EXTRUSION

Module IV: Lesson Plan

MODULE GOALS

Extrusion type printing is the most accessible, simple, and robust type of 3-D printing. An extensive understanding of how it works will help students to understand the parameters that impact the final part quality. In this module, students will engage in material experimentation with hand-held plastic extrusion devices ("3-D printing pens"), and become acquainted with how their operation reflects the ways 3-D printers **additively** build form.

ESSENTIAL QUESTIONS

- What is the **extrusion** process?
- What is a **filament**?
- How do forms build in the **additive** manufacturing process?
- What kinds of objects can and cannot be produced by using extrusion?
- What are some of the material limitations usually faced within the extrusion process?
- What tools or software are used to manipulate the extrusion process?

MEANING AND ACQUISITION

- Students will learn about the material extrusion process of 3-D printing. The process of melting filament, extruding it, and its solidification.
- Students will understand extrusion-specific limitations and opportunities. For example: the need for support and flexibility in design, and the need for methodical, layer-by-layer construction.
- Students will experiment with a 3-D pen extruder.
- Students will learn about the variety of material that can be used for extrusion as well as material-specific limitations and opportunities.

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FORMATIVE ASSESSMENT STANDARDS

- Students demonstrate willingness to experiment and develop skills in new art-making techniques, such as the 3-D drawing with 3-D pens **(Cr2.1.5a)**.
- Students know and use fundamental vocabulary relevant to the extrusion process **(Cr3.1.1a)**.
- Students demonstrate quality attention to craft by carefully using the materials and tools provided **(Cr.2.2.5a)**.
- Students are able to discuss and explain the extrusion process to their peers and help facilitate peer-to-peer learning **(CrI.1.II)**.

SUMMATIVE ASSESSMENT STANDARDS

- Student work exemplifies an effective use of materials, equipment and tools into the creation of 3-D objects **(Cr2.1.IIa)**.
- Student work exemplifies a synthesis between creative and analytical principles and techniques of the visual arts and the sciences **(Cr2.3.IIa)**.
- Student work demonstrates an understanding of the different approaches utilized in creating 3-D objects from scratch in a creative way **(CrI.1.Ia)**.
- Student work demonstrates the conceptualization and use of both traditional and contemporary techniques and technologies (hand and 3-D pen drawing) within the design **(CrI.2.IIa)**.

MATERIALS

- Work table
- Handouts
- Paper
- 3-D pens
- (Optional) Physical objects (including old or failed 3-D prints!) to extend, connect, revisit, and adjust using the 3-D pens

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KEY TERMS

- **Additive manufacturing** - Also known as 3-D printing or digital fabrication, additive manufacturing is creating physical objects, by building up, layer by layer, building material (General Electric, n.d.).
- **Extrusion** - The process of forcing a soft material, such as clay or heated plastic or metal, through an opening for manufacturing purposes (ScienceDirect, 2005).
- **Filament** - A slender, threadlike object/material. In 3-D printing, plastic filament is extruded through the 3-D printer or 3-D pen to build forms.

Derived from:

General Electric. (n.d.). What is additive manufacturing? https://www.ge.com/additive/additive-manufacturing

ScienceDirect. (2005). Extrusion. https://www.sciencedirect.com/topics/materials-science/extrusion

PROPOSED ACTIVITY

1. Students will use the 3-D Pens to create a 3-D monogram:
   - Students will write/design a monogram using their initials on a piece of paper.
   - Students will trace and fill the letterforms on the paper using the 3-D pen, then peel off the plastic once it has cooled down.
   - Students will make a rectangular base with the pen, and attach it to the monogram/letters so it stands.
   - Look at the handout for more specific instructions.
2. Students will use the 3-D Pens to mimic a 3-D printer, in order to understand how the extrusion process works:
   - By tracing the 2-D shapes on the provided sheets, and building them up vertically, layer by layer, students will build a 3-D form.
3. After these exercises, students will use the 3-D Pens to create their own free-form design by drawing in 3 dimensions:
   - Draw anchor points on a surface.
   - Draw vertically from the anchor points to create a 3-D form.
     - Refer to the handout for more specific instructions.

