

MAKERBOT EDUCATORS GUIDEBOOK

The Definitive Guide to 3D Printing in the Classroom

THIRD EDITION

Copyright © 2021 by MakerBot Industries, LLC

WWW.MAKERBOT.COM

All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of the publisher, except in the case of brief quotations embodied in critical reviews and certain other noncommercial uses permitted by copyright law.

The information in this document concerning non-MakerBot products or services was obtained from the suppliers of those products or services or from their published announcements. Specific questions on the capabilities of non-MakerBot products and services should be addressed to the suppliers of those products and services.

Printed in the United States of America

ISBN: 978-0-9991345-2-8

THIRD EDITION

10 9 8 7 6 5 4 3 2 1

MAKERBOT EDUCATORS GUIDEBOOK

The Definitive Guide to 3D Printing in the Classroom

THIRD EDITION

INTRODUCTION

Why We Wrote This Book

Since 2009, MakerBot has been a leader in bridging the gap between classroom learning and 3D printing - this is only possible because of educators like you. Through the years, MakerBot has worked hand in hand with pioneering educators all over the world who realized early on that 3D printing had the potential to engage students on levels not seen before, and to demonstrate ideas and principles in a new light.

We've seen how educators have taken our previous MakerBot Educator Guidebooks to bring 3D printing into the classroom successfully, and that was our original goal. However, through the years, we've seen first hand how our content was further adapted to give students the ability to follow their own ideas and develop them through brainstorming, prototyping and iterating - astonishing us every day with what today's students are able to do both in and out of the classroom.

Our mission for this third installment of the MakerBot Educators Guidebook is to continue helping educators provide what they need to light the path for their students. Included you'll find components on getting started with our new MakerBot® 3D printers, applications, difficulty levels and ideal grade levels for each printer as well as project ideas to supplement each printer. We've also included innovative ways teachers have found to use their printers with their students, methods born out of time worked with the printers. The end of this book also contains case studies and stories on how these same MakerBot printers are currently used in exciting industries such as robotics, automotive and aerospace.

Welcome to the third edition of the MakerBot Educators Guidebook.

Happy Printing,

MakerBot Education

HOW TO USE THIS BOOK

START WITH THE GUIDEBOOK

Part 1: The Ins and Outs of 3D Printing in the Classroom

How to begin applying 3D printing in the classroom and how 3D printing projects are categorized based on students' level of involvement with 3D printing. Find out how to use 3D printing in a hybrid/remote classroom and how to use the Design Thinking process with 3D printing.

Part 2: The X, Y, Zs of 3D Printing

The basics on how 3D printers work and how to use them, including a recommended list of different 3D design programs to start out with.

Part 3: Get to Know Your MakerBot 3D Printer

Learn how each of our MakerBot 3D printers work and how to best use MakerBot CloudPrint™ software for your classroom.

Part 4: Curriculum Project Ideas

Find projects in multiple subjects ranging from Natural Sciences, Engineering, Robotics, and Mathematics to Art, History, and Music.

Part 5: Teachers' Tricks of the Trade

Discover different tricks and tips that educators have discovered in their journey with 3D printing. Suggestions included in this chapter will help you better leverage 3D printing in the classroom.

Part 6: 3D Printing Beyond the Classroom

See how 3D printing is used by professionals working in various industries today and how your students can use similar applications in the classroom.

EXPLORE MAKERBOT THINGIVERSE

Many of the projects included in this book are available at thingiverse.com. Thingiverse® is the world's largest 3D printing community with over millions of free designs available for use. You can find these projects as well as many others relating to your subject or curriculum. Use Thingiverse and the MakerBot Educators Guidebook as inspiration to remix existing lesson plans, create your own, and explore new subjects and applications for 3D printing.

PRIVACY AND YOUR STUDENTS

MakerBot takes the privacy of our educator community very seriously. Therefore, we want to be as transparent as possible. By using some of the online resources referenced in this Guidebook, you are consenting to provide MakerBot with a wide range of personal information, as we stipulate in the MakerBot Privacy Policy, which can be found at makerbot.com/legal/privacy and <https://www.makerbot.com/legal/childrenprivacypolicy/>

Please make sure that your use of this Guidebook and the online resources referenced inside comply with the privacy standards of your school and school district for students under the age of 13.

