

MECHANICAL & NUCLEAR ENGINEERING

INNOVATION LAB

Introductory Guide to 3D Printing



MakerBot®

MakerBot Rapid Prototyping Equipment User Guide

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INTRODUCTION TO PROTOTYPING OVERVIEW

We believe that 3D printing and modeling offer a rich way to enhance and reinforce science, technology, engineering, art, math, and design skills already being taught in the various classroom environments. Presenting real-world challenges to students engages them with a hands-on approach to problem solving.

Everyone's journey when approaching 3D printers is different. It doesn't matter what your background is at this time, because anyone can learn to create with 3D printing through project-based learning and experimentation.

3D printing is a tool that allows people to create new things, limited only by imagination. 3D printing and modeling projects should empower you to take chances and make mistakes. Though it may sound unconventional, we encourage young designers to fail early and often, thereby acquiring the problem-solving skills and confidence that will convince them to keep trying until their designs succeed.

Use this document as a starting point to help you understand 3D printing and educate yourself in the basics of 3D printing. Before you know it, you will be creating amazing things that you never thought possible.

Inspiration is all around you. We can't wait to see what you make!

LEARNING OBJECTIVES

Our goal is to provide you with:

- A solid foundation to learn and understand 3D printing
- Ideas for bringing 3D printing from a concept to a realization
- Knowledge about different types of 3D modeling software and their strengths
- Foundational projects that make it easy to integrate 3D printing into your specific design
- Confidence to take projects further and tailor them to your needs

Our goal is to help students:

- Increase their planning, critical thinking, reasoning, and creative skills
- Develop strong communication and collaboration skills
- Practice visualization and decision making
- Know how and when to use this technology and how to choose appropriate tools
- Learn the importance of iteration in the design cycle
- Understand how to use a 3D printer

3D PRINTING AS A TOOL

Remember that a 3D printer is another tool in your toolbox, one that's immensely helpful for creating a range of objects, both simple and complex. By learning the ins and outs of this emerging technology, you can find new and interesting uses beyond just the printer itself.

HOW TO USE THIS DOCUMENT

Use this document as a starting point to approach 3D printing. In the following sections, we'll share our knowledge on 3D Printing associated with MakerBot Prototyping equipment. However, what you can do with a 3D printer doesn't stop at what has been outlined. 3D printers can be a part of any subject if you understand a few basics and think outside the box.

The first portion of this book focuses on how MakerBot Replicator 3D Printers work and how to understand the technology of the printers themselves. Each section provides you with background knowledge, learning objectives, terminology, example activities, and discussion materials.

The second portion covers Three Ways to Make, the three major approaches to finding models to 3D print. We will go over downloading from an online community and designing models from scratch using a variety of 3D design programs.

SECTION 1:

INTRODUCTION TO 3D PRINTING

While desktop 3D printing has only been widely accessible to consumers in recent years, the technology has been around commercially since the 1990s. Several types of 3D printers have been developed, but throughout this document we'll focus on the technology that MakerBot Replicator 3D Printers utilize. Let's dive in and learn the basics.

BACKGROUND: WHAT IS 3D PRINTING?

3D printing is the process of taking a digital model and making it a physical object. When you write a document on your computer, you create a digital version, then press "Print" to create a physical copy. 3D printers work the same way with one more dimension.

Unlike a traditional subtractive manufacturing process, in which an object is carved out of a piece of material, 3D printing is an additive manufacturing process in which an object is built over time by stacking layers of material directly on top of each other. These layers fuse together to create 3D printed objects.

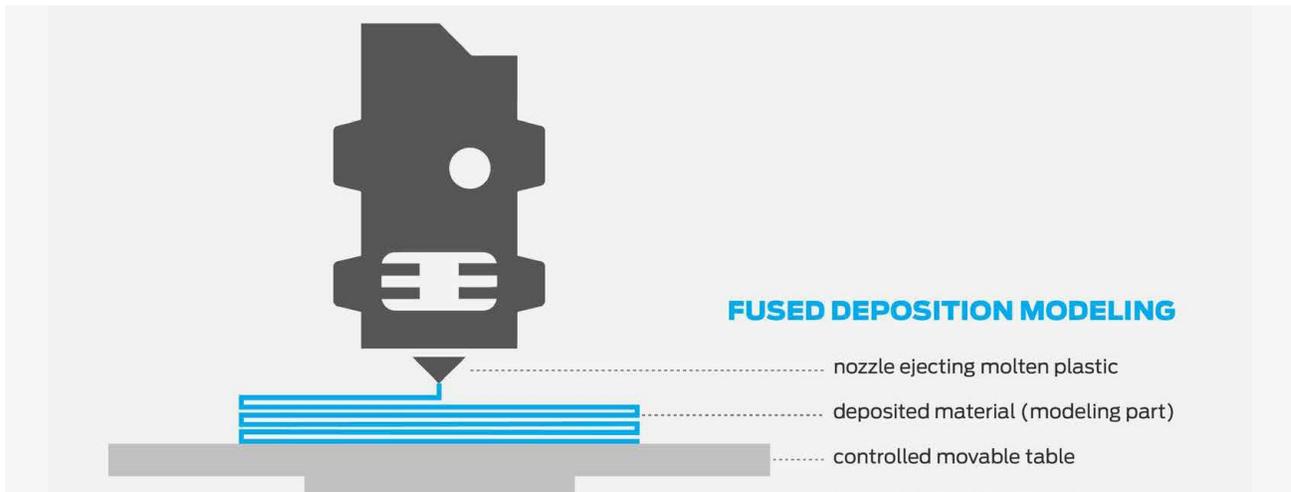
Question: Can you think of any other examples of things that are made by stacking layers? (Building blocks, cakes, stones, etc.) What others can you think of at this time?

LEARNING OBJECTIVES

- Understand what 3D printing is and how it works
- Know what kind of technology MakerBot Replicator 3D Printers use and the history of the technology

TERMINOLOGY

- **FDM:** Fused deposition modeling, the 3D printing technology used by MakerBot
- **Slicing:** The act of turning a digital 3D model into thin layers used for 3D printing
- **Filament:** Material used to build your 3D prints
- **Extruder:** The "hot glue gun" of your 3D printer; it uses filament to draw out the layers of your 3D prints
- **Build plate:** Surface on which prints are built



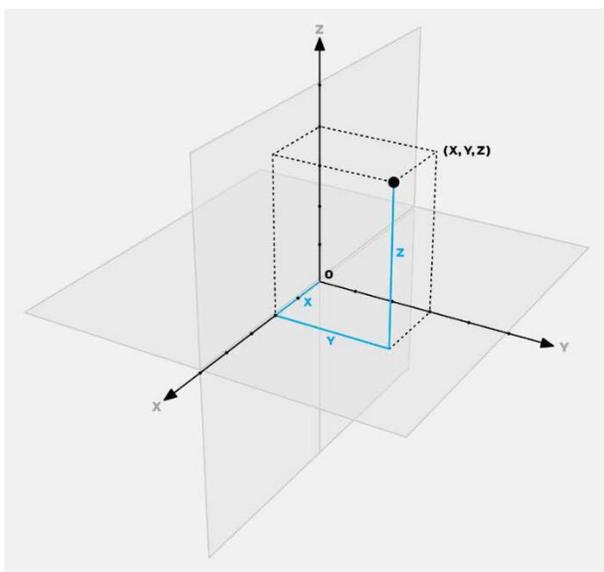
MAKERBOT TECHNOLOGY

Fused deposition modeling (FDM) is the additive manufacturing technology that MakerBot Replicator 3D Printers utilize to create 3D models.

Question: What are other 3D printing technologies? (SLA, SLS, PolyJet, etc.)

How does it work? FDM printing starts with a digital 3D model that's "sliced" into thin layers. On the printer, filament is fed into an extruder that draws out each slice, layer by layer. Over time, these thin layers stack on top of each other until your object is finished.

History: Scott Crump invented FDM in the late 1980s by creating a system to draw out layers on an x-y-z matrix. Although 3D printing has been around since then, the technology has only become widely accessible in the past five years. Just like the rise of computers, the 3D printing revolution started with a select few. In 2009, MakerBot brought desktop 3D printers to market and created a new wave of accessible 3D printing.



The Cartesian Coordinate System

Example: Imagine using a hot glue gun, draw out a square. Let it cool and repeat the process, directly on top of the first square. This demonstrates the original idea behind FDM 3D printing. Alternatively, draw out the layers with frosting or whipped cream.

The Cartesian coordinate system is a method for specifying the location of points in a 2D or 3D grid. Every 3D model has its own unique set of coordinates that defines its shape. Our printers use these points as instructions to create your object.

Once a layer is drawn out, the build plate takes a step along the z-axis. Then the next layer is drawn on top. Over time, the layers stack together, kind of like the layers of a multi-tiered birthday cake, to create your 3D object.

KNOWLEDGE CHECKS

- What technology do MakerBot Replicator 3D Printers use?
- How does the technology work?

Going further: Explore MakerBot Thingiverse (<http://www.thingiverse.com/>) and GrabCAD, great places to get inspiration for your next project. Both are online libraries containing hundreds of thousands of free 3D models to download and 3D print.

SECTION 2:

HOW TO USE A 3D PRINTER

This section focuses on the MakerBot Replicator Desktop 3D Printer but includes callouts for other MakerBot 3D printers. All material covered should be applicable regardless of which 3D printer you're using.