EXTRUSION

Module IV: Case Study I

TOM LAUERMAN

Tom Lauerman is an artist and professor at the Pennsylvania State University whose practice integrates traditional techniques such as sculpture, craft, and design, along with contemporary digital processes that aid creative ways of working (Lauerman, n.d., para. 1). Beginning in the Fall of 2015, Lauerman became interested in developing and exploring extrusion-based processes for 3-D printing in clay, and his current work spans methodological and technical boundaries, seeking to synthesize traditional craft techniques with digital fabrication strategies (Lauerman, n.d., para. 1). Lauerman's innovations in the field, including his progressive development of an open source 3-D clay printer, is shared freely with the public ("Shaping Code, Shaping Clay: Developing, Sharing, and Teaching via Open Source Tools and Techniques for 3-D Printing in Clay", 2017). In this way, Lauerman hopes that innovators in the field will continue to develop and evolve 3-D clay printing (Lauerman, n.d. para. 8).

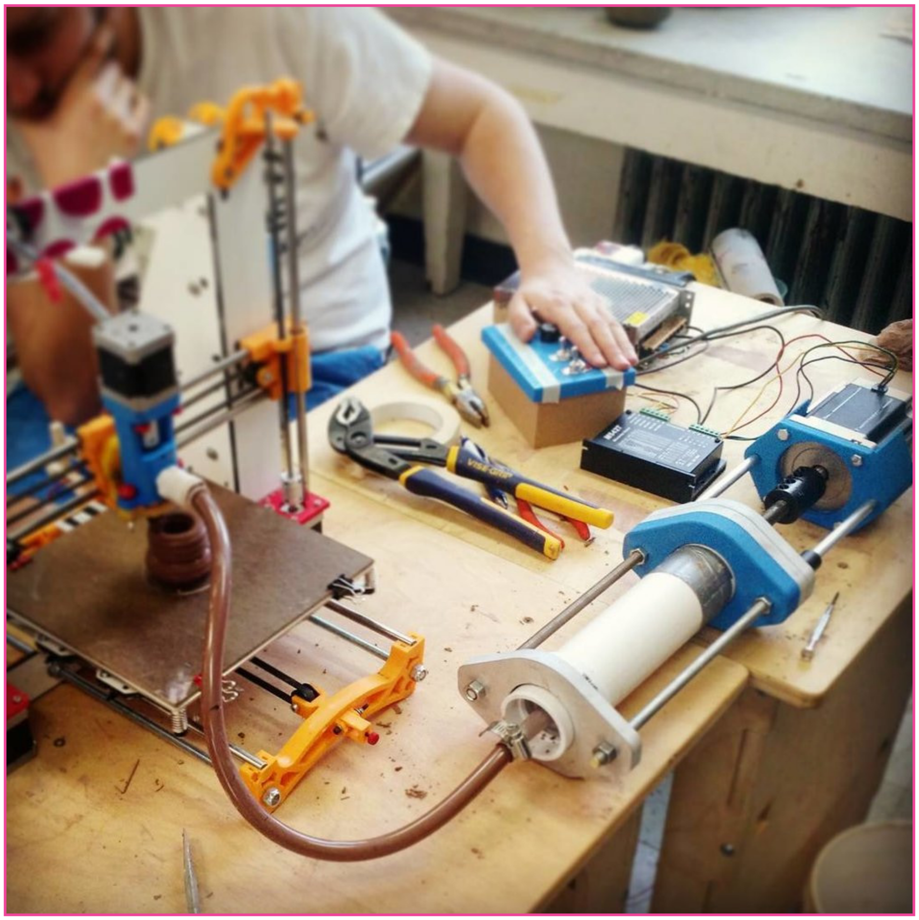

Figure 1. Experimental clay printing with PSU capstone students in 2016.