For more information, the Federal Trade Commissions (FTC) has set forth very helpful best practices and guidelines for educators with respect to online student privacy; please see ftc.gov/tips-advice/business-center/guidance/complying-coppa-frequently-asked-questions#Sc

TABLE OF CONTENTS

TABLE OF CONTENTS

CHAPTER 1 THE INS AND OUTS OF 3D PRINTING IN THE CLASSROOM		CHAPTER 2 THE X, Y, Zs OF 3D PRINTING		CHAPTER 3 GET TO KNOW YOUR MAKERBOT 3D PRINTER		CHAPTER 4 CURRICULUM PROJECT IDEAS	
10	SECTION 1.1 HOW TO START APPLYING 3D PRINTING IN THE CLASSROOM	30	SECTION 2.1 FROM DIGITAL MODEL TO PHYSICAL PRINT	41	SECTION 3.1 SKETCH 3D PRINTER	60	SECTION 4.1 NATURAL SCIENCES
16	SECTION 1.2 ADAPTING 3D PRINTING INTO A REMOTE/HYBRID CLASSROOM	31	SECTION 2.2 HOW DOES IT WORK?	45	SECTION 3.2 METHOD SERIES 3D PRINTER	69	SECTION 4.2 ENGINEERING
		33	SECTION 2.3 COMPONENTS OF A 3D PRINT - BRINGING IT ALL TOGETHER	50	SECTION 3.3 MATERIAL COMPATIBILITY	81	SECTION 4.3 MATHEMATICS
		35	SECTION 2.4 3D DESIGN	53	SECTION 3.4 MAKERBOT LEGACY 3D PRINTERS - REPLICATOR SERIES	91	SECTION 4.4 ROBOTICS
				54	SECTION 3.5 PRINTING REMOTELY - MAKERBOT CLOUDPRINT	105	SECTION 4.5 ART, HISTORY & MUSIC

TABLE OF CONTENTS

CHAPTER 5 TEACHER'S TRICKS OF THE TRADE	
117	SECTION 5.1 TURNING A SKETCH INTO A 3D PRINT
120	SECTION 5.2 Z-PAUSE - ADDING MORE TO THE 3D PRINT
122	SECTION 5.3 PRINTING BIGGER THAN THE BUILD PLATE
131	SECTION 5.4 REDUCE 3D PRINTING TIME
134	SECTION 5.5 ADVANCED DESIGN FOR 3D PRINTING

CHAPTER ONE

THE INS AND OUTS OF 3D PRINTING IN THE CLASSROOM



SECTION 1.1

How to Start Applying 3D Printing in the Classroom

Beverly's Words of Advice:

"When I first saw a 3D printer, I thought it was amazing. I also thought that I would never be able to use it. I've always considered myself as "not very tech-savvy," and technologies like 3D printing were intimidating to me. After observing others using a MakerBot 3D printer and watching a few instructional videos, I decided to take a leap of faith and try my hand at 3D printing. That first experience got me hooked and gave me confidence in my ability to use a 3D printer.

After looking around on Thingiverse [MakerBot's online repository for 3D printable files], I saw that there were a lot of amazing things that I could print and use in my classroom. I didn't have to design anything! Printing out models to supplement my instruction was a great way to start. There are so many ways that 3D printing can enhance the curriculum and help students engage in authentic learning. I introduced students to different aspects and applications of 3D printing, and allowed them the opportunity to print out their own designs.

Providing tiered supports and guidance for students has led my classroom to being an environment in which students can iterate on designs and solve problems using technology. With 3D printing, my students are only limited by the breadth of their imagination."

**BEVERLY OWENS**

11th Grade Chemistry Teacher
Cleveland Early College High School
Co-Author, MakerBot Educators Guidebook

USE WHAT YOU ALREADY KNOW

**Beverly's Words of Advice:**

"When I first heard about 3D printing, I never thought I would be able to use that "magic box." I started searching MakerBot's file repository, Thingiverse.com, and downloaded files: things that I was interested in, and things that I could use to support my classroom instruction. Years later, I've learned a thing or two about printing and design, and my students are now designing their own projects! There are so many ways to use 3D printing in the classroom."



WHAT IS YOUR 3D PRINTING GOAL?

Getting started can sometimes seem like a mountain to conquer at the beginning of the journey, but it all starts with taking that first step. The key is to start small and work your way up, and that starts with outlining your goals or purpose for bringing 3D printing into the classroom.