LEARNING OBJECTIVES

- Understand how to set up a MakerBot Replicator 3D Printer
- Be able to identify and define key components of your printer
- Define leveling and its importance

TERMINOLOGY

- **Gantry:** A pulley and belt system that moves the carriage
- **Carriage:** The part of the printer that carries the extruder on the x-axis and y-axis
- **Build plate:** Surface on which prints are built
- **MakerBot PLA Filament:** The best and most consistent filament designed for MakerBot 3D Printers
- **MakerBot Replicator Smart Extruder:** The “hot glue gun” of your 3D printer; it uses filament to draw out the layers of your 3D prints
- **Leveling:** Process to ensure proper distance between the nozzle of the Smart Extruder and the build plate
- **Purge line:** Straight line drawn across the front of the build plate at the start of every print
- **Firmware:** The code installed on the printer's hardware that allows it to operate
- **MakerBot Desktop:** Free 3D printing software for discovering, managing, preparing and sharing your 3D prints

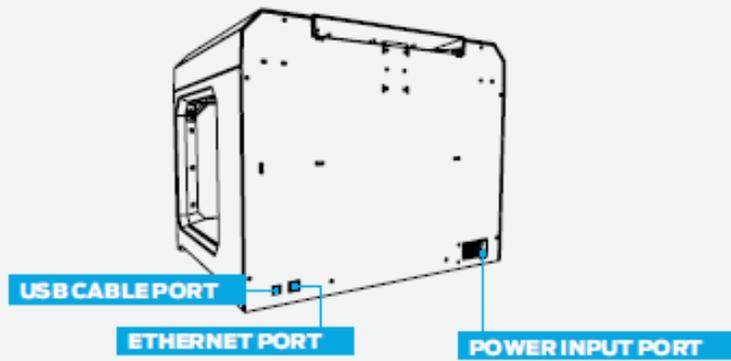
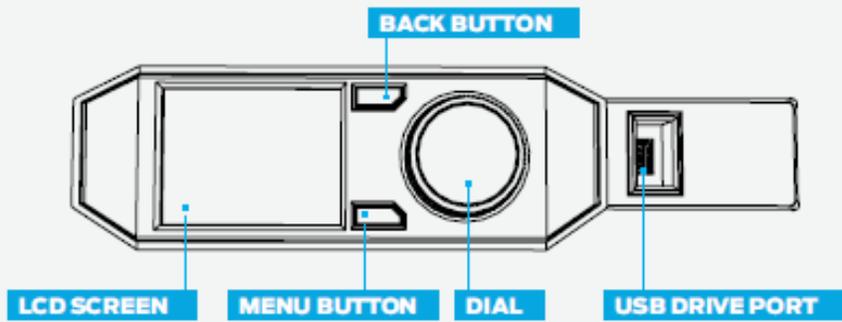
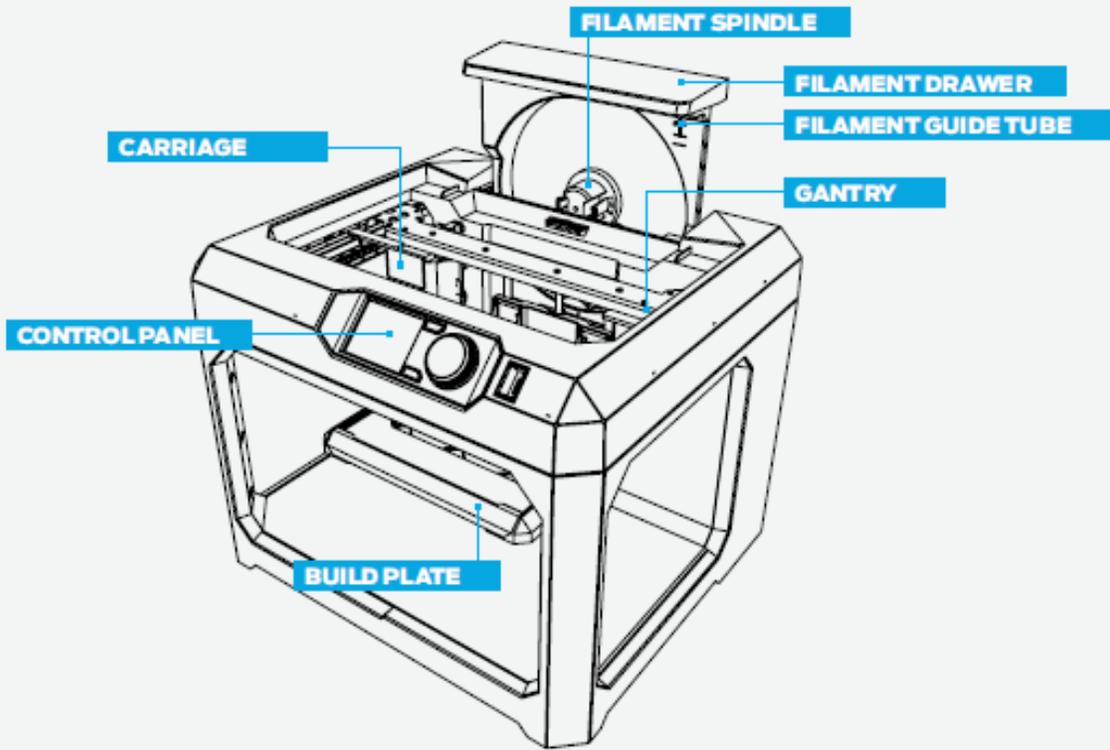
UNBOXING AND SETUP

Refer to your User Manual for detailed unboxing and setup instructions. Make sure you're running the most current version of MakerBot Desktop and Firmware before starting to print. More information can be found on page 53 in the MakerBot Replicator User Manual.

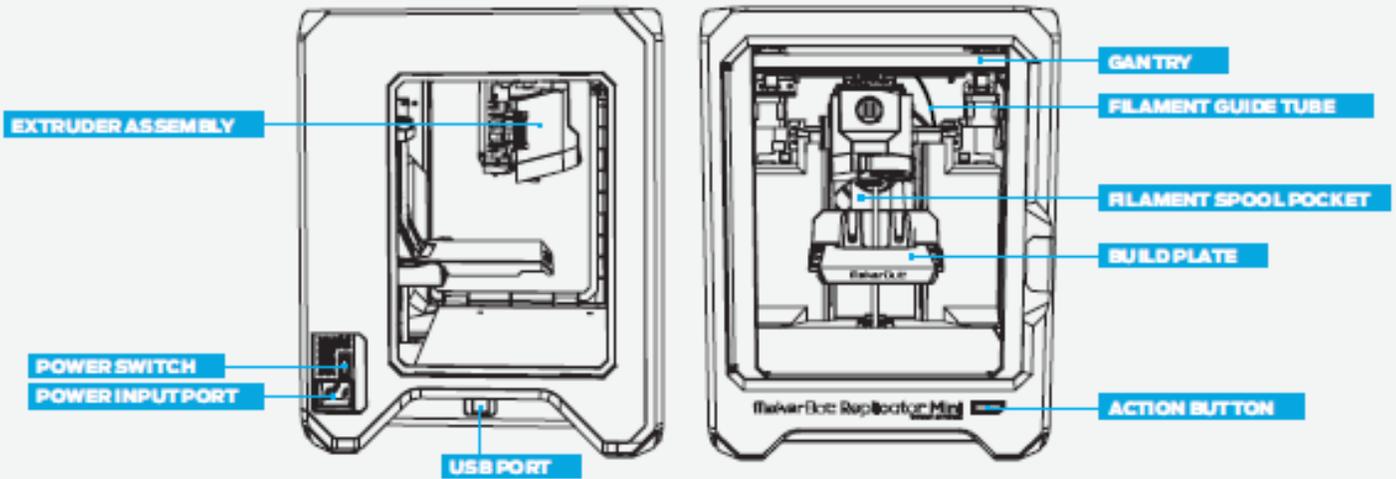
The following diagrams detail the main components of each of the printers.

Activity: Study the following diagrams and terminology of each of the printers. After your review, correctly identify and define the main components.