EXTRUSION

Module IV: Case Study I

PROJECT DESCRIPTION

Although rapid prototyping (3-D printing) technologies have been around since the invention of resin printing* in the late 1980s, clay extrusion printing didn't become a focus of makers and innovators until the early 2000s ("A Detailed History of 3-D Printing and 3-D Printing Technologies", 2017, para. 8).

The Unfold Design Studio in Antwerp first began developing clay extruded projects as a 3-D printing method in 2009, using an altered printer inspired by the 2005 RepRap open source 3-D printing project (Wornier & Verbruggen, 2009, para. 5).

Lauerman himself become motivated to enter the conversation and begin experimenting with this new art-making technique in 2014, when British potter Jonathan Keep shared on an internet forum on how to build a 3-D printer from scratch (Lauerman, n.d. para. 8).

Over time, 3-D printing and digital fabrication technologies have begun to alter the landscape of making and design at all levels ("Shaping Code, Shaping Clay", 2017). From factory production to fine art, 3-D printing sits at the intersection of digital technology and the physical object, giving it the potential to significantly impact the culture of making, manufacturing, and education (Lauerman, n.d. para. 9).

It is because of this potential that artists and innovators like Tom Lauerman offer their ideas to the public via open source content. By sharing his progress with the public, the underlying processes make his ideas accessible, able to be studied or duplicated, and even altered (n.d.). Additionally, the solutions offered by makers like Lauerman are low-cost, openly shared, and self-made, subsequently opening up the field of additive manufacturing to those who might not otherwise have access. This open-source approach empowers the individual "tinkerer" with a limited budget, and encourages creative risk-taking and experimentation that challenges traditional means of creating form ("Shaping Code, Shaping Clay", 2017).

*Resin printing is a form of 3-D printing that doesn't use extrusion. Instead, a liquid called resin is chemically treated to become hard when hit with a laser. A computer-controlled laser is fired at a container of resin, and hardens it, layer by layer, to additively build the form.

EXTRUSION

Module IV: Case Study I

REFLECTION QUESTIONS

1. What other unconventional materials might be used in additive manufacturing (3-D printing)? What kinds of artifacts or projects can you imagine making with a 3-D printer that worked with something other than plastic?
2. What are possibilities does extruded (3-D printed) clay have that traditional clay-making does not? What are possibilities it has that traditional plastic 3-D printing does not? What are limitations of this way of working?
3. How might the open source nature of Lauerman's 3-D clay printer affect how and when is 3-D clay printing used? What are the benefits of this open-sourcing of his design? What are the limits or drawbacks? Could you build a printer with his open-source design? What factors in your life contribute to your answer?

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Warnier, C., & Verbruggen, D. (2009). Ceramic 3-D printing. http://unfold.be/pages/ceramic-3d-printing

IMAGE ATTRIBUTIONS

Figure 1. Retrieved from http://www.tomlauerman.com/3d-printing-in-clay-1/

EXTRUSION

Module IV: Case Study II

FELFIL- OPEN AND DIY FILAMENT EXTRUDER

Felfil is on open-source DIY filament extruder that makes custom filament from recycled plastic pellets and failed print material (Nelli, 2016, para. 1). The project was created by Collettivo Cocomeri (CC), an Italy-based collective founded by alumni from Politecnico di Torino with a focus on multi-disciplinary and sustainable design solutions (Severini, Posquero, Crovino, & Mesiana, 2017).

The Felfil project focuses on open-source solutions for recovering and repurposing plastic waste to reduce its environmental impact. It also aims to address concerns regarding the cost of, and access to, additive manufacturing for individuals (Grunewald, 2015, para. 3). The open-source nature of the project promotes equitable access to additive manufacturing by effectively utilizing unsuccessful prints, old models, packaging or plastic pellets to reduce waste and save money for makers (Severini et. al., 2017).

