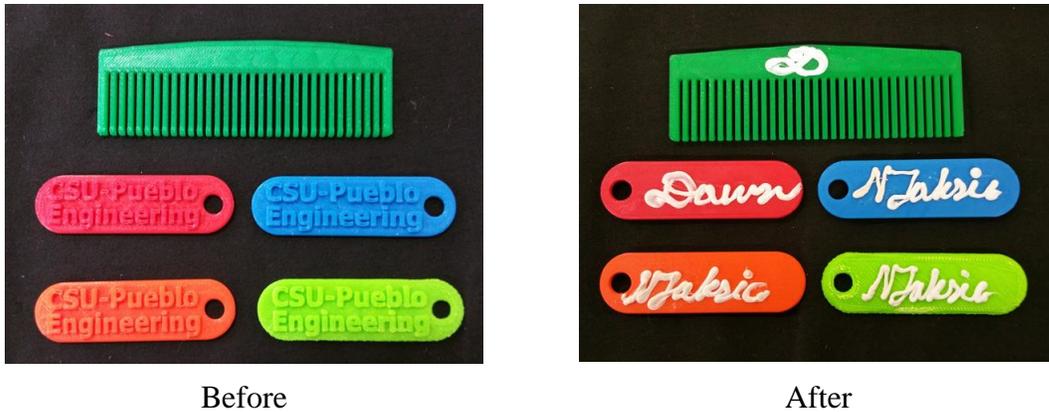


Figure 8. Samples 3D-printed objects personalized with 3D pens

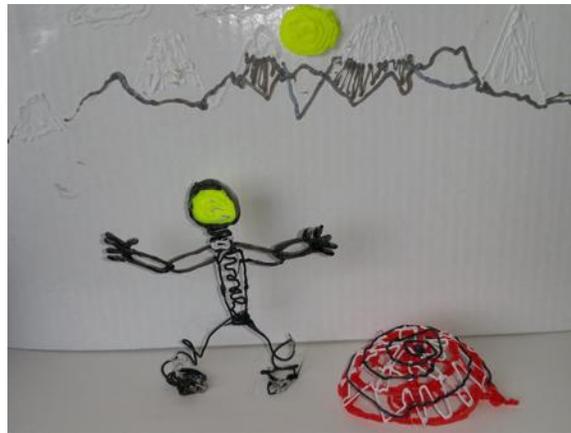


Figure 9. A free-hand 3D sculpture

### 3D Pen Laboratory Exercises

Two laboratory exercises are designed to introduce students to 3D pens, devices similar in operation to glue-guns or welding machines except that 3D pens use plastic filament instead of glue sticks or metal rods/wire. In the first exercise, 3D pens are used for plastic welding, a process similar to arc welding using continuous wire electrodes except that it is simpler (there is no need for inert gas shield since plastic does not oxidize) and safer (comparatively low temperatures are used to melt plastic). In the second exercise, students write in plastic to personalize their 3D-printed objects. Both lab exercises are designed to help students gain practical experience with 3D pens as useful tools in post-processing 3D-printed objects.

#### *Plastic Welding Laboratory Exercise*

In this exercise, students are asked to create five basic weld joints (butt, corner, lap, tee, and edge) using continuous fillet welds for corner, lap, and tee joints; using continuous groove welds for butt joints; and using flange welds for edge joints. Each successfully welded joint should be able to withstand a fall (without separating) onto the tile floor of the lab from a height of about three feet.

Students are to use the following procedure.

1. Design in CAD software (SolidWorks) a 2" x 2" x 0.5" rectangular prism beveled (0.25") on one side only.
2. Save the design as an *stl* file.
3. 3D print ten prisms (two prisms per weld joint) using ABS filament without raft and at 15% density. Since it takes about an hour per prism, multiple prisms can be printed simultaneously to save time.
4. Using a 3D AirPen and continuous fillet welds create a corner, lap, and a tee joint. These joints cannot be created using Ahiro 3D pens or Rainsun 3D pens since these 3D pens cannot reach the required surface junctions.
  - a. Read the instructions on using 3D AirPens.
  - b. Choose ABS filament color to create strong color contrast with the parts.
  - c. Load the filament per 3D pen instructions.
  - d. If needed, use a vise or other means to hold the parts together during welding.
  - e. Make sure that the two parts to be joined are properly heated with the 3D pen before the start of welding.
  - f. Weld the parts together considering that the plastic will continue extruding a couple of seconds after the Forward button is released.
  - g. Test the joint by dropping the weldment on the floor of the lab from the height of about three feet.
5. Using an Ahiro 3D pen and a continuous V-groove weld create a butt joint where the welding surfaces create a v-groove by two beveled edges. Use the procedure in step 4 for Ahiro 3D pens.
6. Using a Rainsun 3D pen and a flange weld create an edge joint with beveled edges facing each other. Again, use the procedure in step 4 for Rainsun 3D pen.

An example of creating various weldments is presented in Figure 10.