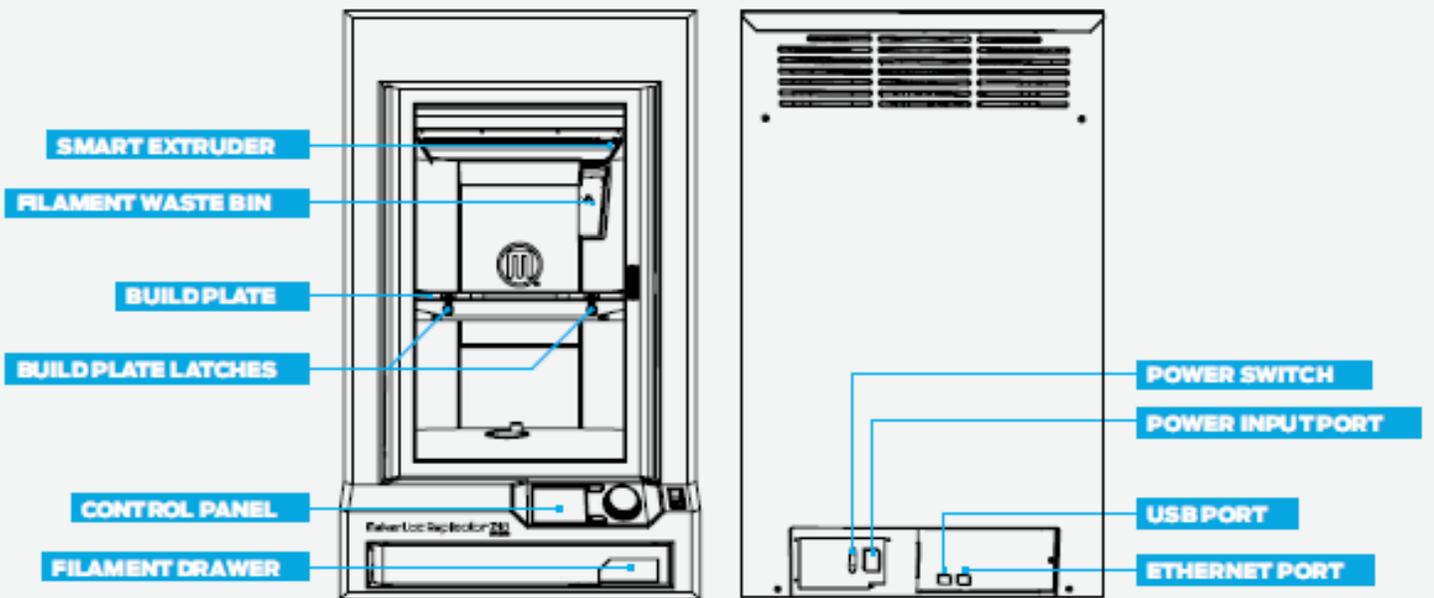
MAKERBOT REPLICATOR DESKTOP 3D PRINTER



MAKERBOT REPLICATOR MINI COMPACT 3D PRINTER



MAKERBOT REPLICATOR Z18 3D PRINTER



PRINTER SETUP LOGISTICS

Printer and Filament Placement

Placement of your printer(s) can have an impact on its use as well as its performance:

- Set up your printer in a stable location that doesn't have excessive temperature fluctuations throughout the day (e.g., do not place it near an air-conditioning vent).
- It's helpful to have a space near the printer to clean prints off. You'll also need a place for print tools (see Suggested Tools below).
- Store filament in a cool, dry location, preferably in the original packaging, to help guard against humidity.

Other Considerations

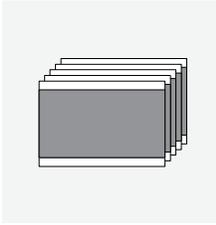
- Placing 3D printer(s) in your classroom allows for a lot of student interaction, hands-on time, and printing during class, but lessens visibility and accessibility to the school community.
- Placing 3D printers(s) in a communal space (library, front office, etc.) ensures visibility and encourages use by students, faculty, and staff, but complicates the logistics of printing during class.
- If the printer is in an openly accessible area, keep the filament and Smart Extruder in your desk or in a closet to prevent unwanted use.

Suggested Tools

The following tools are great to have near your printer for print cleanup and post-processing:

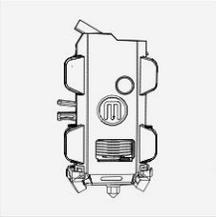
- **Thin metal craft spatula** – for removing prints from the build plate without tearing the tape.
- **Needle-nose pliers** – for removing support material.
- **Small wire-cutting pliers** – for removing support material and cleaning off excess filament.
- **Tweezers** – for removing support material.
- **Hand applicator** – for applying build plate tape and smoothing out air bubbles.
- **Thingiverse** (<http://www.thingiverse.com/>) has a large collection of printable tool holders. The task of organizing your tools is also a great opportunity for one to design and print their own tool holders.

PARTS INCLUDED IN ACCESSORY KIT



Build Plate Tape

Five precut sheets to apply to your build plate. If you have a MakerBot Replicator Z18 3D Printer, you have one sheet.



Smart Extruder

The MakerBot Replicator Smart Extruder is an extruder with a lot of built-in sensors. The sensors help detect filament absence and clogs. The extruder attaches to the carriage via magnets and pins.



Build Plate

The build plates of MakerBot Replicator 3D Printers vary in type and size, depending on the model. We don't recommend printing directly onto the build plate without protective tape.



Filament Spool

2 lb. spool of MakerBot PLA Filament. PLA is polylactic acid. MakerBot PLA Filament is a nontoxic resin made of sugar derived from field corn and has a semisweet smell (like waffles) when heated.



USB Cable

The USB cable is available for local printing or to set up Wi-Fi capabilities.

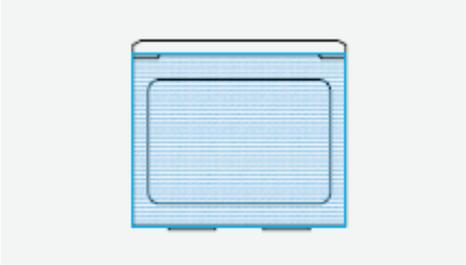


Power Cable

Your printer needs to be plugged into a power source of 100–240 VAC.

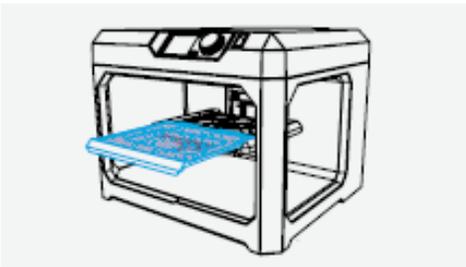
PREPRINT CHECKLIST

Before every print, check the following:



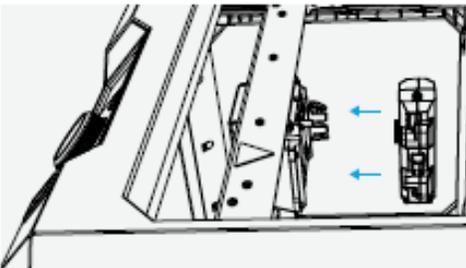
Build Plate Tape Applied

Build plate tape is on the build plate and (mostly) free of tears. If there are more than a few minor tears, remove the build plate and apply new tape before printing.



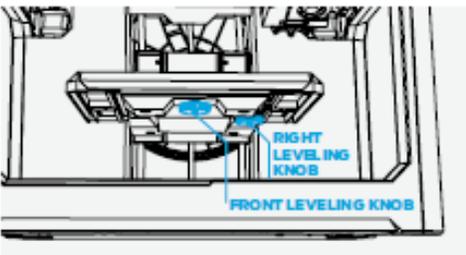
Build Plate Installed

The build plate has been loaded properly onto the Z Stage.



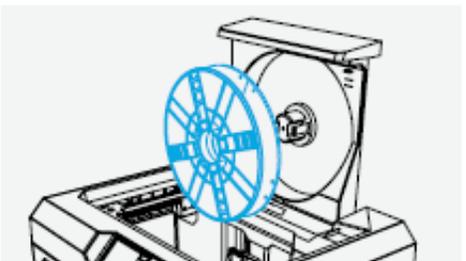
MakerBot Replicator Smart Extruder Attached

A Smart Extruder is attached to the carriage. Double-check that the Smart Extruder is attached by scrolling the dial to **Utilities > Attach Smart Extruder**



Build Plate Is Level

If you were not the last person to use the printer, you should level your build plate before printing. Scroll the dial to **Utilities > Level Build Plate** and follow the on-screen instructions until assisted leveling is complete.



Filament Loaded Properly

Ensure that filament is loaded into the filament drawer correctly. Change filament using the **Filament** menu. When loading new filament, clip off the end, making a pointed tip to prevent clogs in your extruder

WHAT IS LEVELING? WHY IS IT IMPORTANT?

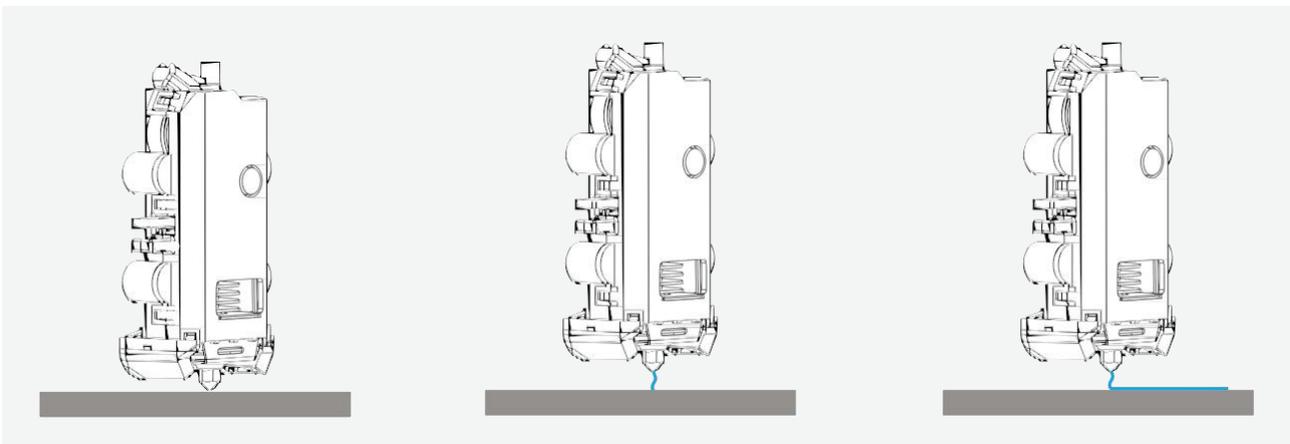
A level build plate means that the distance between the nozzle of the extruder and the build plate is the same at every point. A build plate that's not level will usually result in a poor print. For example, if the build plate is tilted slightly upward on the right side, then the first layer of the print will be squished on the right side and loose on the left side. The first layer of your print is the most important; it's like a foundation for your house. If it isn't laid correctly, the rest of the house could be affected.