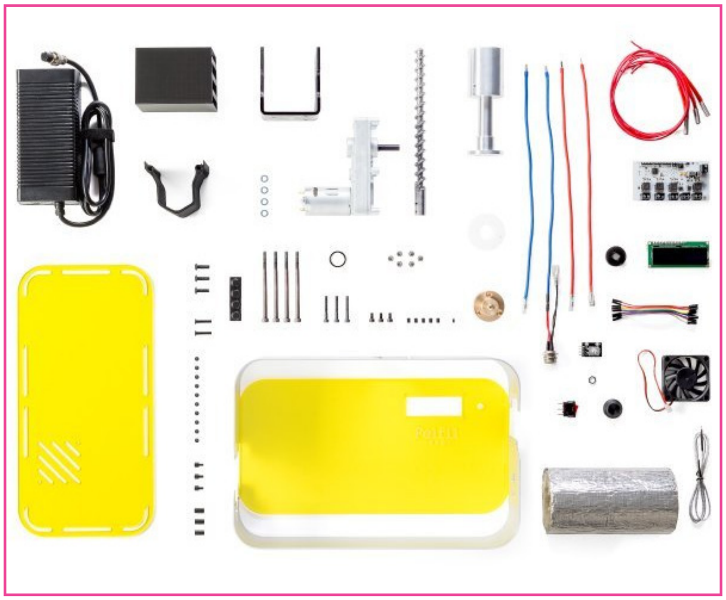

Figure 1. The Felfil EVO kit. Makers can buy an assembled Felfil filament extruder, or save money by buying the kit and assembling the device themselves. This aims to keep the project equitable to creative people with different resources.

Figure 2. An assembled Felfil extruder.

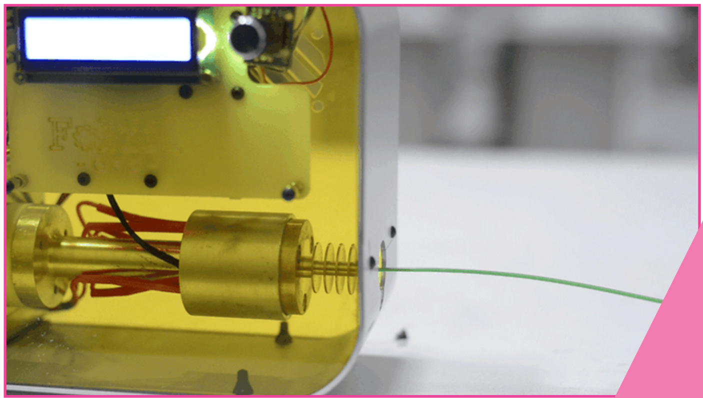

Figure 3. A Felfil device, extruding filament made from recycled pellets.

EXTRUSION

Module IV: Case Study II

PROJECT DESCRIPTION

As 3-D printing increases in popularity and applications, many in the field are concerned with its environmental impacts and the future of plastic waste management (McAlister & Wood, 2014). Many of the filaments available on the market are created from new polymers, and while there are biodegradable materials such as Polylactic Acid (PLA) filament with the potential to lessen the burden of plastic waste over time, it can take years for the decomposition process to be realized (Brice, 2017).

An unsettling reality of additive manufacturing is that the process can end up leaving behind a substantial amount of waste (Kurman & Lipson, 2013). On rare occasions this plastic byproduct can be reused, but in most cases the material properties of the plastic become corrupted as a result of printing and are therefore unfit for recycling (2013).