Example Goals:

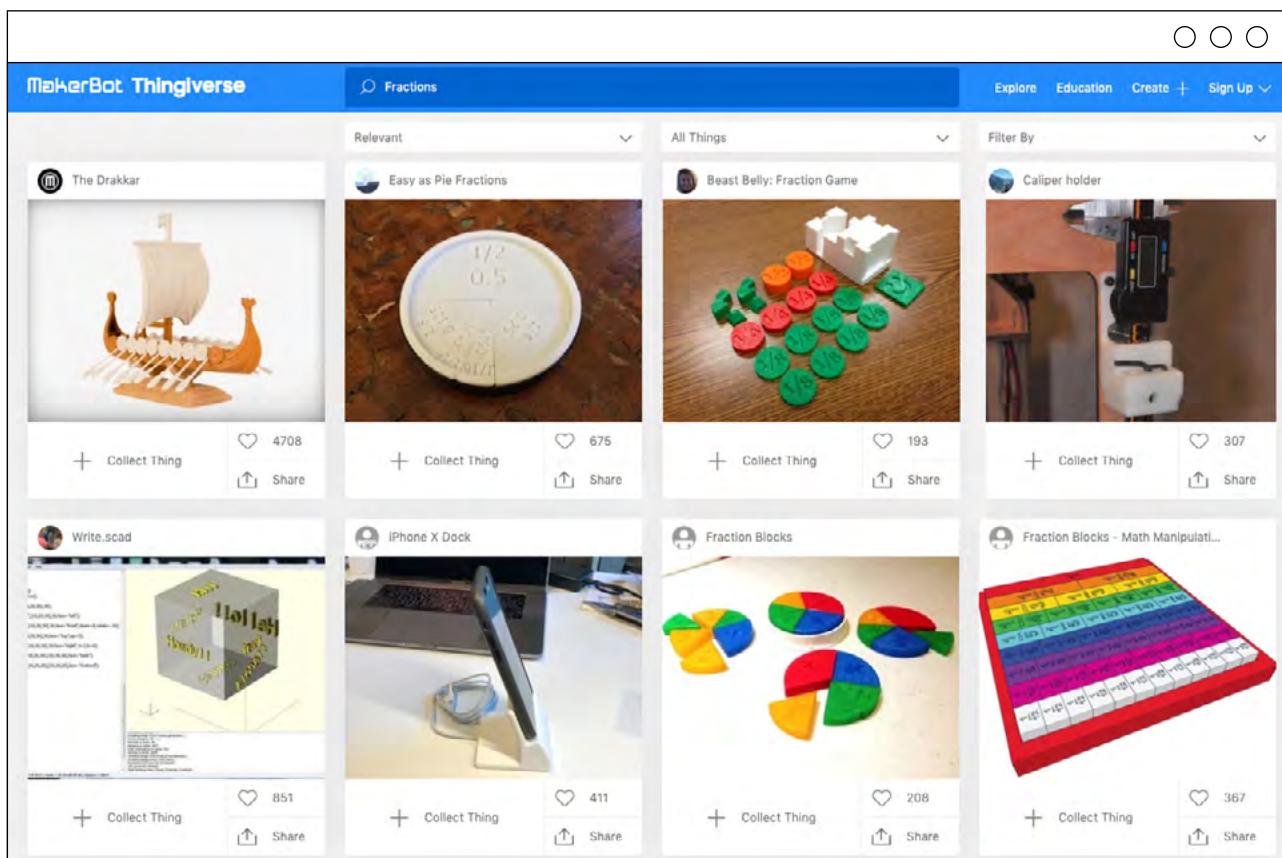
- Learn how to get started with 3D printing and refine an area of focus
- Define methods to implement 3D printing in remote, face-to-face, or hybrid educational settings
- Enable students to take an active role in the learning process and increase engagement

As teachers, we know the curricula that we teach, and we know what types of manipulatives and models can enhance our instruction and benefit student learning - and that's a great place to start when bringing 3D printing into the classroom. You don't have to create 3D models from scratch every time there's an idea or project that can be enriched with 3D printing. Using Thingiverse we can find hundreds of printable files that are ready to be printed, from the anatomy of a heart to articulated robotic arms.