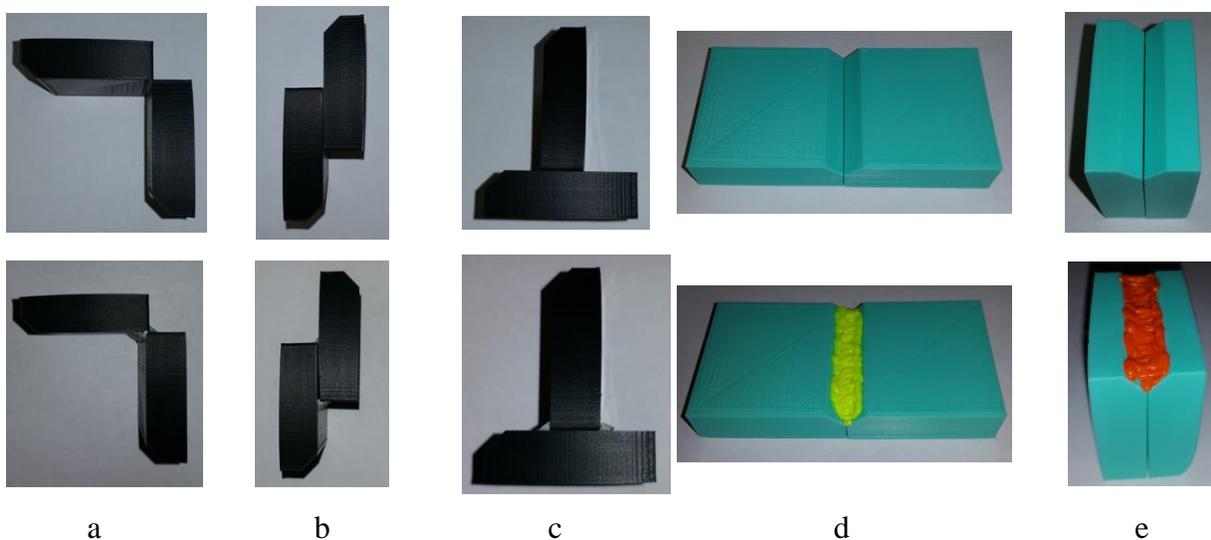


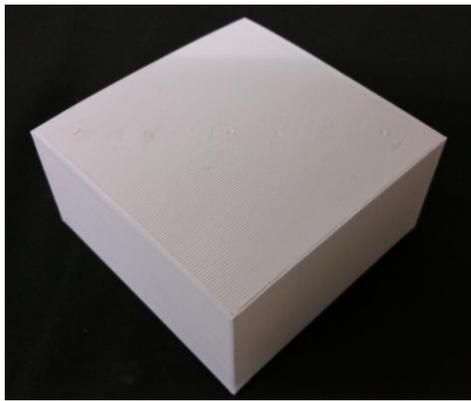
Figure 10. Various weld joints created with 3D pens: a) corner, b) lap, c) tee, d) butt, and e) edge

### **3D-object Personalization**

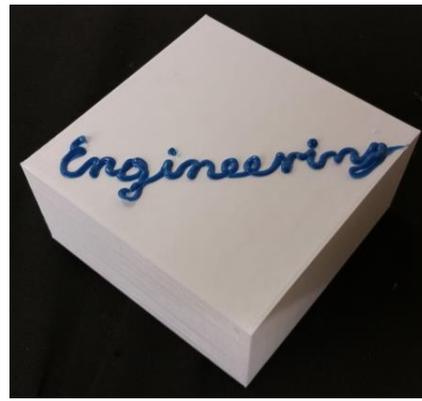
Students are asked to “decorate” a 2” x 2” x 1” rectangular prism (or any other 3D-printed object) to gain experience in personalizing 3D-printed objects using 3D pens. They are to use the following procedure.

1. Use a 3D printer to build a 2” x 2” x 1” rectangular prism (or any other small object) with 10% fill and no raft.
2. Choose a 3D pen and load filament into the pen.
3. Draw your artwork on a piece of paper.
4. Practice your artwork by tracing lines on paper in plastic using the 3D pen.
5. When satisfied, “draw” your artwork on a surface of your 3D-printed object.

As shown in Figure 11, word “Engineering” was written in plastic on a 3D-printed rectangular prism.



Before



After

Figure 11. Personalizing 3D-printed objects

### **Summary**

A novel device, 3D pen, is introduced. The device is a manual plastic extruder designed for creating free-hand 3D drawings and sculptures. In this study three novel applications for 3D pens are explored. 3D pens are used in enhancing and repairing 3D-printed objects. Three current 3D pens (Ahiro-002A, 3D AirPen, and Rainsun 3D pen) are described. A number of examples are illustrated. Two laboratory exercises, one using 3D pens for plastic welding and another for personalizing 3D-printed objects, are described.

## Bibliography

1. Kolb, D. A., *Experiential Learning: Experience as the Source of Learning and Development*, Prentice Hall, Englewood Cliffs, N.J., 1984.
2. Jaksic, N., "Novel Experiential Learning Practices in Engineering Education Based on Inexpensive 3D Printers," *Computers in Education Journal*, Vol. 5, No. 4, pp. 2-17, October-December 2014.
3. Planchard, D. C., *Engineering Design with SolidWorks 2015 and Video Instruction*, SDC Publications, Mission, KS, 2015.
4. Jaksic, N., "What to do when 3D Printers go wrong: Laboratory Experiences," *2015 American Society for Engineering Education Annual Conference and Exposition Proceedings*, Seattle, WA, June 14-17, 2015. Submitted.
5. Griffin, M., "Finishing and Post-Processing Your 3D-Printed Objects," *Make*: Vol. 34, pp. 88-99, April 2013.
6. 3D paint pen Ahiro-002A, manufacturer Nanjing Yahong Electrical Co., Ltd., available at <http://www.goodluckbuy.com/ahiro-002a-3d-printing-pen-3d-painting-drawing-pen-printer-white.html>
7. Groover, M. P., *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*, 5<sup>th</sup> Edition, John Wiley & Sons, Inc., 2012.
8. 3Doodler, available at <http://the3doodler.com/store/>
9. 3D AirPen, available at [www.3dairpen.com](http://www.3dairpen.com)
10. 3D printing pen, manufacturer Rainsun International, Ltd., available at [www.rainsunintl.com](http://www.rainsunintl.com)