The MakerBot Replicator Smart Extruder tests this distance automatically. All you need to do is adjust the build plate so it's not too close or too far away. If the printer has been moved around recently, or you're not sure when it was last leveled, it's safer to level your build plate before printing. Scroll the dial to **Utilities > Level Build Plate** and follow the on-screen instructions until assisted leveling is complete.

Leveling your build plate is perhaps the most important part of setting up and maintaining a 3D printer. If your prints are not adhering properly, chances are, you need to re-level the build plate.

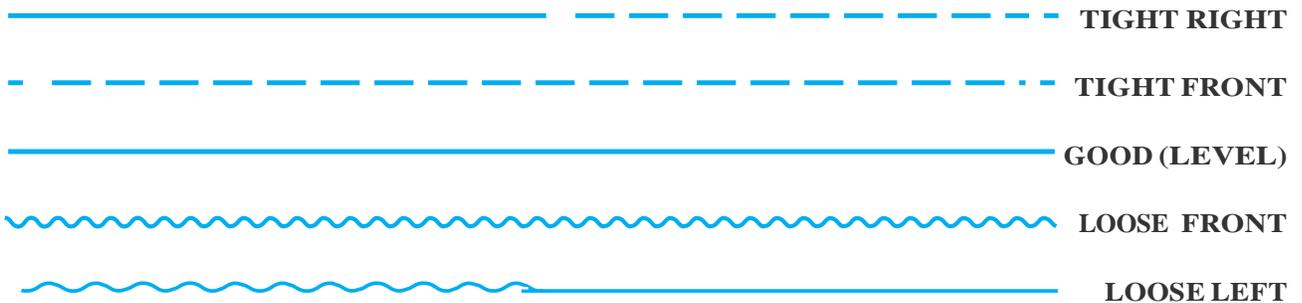
When To Level

- The first time you unbox a new printer or attach a new Smart Extruder
- After changing the printer's location
- If filament appears squiggly on the first layer of a print
- If you hear a clicking sound on the first layer of a print
- If the nozzle is cutting into the build plate tape or filament is blocked from extruding
- After firmware updates
- When you can't remember the last time the build plate was leveled



Activity: The MakerBot Replicator draws a straight line across the front of the build plate at the start of every print. This “purge line” can tell you a lot of important information about your printer.

1. Start a sample print. Pay close attention to the purge line.
 - a. What does the purge line look like?
 - b. What does this purge line tell you?
2. Look at the following purge line examples. Explain what each tells you about the printer.



3. Save them! Label them on a sheet of paper for future reference.

KNOWLEDGE CHECKS

- What are the key components of a MakerBot Replicator?
- Why is it important to level your printer’s build plate?
- What should you check before starting every print?

I’VE SET UP MY PRINTER; NOW WHAT?

There are two major components of 3D printing with a MakerBot Replicator. One is the hardware, the 3D printer itself. The other is the software, MakerBot Desktop, which prepares your 3D designs for printing. Next, we’ll explore how to set up a file for printing and the kinds of settings you can adjust to modify your 3D print.

SECTION 3:

PREPARING FILES FOR PRINTING

Once your printer is set up, download, install, and open the MakerBot Desktop software from www.makerbot.com/desktop (software is installed on engineering school computers). The primary function of MakerBot Desktop is to turn 3D models into 3D printable files. MakerBot Desktop consists of five sections: **Explore**, **Library**, **Prepare**, **Store**, and **Learn**. The **Prepare** tab helps you translate from the digital to the physical world.

LEARNING OBJECTIVES

- Explore MakerBot Desktop and its functions
- Learn essential considerations when preparing models for 3D printing
- Use MakerBot Desktop to properly prepare files
- Learn the significance of print settings (resolution, infill, shells)
- Distinguish the main file types associated with MakerBot Desktop

TERMINOLOGY

- **STL:** Stereolithography file format, commonly used in 3D printing
- **OBJ:** Object file format, commonly used for on-screen visualization and 3D printing
- **Build volume:** Maximum physical size you can print on your printer
- **Layout:** Arrangement of STL and/or OBJ files within MakerBot Desktop
- **Thing:** File type for saved MakerBot Desktop layouts
- **Slice:** Process of exporting a .makerbot or .x3g file
- **.makerbot:** File type that MakerBot Replicator 3D Printers use to print; only readable by these printers
- **.x3g:** File type that is used by previous generations including the MakerBot Replicator 2 and MakerBot Replicator 2X
- **Resolution:** The surface quality of a 3D print, dictated by the height of each layer
- **Raft:** Flat surface that provides a large foundation for print adhesion
- **Overhang:** When a layer extends outward, potentially unsupported, over the previous layer
- **Supports:** Removable scaffolding structure built to help parts of an object that are in midair with no material below (see **Overhang**)
- **Bridge:** When a layer prints in the air between two pillars
- **Infill:** Hexagonal support structure built in the interior of the model
- **Shells:** Outside walls that make up the perimeter of your object
- **Print-in-place:** A design with parts that can move immediately after printing
- **MakerBot Cloud Library:** Allows you to access files from the cloud, either on your printer or within MakerBot Desktop

USING MAKERBOT DESKTOP TO PREPARE FILES

On the main screen, there are five options at the top.

- **Explore** gives you access to Thingiverse and the hundreds of thousands of 3D printable objects designed by the Thingiverse community. Use Explore to search Thingiverse for inspiration or new things to print, then save them to your Collections or prepare them for printing.
- **Library** gives you access to your MakerBot Cloud Library and helps you organize your 3D model files. Use it to access things you've collected on Thingiverse or purchased from the MakerBot Digital Store as well as your own original models.
- **Prepare** is where you'll turn 3D models into print files. Bring 3D models into the Prepare screen to manipulate them on a virtual build plate. Then specify print options and send print files to your MakerBot Replicator 3D Printer.
- **Store** lets you buy print files for premium 3D models. The MakerBot Digital Store sells original, fun, and collectible digital content specifically designed for MakerBot Replicator 3D Printers. When you buy a model in the MakerBot Digital Store, a print file for your MakerBot Replicator will be added to your MakerBot Cloud Library.
- **Learn** provides video tutorials on common processes such as Exporting Files, Preparing to Print, and Exploring Thingiverse. Look for new tutorials with each update of MakerBot Desktop. You can also replay the MakerBot Desktop walkthrough in the Learn tab.

To review: Use **Store** and **Explore** to find 3D models, **Library** to keep them organized, and **Prepare** to send them to your MakerBot Replicator for printing. Use **Learn** to view tutorials.

Prepare

Prepare in MakerBot Desktop is where you get to decide how your 3D printer will build your model. Similar to Print Preview in 2D printing, Prepare serves as the utility where you pick your settings. Once you've decided how you want your object to be printed, your 3D model will be translated into a language that the printer can understand. This is referred to as **slicing** a file. The **.makerbot** file determines the path that your printer takes to build your model.



Steps in preparing files for 3D printing in the MakerBot Innovation Center:

1. Design the model in any CAD Software (Autodesk, NX9, SolidWorks, etc.)
2. Save the file as an .STL (stereolithography) file
3. Open MakerBot Desktop
4. Add .STL file(s) and begin preparing file(s) for print (.makerbot files)



Getting to Know the Interface

In Prepare, various buttons help you set up your layout.

Top Section (7–12)

- These buttons will let you add files, determine print settings, and export files.

Side Section (1–6)

- These buttons will allow you to control the layout of prints on the build plate.

Bottom Section (13)

- This button will let you monitor and control any printer you're connected to.

Which File Types Can Makerbot Desktop Read?

MakerBot Desktop can open 3D models in the **STL** and **OBJ** formats. These two formats have become an industry standard across nearly all 3D modeling programs. It can also open **Thing** files, which are native to MakerBot Desktop.

Which Files Types Can I Print With?

The printer you select in the Prepare tab dictates which file type your model will be saved as upon Export. Once files are sliced into these formats, they're only readable by the printer.

MakerBot Replicator Desktop 3D Printer, MakerBot Replicator Z18 3D Printer, and MakerBot Replicator Mini Compact 3D Printer: **.makerbot**

MakerBot Replicator 2 Desktop 3D Printer, MakerBot Replicator 2X Experimental 3D Printer, and MakerBot Thing-O-Matic: **.x3g**

How Big Can I Print?

Each printer has a different **build volume**. When you select the proper device in the Device dropdown menu, the build volume will virtually display to show your maximum possible print size.

- MakerBot Replicator Mini: 3.9 L x 3.9 W x 4.9 H in
- MakerBot Replicator: 9.9 L x 7.8 W x 5.9 H in
- MakerBot Replicator Z18: 11.8 L x 12.0 W x 18.0 H in
- MakerBot Replicator 2X: 9.7 L x 6.0 W x 6.1 H in

WALKING THROUGH MAKERBOT DESKTOP



Bringing in a File

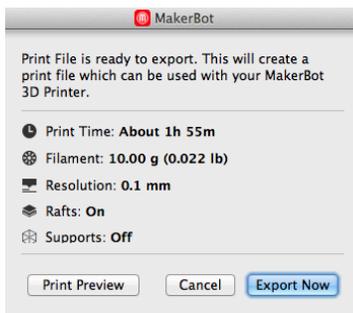
Select **Add File** from the top bar in the **Prepare** tab to open your **STL** and **OBJ** files in MakerBot Desktop.