Find 3D models on Thingiverse that you know will help your students better connect to the curriculum at hand.

Keep in mind while searching on Thingiverse:

- Start with a passion project and find resources in Thingiverse that align with your goals
- Can 3D printed models be used to inspire students to engage more deeply with the content? The bust of a US President, a Grecian statue, Shakespeare's Globe Theatre, or an articulated Tyrannosaurus Rex model can all provide high visibility models for engagement.
- Could manipulatives be used to foster student understanding? Think about parts of your curriculum that might be better understood by students holding a tangible object and interacting with it or moving the pieces around.



GETTING TO THINGIVERSE

Go to thingiverse.com. Using Thingiverse's search bar, enter a keyword that relates to a topic or project you're looking to enrich with 3D printing. Use "fractions" as an example keyword and work your way up from there!

WHO WILL BE USING YOUR 3D PRINTER AND HOW?

Consider who will primarily be using the 3D printer - students can quickly adapt to new technology, but it's important to think through how students will interact with the 3D printer(s), the types of projects students will be doing and the age of the students.

Questions to consider:

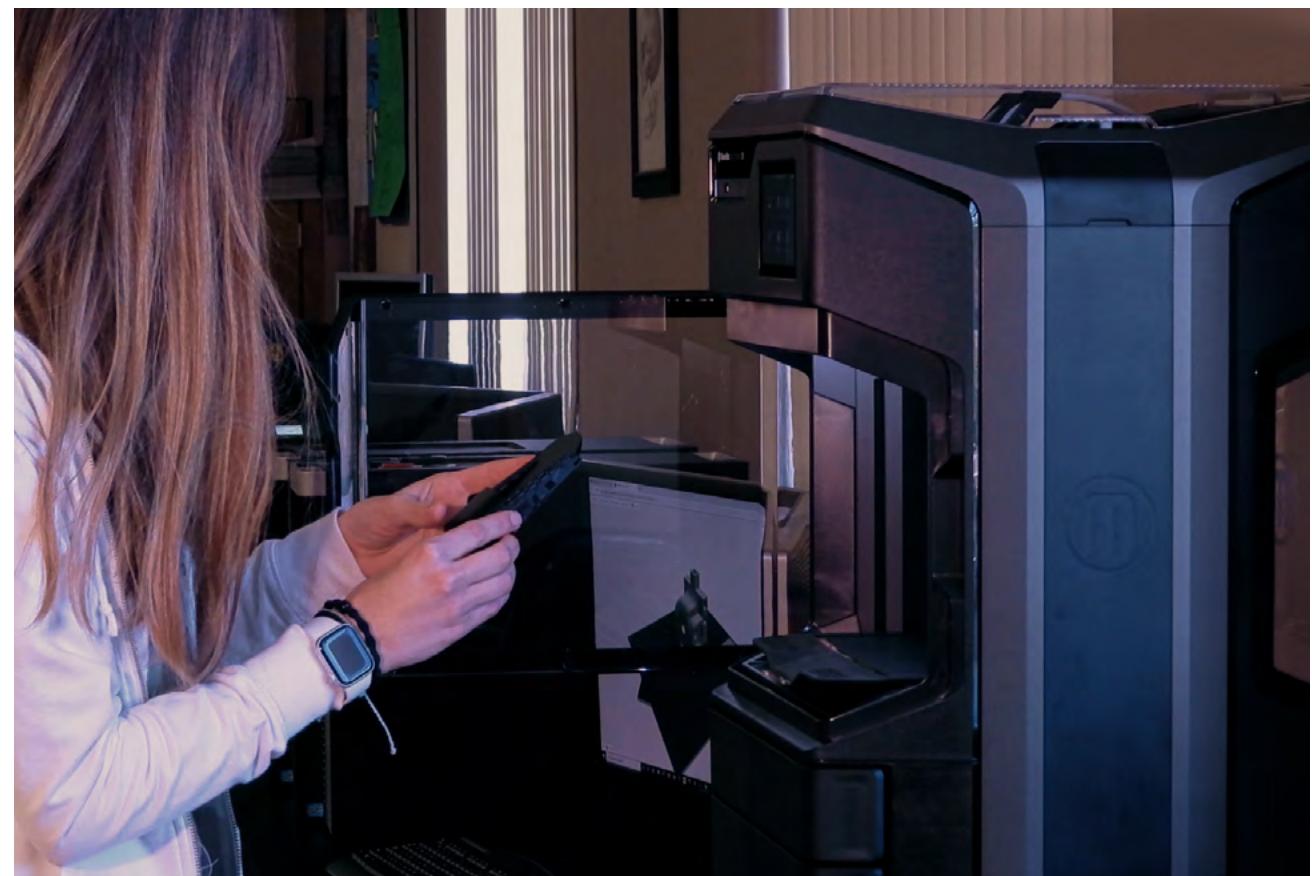
Printer Access:

- Will only the classroom teacher have direct access to the printer?
- Will there be a designated "hero student" who can help manage the printer?
- Will other students be able to interact with the printer directly?

Printer Usage:

- Will there be an implementation of set rules regarding print time and size of each print?
- Will there be a limit on how many times students can print?
- Should there be a schedule setup for students to reserve time with the printers?

Chances are, one or more of your students are going to be really interested in 3D printing. This is a great opportunity for them to act as leaders. If you've identified any student experts, have them help manage the operation of the printer. They can also lead the charge in teaching best practices to their classmates and other teachers.



TYPES OF 3D PRINTING PROJECTS

3D printing can be used in a multitude of methods to better reinforce core learning objectives across several subject areas - from clear STEM applications in engineering and physics, to blended cross-curricular projects involving history, music, foreign languages and more.

As a teacher's confidence and know-how in 3D printing continue to grow so too will the level of integration between the curriculum and the technology - further allowing teachers to leverage the many benefits of 3D printing in the classroom. We've broken down this process into four project categories that typically hold different ranges of difficulty and degree of student involvement.

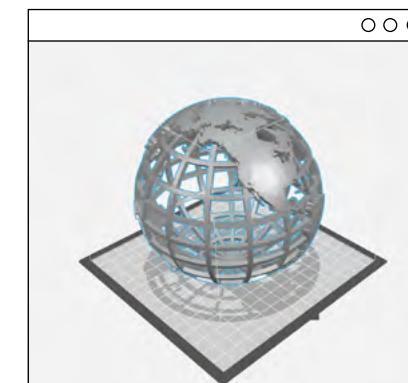
1 Exploratory Printing with Thingiverse Prints

Downloadable 3D models from thingiverse.com offers student a quick way to see 3D printing in action. Students and teachers can quickly find a file to print, such as a favorite animal, download it, prepare it and quickly send it to print.

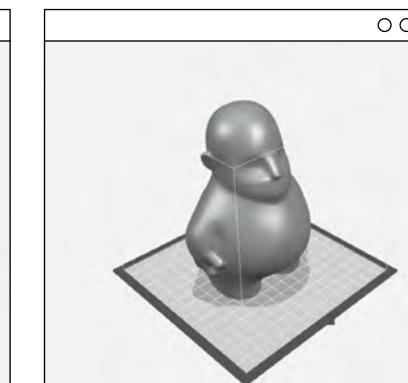
Benefit: Fast understanding of going from a digital model to a 3D printed model while demonstrating quick usefulness of 3D printing without requiring knowledge of 3D design.



Piggy Bank



Gridded Globe

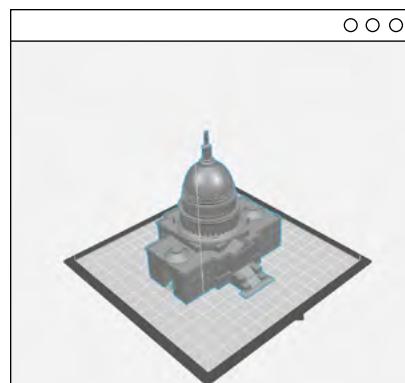


Zee Blank

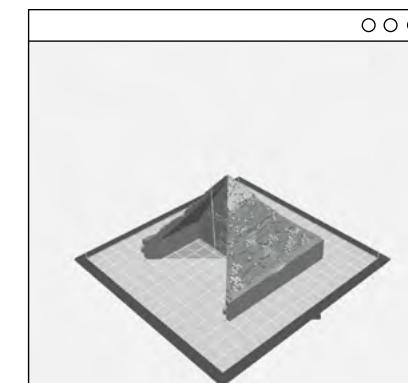
2 Teaching Aids

3D printed objects that are used as teaching tools to engage students with hands-on learning. Visual & tangible learning aids improve students' understanding of the world, being able to touch and see abstract ideas and seeing principles come to life. Teachers have the ability to print math models, plant cells, simple machines, etc.