In direct response to this issue are innovations like Collettivo Cocomeri's Felfil. Felfil is a DIY filament extruder invented by Alessandro Severini, Fabrizio Pasquero, Giulio Cravino, and Fabrizio Mesiana (Nelli, 2016, para. 3). It was initially developed as part of a thesis project born from an Ecodesign course at the Politecnico di Torino in 2011 (Severini, et al., 2017). The Felfil extruder can treat any thermoplastic polymer which has a melting temperature of up to 300 ° C, giving it the potential to create filament from a broad range of materials such as plastic bottles in addition to failed print material and raw plastic pellets (Severini, et al., 2017).

As such, the goal was to increase the variety of available materials for extrusion, thus providing the public with the ability to create their own custom filament for 3-D printing that is fully recycled and therefore more financially and environmentally sustainable for independent makers (Nelli, 2016, para. 4).

Since its conception, the original Felfil extruder has been further developed into the Felfil EVO, a streamlined electronic system compatible with Arduino, a programmable device popular with makers (Nelli, 2016, para. 6). In the tradition of the maker movement, the instructions for the original Felfil extruder and the Felfil EVO are open-source and readily downloadable from the project's web site, https://www.felfil.com/ (Severini, et al., 2017).

EXTRUSION

Module IV: Case Study II

REFLECTION QUESTIONS

1. The plans for the Felfil extruder were released under the Creative Commons License, which allows anyone to build or modify their own versions. What are the potential implications of individuals creating custom filaments, in terms of both design and sustainability issues?
2. What kinds of limitations may plastic filament have? In addition to plastic waste, what are some of the potential environmental impacts to consider when weighing the sustainability of 3-D printing against other forms of manufacturing?
3. In what ways can extrusion-based 3-D printing technologies solve current issues of sustainability in manufacturing and design? What new issues/problems might they produce?

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IMAGE ATTRIBUTIONS

Figures 1 and 2. Retrieved from https://felfil.com/felfilevo-filament-extruder/

Figure 3. Retrieved from https://atmelcorporation.wordpress.com/2015/10/22/felfil-evo-is-an-open-source-filament-extruder/

EXTRUSION

Module IV: Handout

EXTRUSION

Extrusion has been used for forming many materials for centuries, long before 3-D printing. If you've ever squirted Play-Doh through a hole or frosting out of a tube, you've used extrusion.

Most common 3-D printers use extrusion to build forms out of plastic filament. By experimenting with a hand-held extrusion tool - a 3-D pen - you can develop an embodied understanding of how 3-D printing works, and what makes for an effective 3-D print.

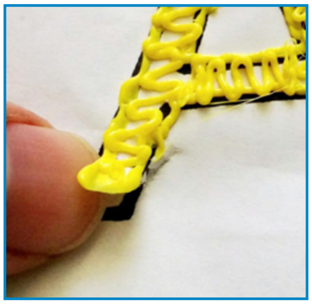
Monogrammed business card by Amanda Salcido.

"Love," by Robert Indiana.

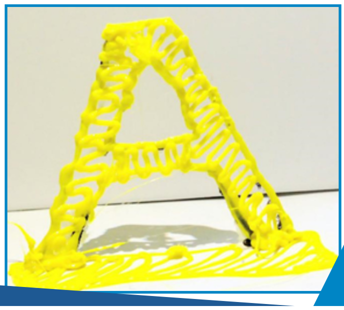
ACTIVITY 1: EXTRUDING with 3-D PENS

A good starting activity with 3-D pens is to create 2-D shapes like letters, and then peel them off of the page.

1. On paper, with a thick pen, develop an interesting shape using letter forms. You could create a **monogram** by artfully combining your initials, or create **typographic art** that emphasizes a meaningful word in a visually interesting way.
2. Using your warmed-up 3-D pen, outline your letterforms on the paper and use zig-zagged lines to fill it in. Peel the letters off of the paper after it cools down.