Creating a Layout

A layout is how you arrange your file(s) in your build envelope. You can print one at a time or add multiple objects. You can easily duplicate objects by copying and pasting.

What Do I Need to Consider?

With every file, you need to consider where you want it placed and how you want it oriented on the build plate. You can also adjust the size of your object if needed. Here are some helpful tips for laying out your print:



- Place the largest flat surface of your object on the build plate.
- If your object doesn't have a flat surface, pick the section with the most surface area.
- Place print(s) as close to the center of the build plate as possible.
- Export **Print File** and always check **Print Preview** to see how different layouts will build before sending to your printer.

How Do I Adjust the Layout?

Move: Controls the positioning of your object(s) in relation to the build plate. Click it again to open the submenu. **On Platform** and **Center** are useful tools for quickly positioning your object(s).

TIP: GENERALLY, THE MOST LEVEL AREA OF THE BUILD PLATE IS THE CENTER.

Turn: Rotates your object in relation to the build envelope. Click it again to open the submenu. Use **90° snaps** and **Lay Flat** to flip the object around.

TIP: CHANGING THE ORIENTATION OF A PRINT CAN AFFECT MANY CHARACTERISTICS OF YOUR MODEL. WE ENCOURAGE YOU TO EXPERIMENT WITH A VARIETY OF ORIENTATIONS TO SEE WHAT EACH CAN AFFECT

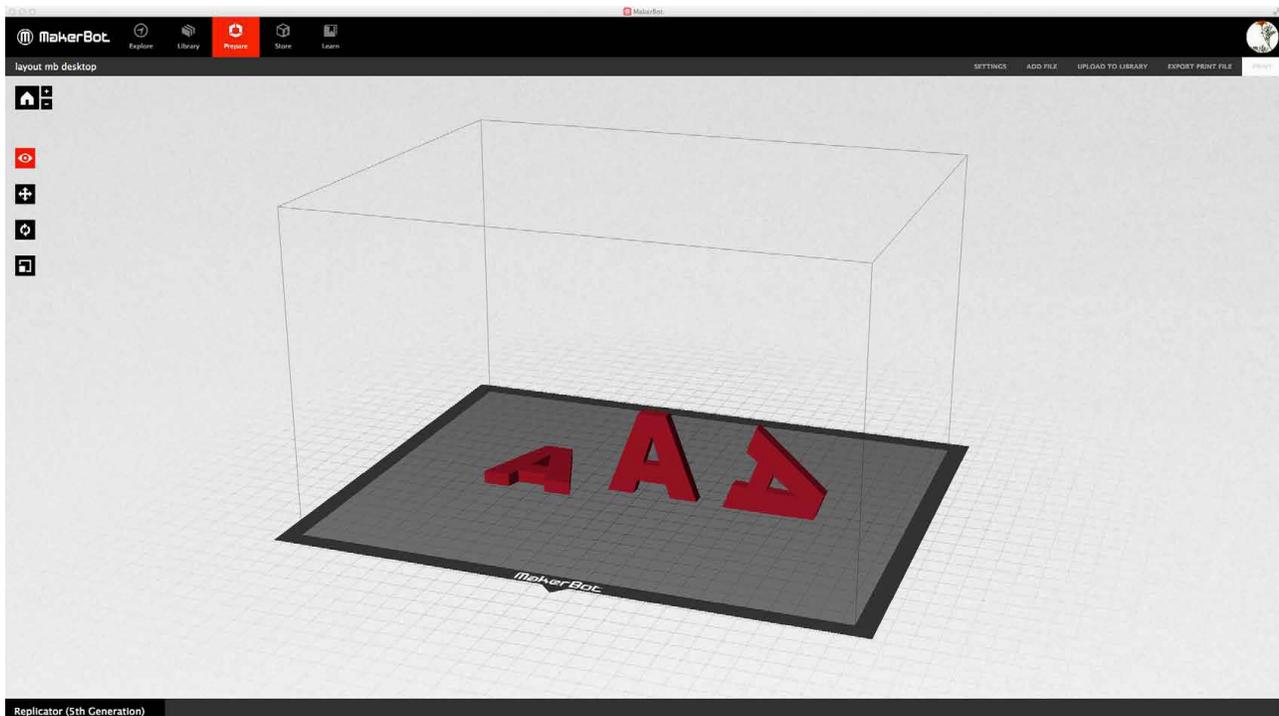
Scale: Adjusts the size of your object. Click it again to open the submenu. **Maximum Size** is a quick way to get the largest print possible based on your maximum build volume.

TIP: IF YOU DESIGN IN INCHES, THE INCHES » MM TOOL WILL QUICKLY SCALE YOUR OBJECT TO THE PROPER SIZE.

Can I Save a Layout?

You sure can! Upload to Library will let you save a layout to the Library tab. You can also **Upload to Library > Save Local File**, which will save your layout as a Thing file.

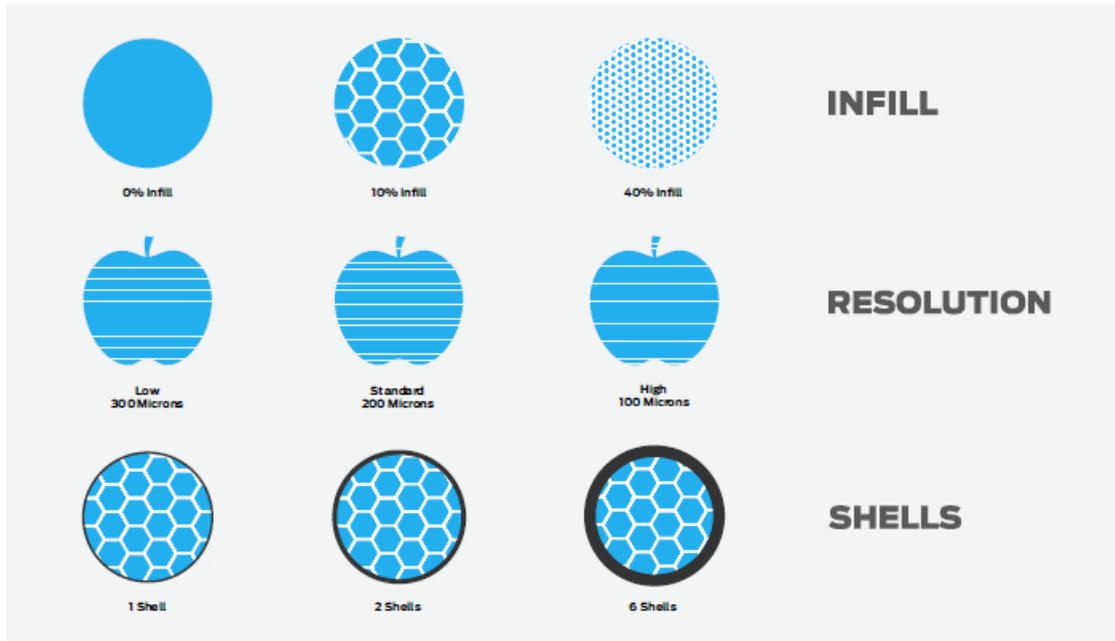
Activity: Download the file “A MakerBot Desktop Example” (thing: 814499) from Thingiverse. Orient, scale, and copy to match this layout:



Each one of the letter As can print without support.

What Print Settings Can I Pick?

Print settings allow you to dictate how your print will be made. Print settings will affect the printed object's properties, such as strength, surface quality, weight, and print time. Experiment with some of the settings and note how your prints are different.



Resolution refers to the thickness of each layer in your print.

- Standard resolution (0.2 mm) the most commonly used because it's the sweet spot between surface quality and speed.
- Low resolution (0.3 mm) prints draft quality quickly and will have a rougher surface.
- High resolution (0.1 mm) builds very smooth surfaces but will have a longer build time.

Raft: Select the checkbox to have your object built on a raft. The raft acts as a base for your object and any support structures. It ensures that everything adheres well to the build plate. The raft is removable once your print is complete.

Supports: Select the checkbox to have your object printed with support structures. MakerBot Desktop will automatically generate supports for any overhanging sections of your object. Supports are removable using your hands or simple tools once your print is complete. Activate supports when you have an overhang that is greater than 68 degrees for PLA or 45 degrees for ABS. For more information on this subject, check out the Overhangs/Bridges example in the Print Kit section.

Advanced Options

- **Infill** is the internal structure of your object. It can be as sparse or as substantial as you would like it to be. A higher percentage will result in a more solid object, while 0% infill will give you something completely hollow.
- **Shells** are the outlines printed on each layer of your object; they make up the walls of your object. Adding more shells to an object does not affect its external dimension but can increase its strength.
- **Layer Height** sets the thickness of each layer (see Resolution definition above). The smaller the layer height, the finer the resolution of your object. Thinner layers look smoother, but they'll also make your print take much longer. For every layer you would print at 0.3 mm, you have to print three layers at 0.1 mm to make up the same section of your object.