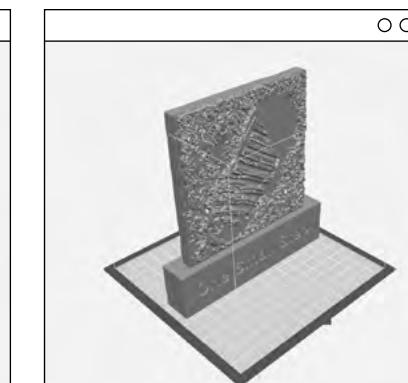
Benefit: Presenting abstract information to students as tangible objects that may have been traditionally difficult or expensive to acquire without 3D printing.



The Capitol



The Great Pyramid of Giza

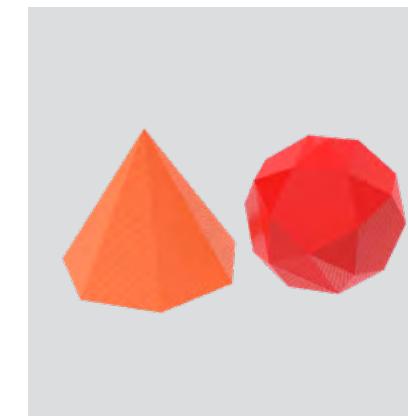


One Small Step

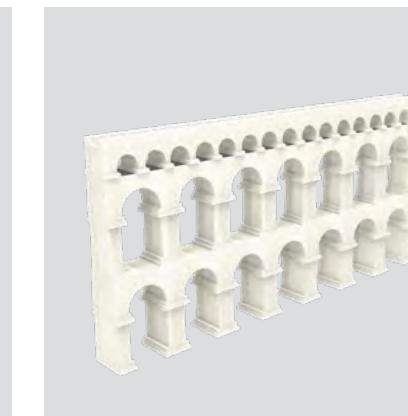
3 Part of the Lesson

Students take a more involved approach to 3D printing and make the 3D printing process an actual part of the lesson.

Benefit: Integrating 3D printing into the lesson can allow students to take a more active role in the learning process and form a more deeper, tangible connection to the curriculum.



Musical Shapes



Roman Aqueduct



Archimedes Screw

4 Student-Led, Student-Created

Student-led projects put the learning directly into the hands of students. These types of projects typically require students to design a solution to either a given problem or a problem they have identified, then they go through the iterative process of prototyping a potential solution.

Benefit: Students become active and engaged participants throughout the conception, design, and execution of their projects and interact with the 3D printer and the teacher.



Planetary Gear System



Mechanical Gripper

SECTION 1.2

Adapting 3D Printing into a Remote/Hybrid Classroom

Adapting to new classroom structures such as going from an in-person environment to fully online or partially hybrid can be challenging for any educator, most especially when you're adding a technology, like 3D printing, into the mix. The methods below are intended to help facilitate the direct benefits that come from 3D printing and the design process, especially when student access to 3D printing is limited.

TEACHING 3D PRINTING IN A HYBRID CLASSROOM:

Create a video or presentation that goes over the basics of 3D printer operation and have students share their thoughts as they go through the content.

1 Topics to Cover:

- Operating a 3D printer
- Different types of 3D printing technologies
- What elements of 3D printing to be aware of
- How to begin designing a 3D model
- How professionals use 3D printing

**TIP:**

Searching for training on how to better answer these questions? Go to www.makerbot.com/certification and check out the **MakerBot Certification™ Program for Educators** for training on how to start answering these questions!

2 Questions to Ask Students:

- In your own words, explain how the process of 3D printing works.
- What would you print with a 3D printer?
- How can 3D printing be used as a tool?
- How do you think we might be able to use 3D printing in our class?
- Why is 3D printing so important to industries like automotive, aerospace and robotics?

**TIP:**

Look for articles and videos for examples of how 3D printing is used.

- 3D Printed Prosthetics
- Artificial Reefs
- Artificial Organs
- 3D Printed Homes

FACILITATING 3D PRINTING WITHOUT THE PRINTER

While it's ideal for students to have in-person interactions with the 3D printer, students and teachers can still improvise with the tools they have to get the 3D printing process started - even if access to the 3D printer is limited.