3. Next, create a rectangular base plate using the same strategy. Then attach your letterforms to it with the 3-D pen.



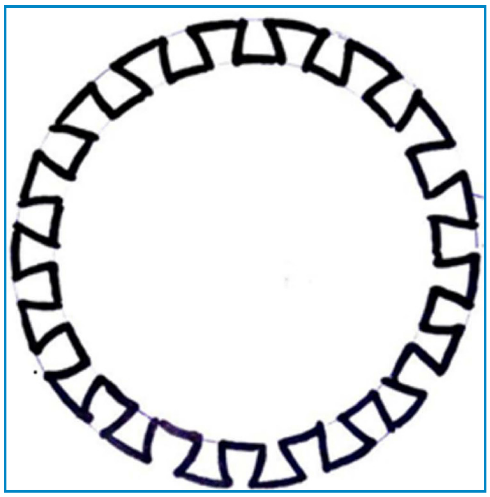
EXTRUSION

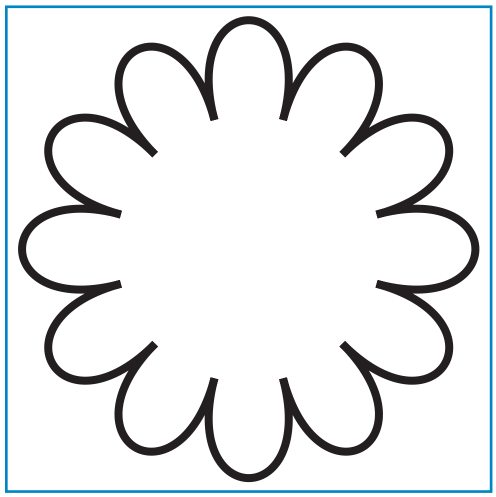
Module IV: Handout

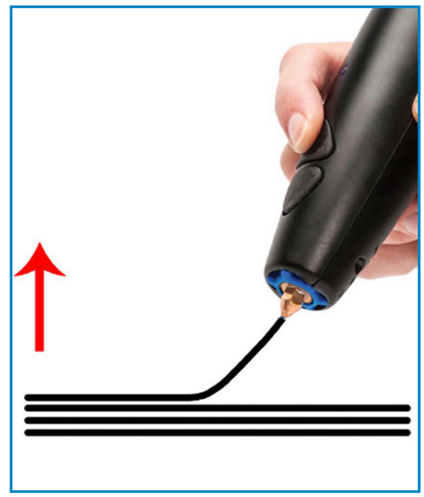
ACTIVITY 2: ADDITIVELY BUILDING A 3-D FORM

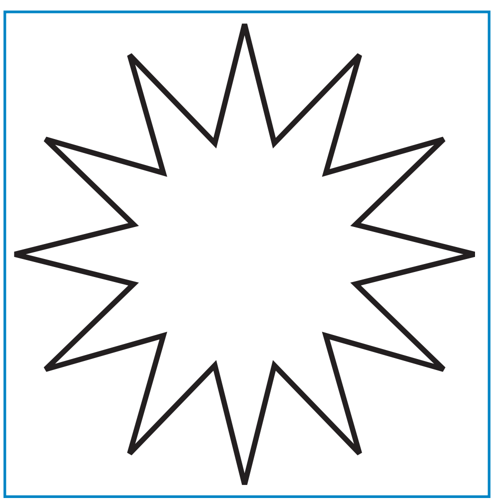
By building up from a 2-D shape layer-by-layer, a 3-D pen can build a 3-D shape using a similar additive process to a 3-D printer. In this exercise, we'll experiment with building up form.

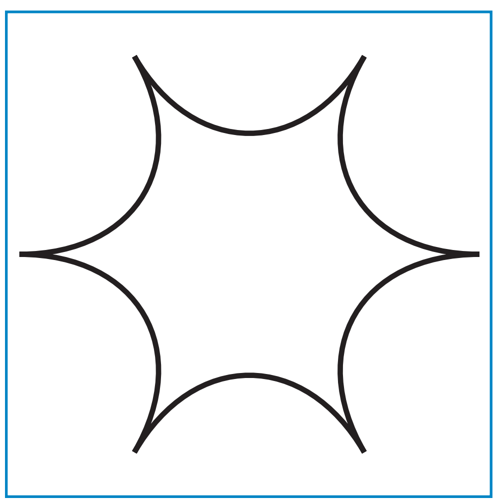
1. Try tracing one of the shapes below repeatedly in order to increase the height of your object. How tall can you make your structure?