Custom Profile

Creating a custom profile is optional and gives you even more advanced access to the code that prepares your models for printing. Click **Create Profile**, give it a name, pick a template, and **Edit Profile** to view the code.

Export & Print Preview

Once you've set your object(s) and saved your settings, you need to export or slice your file to generate a .makerbot file, which the printer will use to create your object.

Print Preview

- Always check **Print Preview** before starting your print
- Scroll down to Layer 1 and move up layer by layer to ensure your foundation is building correctly
- Pay attention to the estimated material use and print time

As a general rule of thumb, if something looks wrong in Print Preview, it's going to cause an issue during printing. Here are some of the most common troubleshooting tips:

| PROBLEM | POSSIBLE CAUSE | POSSIBLE SOLUTION |
|---|--|---|
| Imported model is extremely small in the MakerBot Desktop view. | Your model may have been made in inches, while Desktop is interpreting the model in millimeters. | Click Scale and then select the Inches » mm button one time to resize the model. |
| Model does not adhere well to the build plate while printing. | The build plate of your 3D printer may not be level. | Run through the Utilities > Level Build Plate procedure on your printer. |
| Build plate has been leveled, but model still does not adhere well to the plate while printing. | <ol style="list-style-type: none"> 1. Your model has a small surface area in contact with the build plate. 2. Your model is an organic shape and doesn't have a flat bottom. 3. Your model has a large surface area but is crooked on the build | Use the Turn menu to maximize surface contact. Also ensure that Raft and Supports are checked in the Settings menu. |
| Parts of the model print in the air or have loops of plastic hanging off them. | Your model may have Overhangs that require 3D printed Support | From the Settings tab, make sure that the Supports box is checked. |

PRINTING LOGISTICS

- Many objects you make will require 30 or more minutes of print time.
- Try to plan accordingly prior to printing.
- For large projects, determine the amount of time you have to print and plate your items appropriately, getting as many prints onto the build plate as you can fit within the timeframe.
- Always check the following before leaving a long print unattended:
 - Print Preview – ensure all files are 3D printable and oriented correctly. If one object fails, then the whole plate will likely fail.
 - First layer – ensure that the first layer prints smoothly before walking away from the printer!

File Management

- Sorting through and plating files can be time consuming. Lots of teachers have figured out ways to deal with this. Read through some of the tips below to get some ideas.

Communal Storage

- Use www.vcumne.innovationcenter.makerbot.com, Google Drive, Dropbox, or even a shared USB stick to keep all files in one location.
- Students should name their files with their name, a date, and a revision (if applicable).
- Students upload the STL or OBJ file as well as a pre-sliced .makerbot file if they each have access to MakerBot Desktop.

KNOWLEDGE CHECKS

- What is MakerBot Desktop and why do you need to use it?
- How do print settings work and which options can you pick from?
- What type of files can you import and export from MakerBot Desktop?
- What should you consider when preparing a model for 3D printing?

LET'S GET PRINTABLE OBJECTS

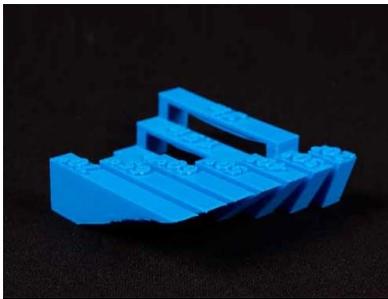
Now that we've reviewed how to get a file to your 3D printer using MakerBot Desktop, let's discuss the types of resources available to help you find and design objects. One of the most approachable ways to get started is to join a 3D modeling community and download existing designs, which we will cover in depth within the next section. Go to Thingiverse.com and log in with your MakerBot account for the next lesson.

EXAMPLES OF PRINTS WITH CORRESPONDING TERMINOLOGY



Resolution

- These three prints were prepared at different resolutions: high, standard, and low. Resolution refers to the surface quality of your 3D print, dictated by the height of each layer.
- Discussion: The high-resolution print has the thinnest layers but takes longer to print. Why?



Overhangs/Bridges

- An overhang is when a layer extends outward, potentially unsupported, over the previous layer. PLA prints can achieve an angle of 68 degrees from vertical without supports.
- A bridge is when a layer prints in the air between two pillars. PLA prints can achieve a two-inch bridge without needing supports.



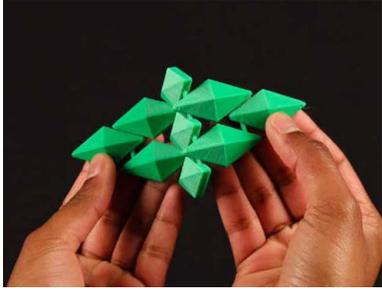
Raft and Supports

- Supports are printed scaffolding for overhangs.
- A raft helps with adhesion to the build plate.
- Remove both the raft and supports after a print finishes.



Infill and Shells

- Infill is the hexagonal pattern that supports the inside of your model. It's represented by percentages beginning with 0%, which is completely hollow.
- Shells are the outside walls that make up the perimeter of your object. Increasing the number will only add to the interior of your object and never affect the exterior dimensions.



Print-in-Place

- Print-in-place files are designs with parts that can move immediately after printing. A lot of thought can go into designing print-in-place files, especially in regard to incorporating **bridges** and **overhangs** creatively in your design. Make sure you don't print these files with **supports**, because the moving parts will be filled in with the extra material.



Assembly

- Assemblies are models broken up into different pieces for printing, then assembled together, to allow you to print in multiple colors or create objects larger than your build plate. You can get creative with how you design your object; breaking it down into multiple pieces can reduce the need for support material.

SECTION 4:

THREE WAYS TO MAKE

There are three major approaches to finding models to 3D print: download, scan, design. Throughout the next three sections, we'll take a deeper look at each of the Three Ways to Make.

Download

Finding files and downloading them to 3D print is an easy way to get started using your printer. There are many places online where you can either download for free or purchase files. As a source of inspiration, find a designer you like and explore what makes his/her designs print successfully. Try to reverse engineer an interesting design. You can also download files and incorporate them into your own custom designs.

Scan

3D scanning is an exciting technology that offers a quick way to translate real objects into 3D files you can print. Scanning an object enables you to obtain a 3D model without using 3D modeling software. Once you have scanned an object, you can print it directly, change its size, or alter its details.

Design

Learning how to 3D design is invaluable to creating your own 3D printable files. There are many different 3D modeling programs available, both free or at a cost, and depending on what kinds of objects you want to make, you might need to learn a few programs. Make sure you try as many software programs as you can, because each software has its own unique strengths.

SECTION 5:

WAYS TO DOWNLOAD

LEARNING OBJECTIVES

- Explore Thingiverse and GrabCAD and define their use
- Use Thingiverse to find inspiration and engage with the community
- Understand Creative Commons attribution

WHAT IS DOWNLOAD?

Download is tapping into ever expanding 3D printing communities such as Thingiverse or GrabCAD to access completely free files. Resources like this are an amazing place for inspiration!

TERMINOLOGY

- **Thing:** Free design file uploaded by a Thingiverse community member
- **Likes:** Uncategorized list of favorite designs to show support for their creators
- **Collection:** A curated folder of things you've categorized. Collections can be viewed by other users and are a great way to organize things for students.
- **Makes / I Made One:** When a user downloads and prints another designer's object and uploads a picture. **Makes** help demonstrate that a model can be printed successfully and are also a great way to show support for the designer.
- **Attribution:** Anytime you print and share anything, make sure you remember who made it! Thing Tags can be easily generated at the bottom of each thing's page. Remind students that when displaying these objects in public, it's vital to give credit to the community members who created them. Tagging is a great way to thank them for their amazing contributions!
- **Remix:** Anytime you download a file, alter it in some way, and re-upload it, attributing the original model to the creator
- **Customizer:** An app built into Thingiverse that gives users the ability to customize 3D models with easy-to-use sliders, text fields, and dropdowns. It's based on the programming language OpenSCAD.
- **Groups:** Community-driven collections of things and discussion boards for specific topics



MakerBot Man Cupid by MakerBot is licensed under the **Creative Commons - Attribution** license.

CREATIVE COMMONS

The Creative Commons license allows our open-source community to share objects freely, while providing parameters for how members give attribution and use the objects.

Discussion: Why is it important to give attribution when using someone else's file? How do Creative Commons guidelines help provide a platform for sharing?

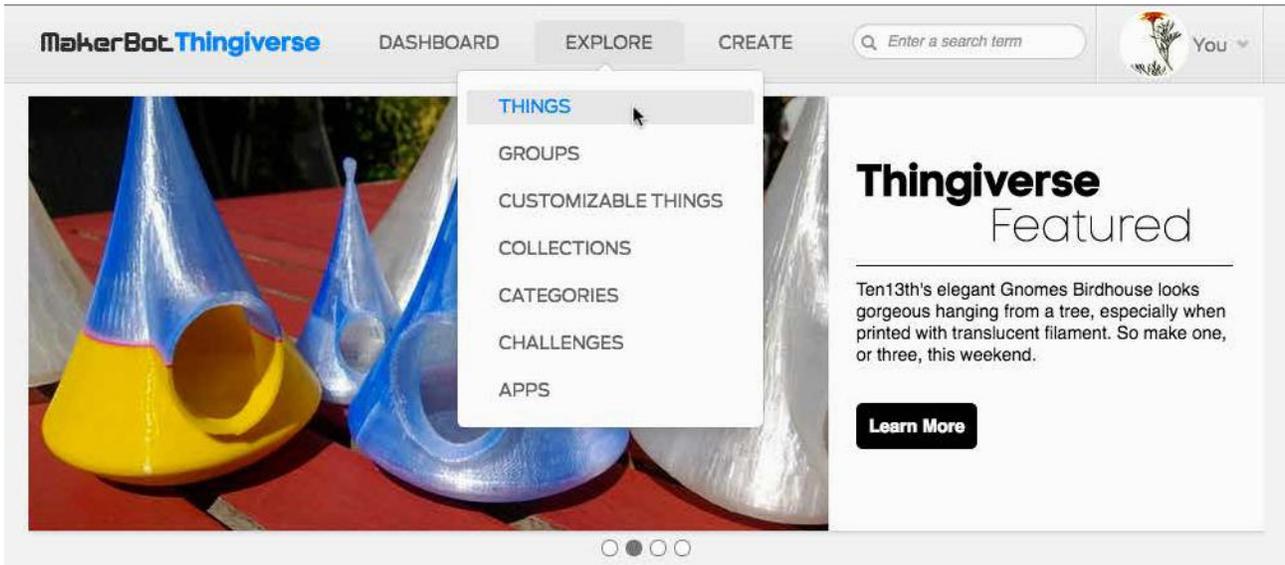
WHAT CAN I DO WITH THINGIVERSE?

The screenshot shows the MakerBot Thingiverse user profile for 'MakerBot Learning'. The profile includes a header with the name and location (Brooklyn, NY), statistics for 53 followers and 108 following, and a list of roles: Teacher and MakerBot Replicator (5th...). The main content area features a navigation menu (ABOUT, DESIGNS, COLLECTIONS, MAKES, LIKES) and a summary of the user's activity: 22 DESIGNS, 17 COLLECTIONS, 14 MAKES, and 2 LIKES. Below this, there is a 'GROUPS' section titled 'You can find MakerBotLearning participating in these groups', which lists four groups: OpenSCAD (27 members, 850 users), Blender 3D (11 members, 402 users), SketchUp (8 members, 380 users), and Classroom 3D (16 members, 322 users).

A Thingiverse user page.

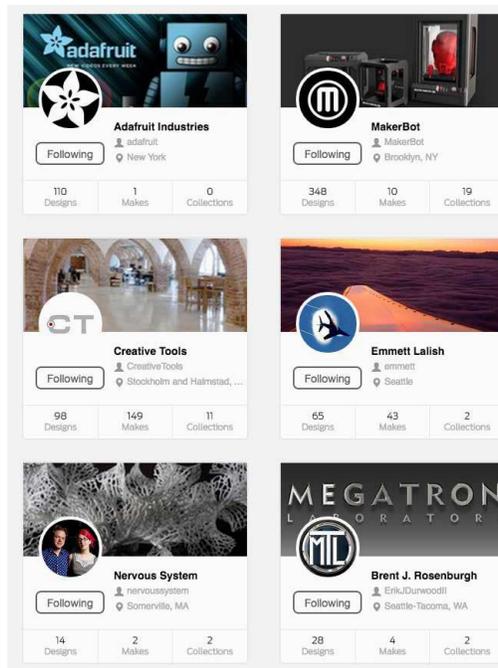
Due to the fact that Thingiverse is built on a principle of sharing, it encourages users to collaborate through community engagement. Whether you post your own thing, download and remix someone else's, or just show support in the comments, Thingiverse is a great way to engage with other people excited about making. Thingiverse groups enable teachers and students across the world to interact and discuss 3D printing.

Here are some activities that highlight a few of the main ways to use Thingiverse. These only scratch the surface; the possibilities are endless!



The homepage updates weekly with featured things that can inspire you.

Thingiverse is a great place to start when first exploring 3D printing. Use the **Explore** tab and the search function to start collecting some objects you want to 3D print.





Check out Three Heart Gears (thing: 243278), by incredible Thingiverse user emmett.

Further Exploration

Thingiverse is an integral resource for designers, engineers, and enthusiasts alike. Throughout this book, we'll continue to reference and tie in using Thingiverse in a variety of ways to find things, get inspired, and engage with the community.

GRABCAD

GrabCAD offers an online community that offers free downloads of 3D designs specifically tailored for engineers. It's a great place to find a variety of different files ranging from program-specific projects to model renderings to 3D printable objects. It also has a large selection of user-created tutorials on how to make models in specific programs. Like Thingiverse, GrabCAD is community-driven and a great way to engage with like-minded people exploring 3D printing and modeling.

Discussion: After exploring both Thingiverse and GrabCAD, discuss the similarities and differences with your class.

KNOWLEDGE CHECKS

- What is a Creative Commons license?
- What is a remix and how does it work?
- What are some of the ways to use Thingiverse?
- What are the differences between Thingiverse and GrabCAD?

SECTION 6:

3D PRINTING AND YOU - WAYS TO DESIGN

LEARNING OBJECTIVES

- Understand the different types of 3D modeling software
- Explore the differences among 3D modeling programs and their strengths and weaknesses

WHAT IS 3D MODELING?

3D modeling is the process of creating a digital representation of objects. Numerous 3D modeling software programs allow for the creation of 3D models in a variety of ways.

Just as pens, pencils, brushes, and clay are tools that you use in your creative process, 3D modeling programs are tools you can use in your digital design process. It's not about learning one right tool, but rather about finding the tool that fits your design the best. Explore a few 3D modeling programs and see which best fit your desired outcomes. In this section, you'll find ways to help you approach this process.

TERMINOLOGY

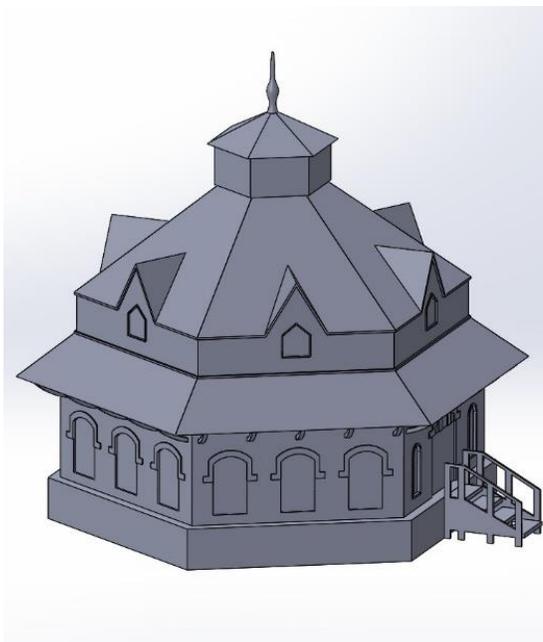
- **Mesh:** The collection of vertices, edges, and faces that defines the shape of a 3D model
- **Watertight:** A continuous outside surface (or **mesh**), necessary for successful 3D printing. For example, an object like a donut, even though it has a hole in the middle, has a continuous outside surface and could be 3D printed.
- **Transform:** A tool that allows a user to move or rotate an object's position
- **Viewport:** Specifies your window into the 3D modeling tool; in other words, the view you see on screen
- **Orbit:** Rotates your viewport around a point or object
- **Pan:** Moves your viewport up and down or left and right
- **Zoom:** Moves your viewport closer to or farther from a point in a scene
- **Perspective View:** Adjusts the point of view to match how the human eye sees. Objects that are further away appear smaller than objects that are closer to the camera.
- **Orthographic View:** Adjusts the point of view to a single perspective. All objects of the same size appear to be the same size, no matter their distance from the camera.

WHAT CAN I DO WITH 3D MODELING?

3D modeling gives you the freedom to design whatever you'd like. For inspiration and references, resources like Thingiverse and GrabCAD can be helpful; use them to find 3D models that other people have already designed. The thing you want to make might be best constructed by remixing a model or building off an existing design (license permitting). As you learn to model, consider uploading your files to Thingiverse and/or GrabCAD so you can continue to grow and engage with the community, and so other people can remix and expand on what you've made.

3D MODELING SOFTWARE

There are a lot of different 3D modeling programs available, all with different strengths and weaknesses. Recently, many programs have launched that are both easy to use and free. In this book we'll focus mainly on these free programs. When looking at 3D modeling programs, you'll find that all of them fall into three major categories: solid modeling, digital sculpting, or polygon modeling.



Solid Modeling

Solid modeling (or CAD) programs work well for creating models with real-world dimensions and are used to make functional parts. In some of the advanced programs you can form complex assemblies of objects, run simulations, and more.