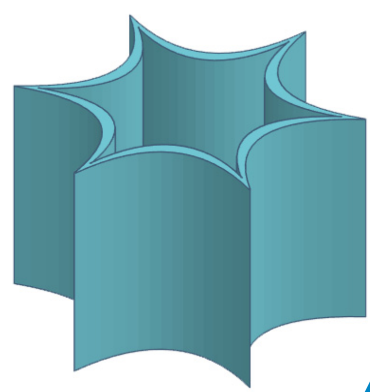










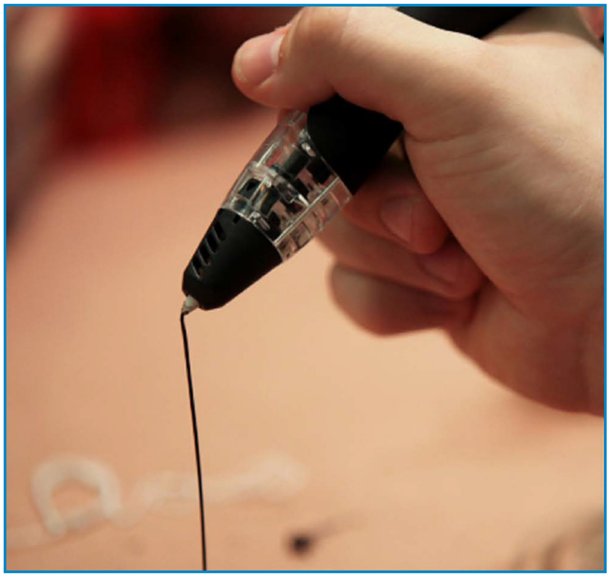


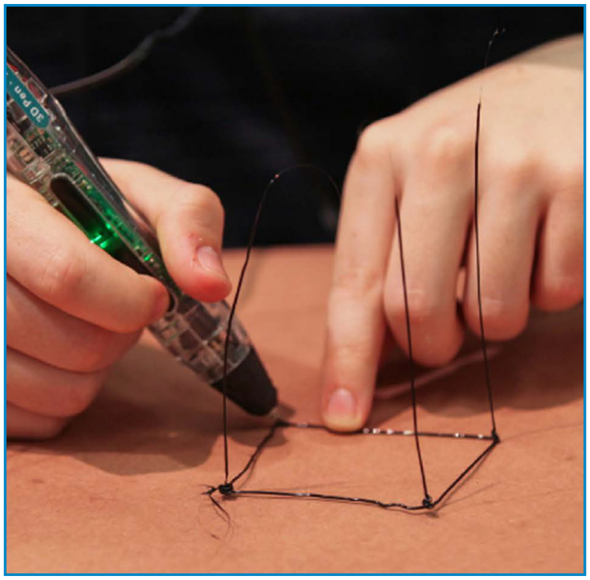
EXTRUSION

Module IV: Handout

ACTIVITY 3: DRAWING FORM - CREATE YOUR OWN FREE-FORM DESIGN

1. The ability to make freehand 3-D drawings in space is a unique feature of the 3-D pen. To begin, start with a solid anchor point by making a large dot of plastic on a flat surface.
2. From the anchor point, lift the pen slowly and carefully into the air. Try to match the speed at which the pen's extruder pushes out the plastic. When you reach the point where you want the line to end, hold the pen still for a few seconds without extruding new material. This will let the filament harden before you pull the pen away.





3. As you create your 3-D free form design, consider how you might use different colors and filaments in meaningful or visually-interesting ways.