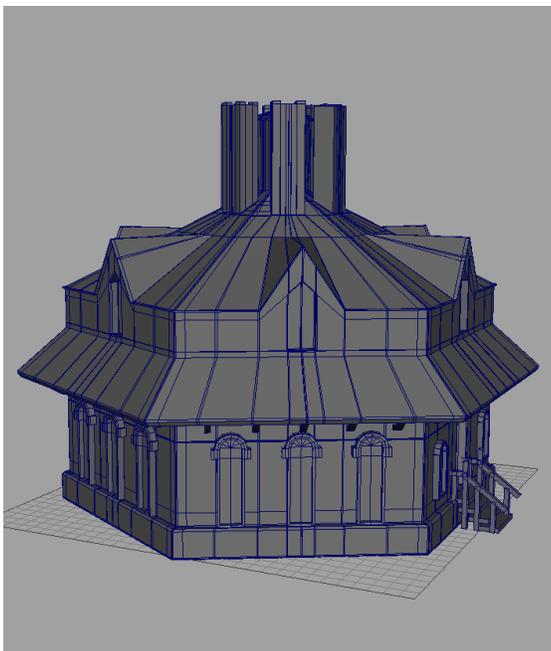
- **Industries:** Engineering, industrial design, architecture
- **Free software:** Tinkercad, 123D Design, and more
- **Paid software:** Inventor, SolidWorks, Rhino, and more
- **Strengths:** Creating mechanical structures with dimension, building assemblies, simulating real-world physics, material property libraries, design history
- **Weaknesses:** Creating organic shapes, detailed surface textures and patterns



Digital Sculpting

Digital sculpting simulates the process of sculpting clay. You're able to push and pull this digital clay to create highly detailed and textured models. It works well for creating organic models such as faces, plants, etc.

- **Industries:** Film, video games, art
- **Free software:** Sculpttris, SculptGL, and more
- **Paid software:** ZBrush, Mudbox, 3D-Coat, and more
- **Strengths:** Highly detailed models, organic shapes, digital painting
- **Weaknesses:** Creating functional parts is difficult, often requires peripherals (drawing tablet), steep learning curve for advanced programs



Polygon Modeling

Polygon modeling gives you direct control of the mesh, faces, vertices, or edges of a model. This allows you to create highly detailed and intricate 3D models. These models can be both organic and rigid.

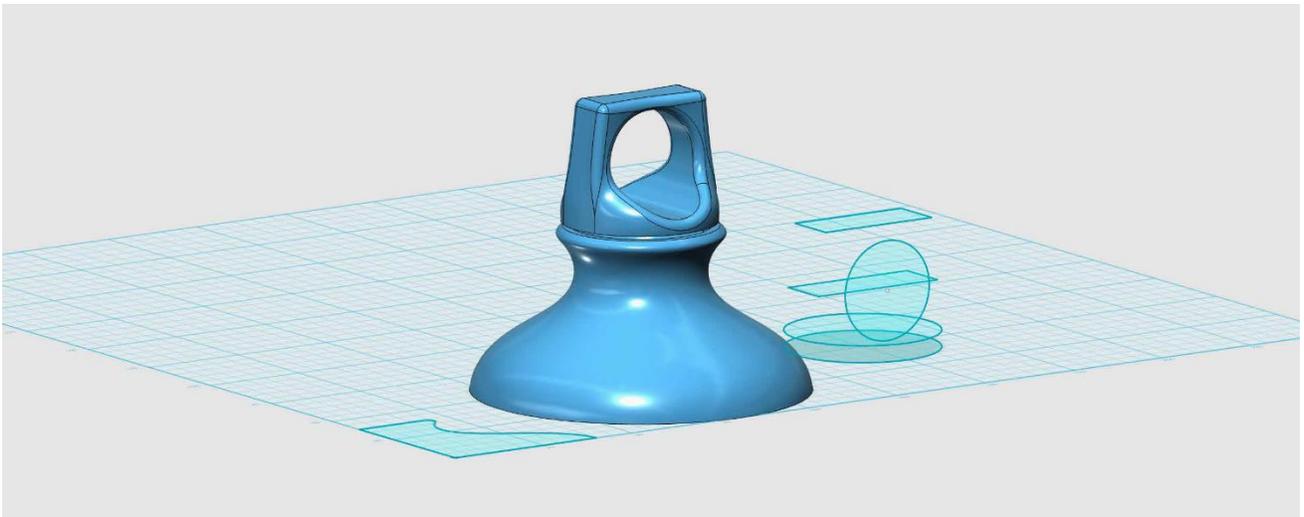
- **Industries:** Animation, visualization, film, video games
- **Free software:** Blender, Wings 3D, and more
- **Paid software:** Maya, 3ds Max, Cinema 4D, and more
- **Strengths:** Can create highly detailed, intricate models; direct control of the mesh; preferred tool for animation
- **Weaknesses:** Because it's intended for on-screen environments, extra consideration must be taken while modeling for 3D printing

GETTING STARTED IN 3D MODELING

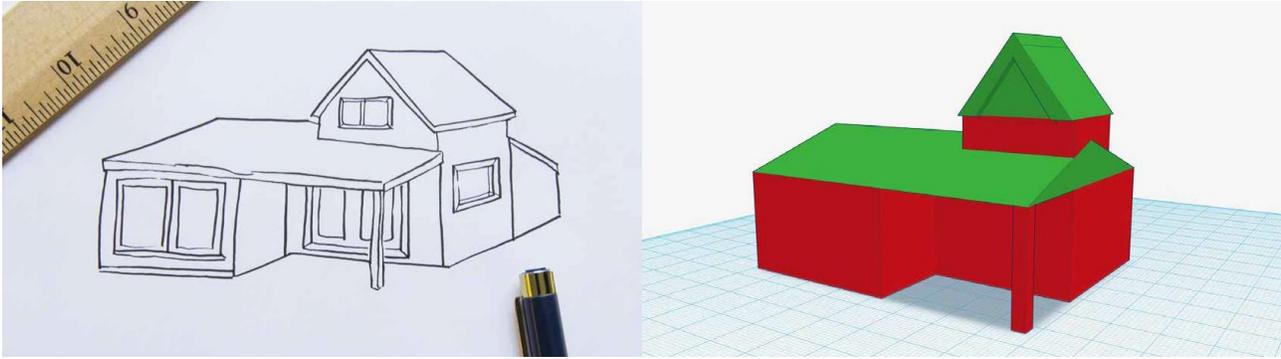
There are a variety of ways to approach learning 3D modeling, and over time you'll develop your own style, techniques, and preferences. Below you'll find some techniques that focus on helping you take that first step, regardless of where you choose to start.

Reference Objects/Images

One of the best ways to start is to find an object and use it as a reference. Thingiverse and GrabCAD are great places to get inspiration and download reference objects. Objects you have around you are another great resource. Pick an object from your classroom, take a look at it, and start to imagine how you would recreate it. Is there any way you could break it down into smaller, simpler parts?

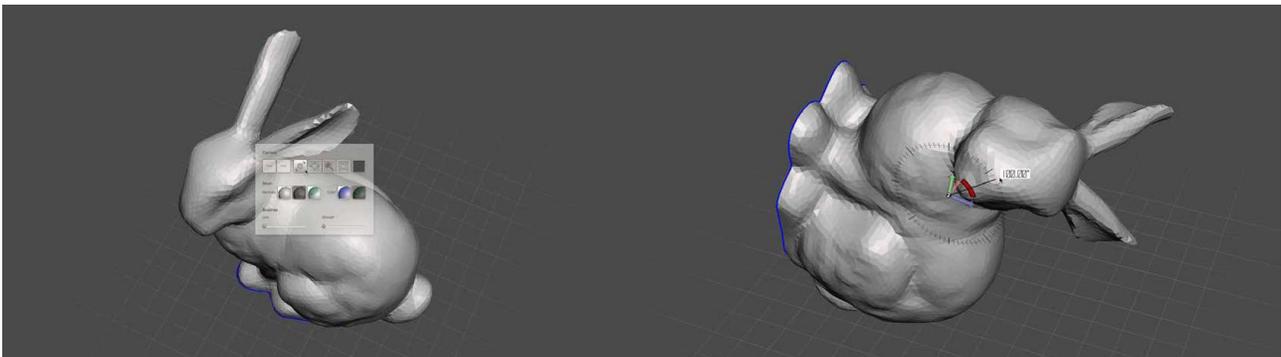


Here we recreated the top of an aluminum water bottle.



Primitive Building

Learning how to 3D model is similar to learning how to draw. Beginners should start with large, simple shapes and then refine the details. These shapes are referred to as **primitives** in most 3D modeling programs. Primitives are often composed of boxes, cylinders, and spheres, and can be modified and assembled to make complex models.



Navigation vs. Transformation

The next step to approaching 3D modeling is to learn how to move objects around versus moving your camera's view in your program of choice.

In 3D modeling programs, your view acts as a camera, exploring objects from different angles within your workspace. In the same way that you would move a camera in the real world to find different frames for shots, you can use the program to look around your objects from a variety of different vantage points. This is referred to **navigating** the scene.

When you want to change the position of an object in your workspace, you're **transforming** it. In the real world, this compares to physically picking up an object and moving it around or rotating it.

Picture an apple sitting on your desk. If you wanted to see the other side of the apple, you could pick the apple up and turn it around (**transforming**) or stand up and walk around your desk until you see the other side (**navigating**).

TIPS: THESE ARE GREAT TOOLS TO HAVE AROUND WHEN YOU START ANY 3D MODELING PROJECT: NOTEPAD, GRAPH PAPER, DRAWING UTENSIL, DIGITAL CALIPERS, RULER, CALCULATOR, GRAM SCALE.

KNOWLEDGE CHECKS

- What types of 3D modeling programs are out there? Why would you want to use one over the other?
- What's the difference between navigating and transforming in 3D space?
- What are some of the ways to approach building 3D models?

CONCLUSION

The most important thing to remember when getting started with 3D printing is to take the first step. It doesn't matter if that step is to download and print a model from Thingiverse, scan and print your favorite souvenir, or design and print your own dream house. There are many options available. Choose one and dive in!