Scenario 1: Limited Access to a 3D Printer

If students have access to school-loaned laptops - students can continue the design thinking process and create 3D models using CAD design programs like Tinkercad or Fusion 360®.

**TIP:**

For a list on the best design programs to use (even for remote learning) go to page 35

Scenario 2: No Access to Both Internet and 3D Printer

Sometimes access to the internet is not guaranteed - if the internet is not a viable option students can instead use their surroundings and objects at hand to start creating, testing and validating ideas even when access to the internet is limited.

STEP 1**NO MATTER THE SCENARIO IT ALWAYS STARTS WITH A SKETCH**

With a pencil and sheet of paper - students can start outlining the needs and requirements for an assigned project and set up the framework for what a possible design solution might look like.

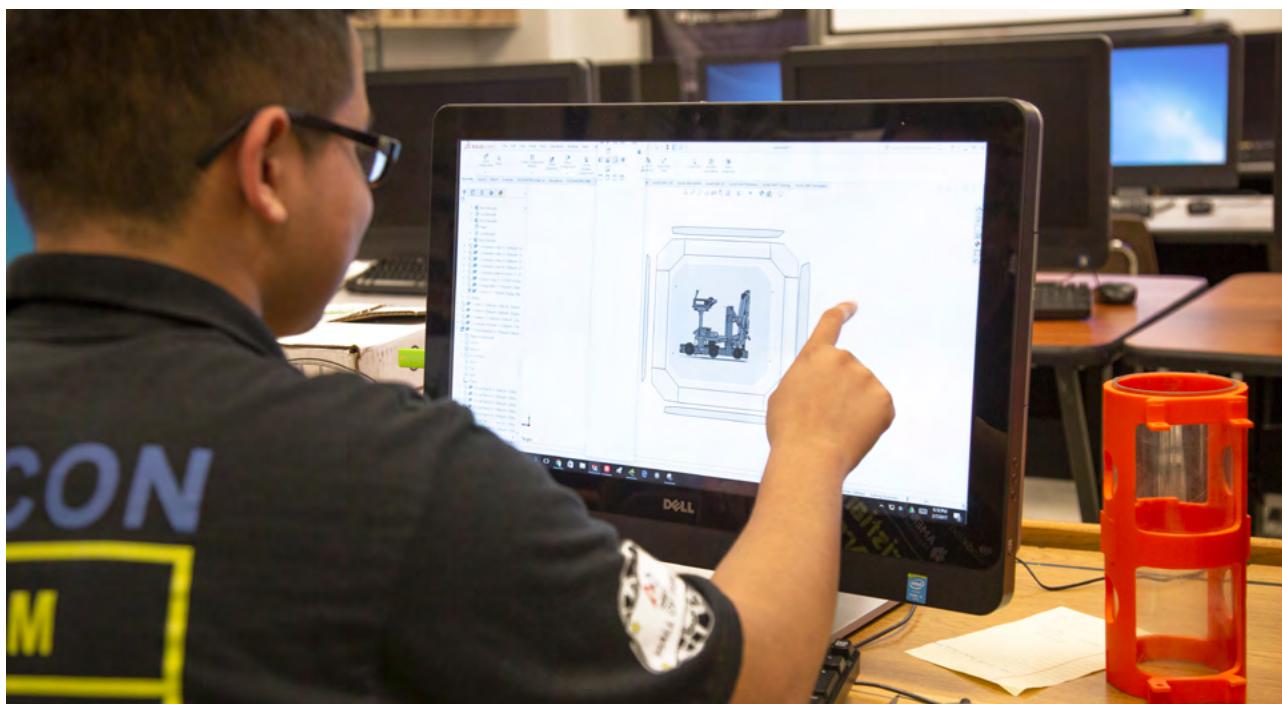
A proper sketch will include the following:

- a. A strong general idea
- b. Different angles of how this idea exists in 3D
- c. A name for the concept
- d. Callouts for specific features in their design



STEP 2 DIGITIZE STUDENT IDEAS AND PROJECTS

While 3D printing is integral to the design thinking process, it's still possible to start the process even if access to a 3D printer is limited. Students are still able to access CAD design programs and create designs to 3D print and test at a later time.

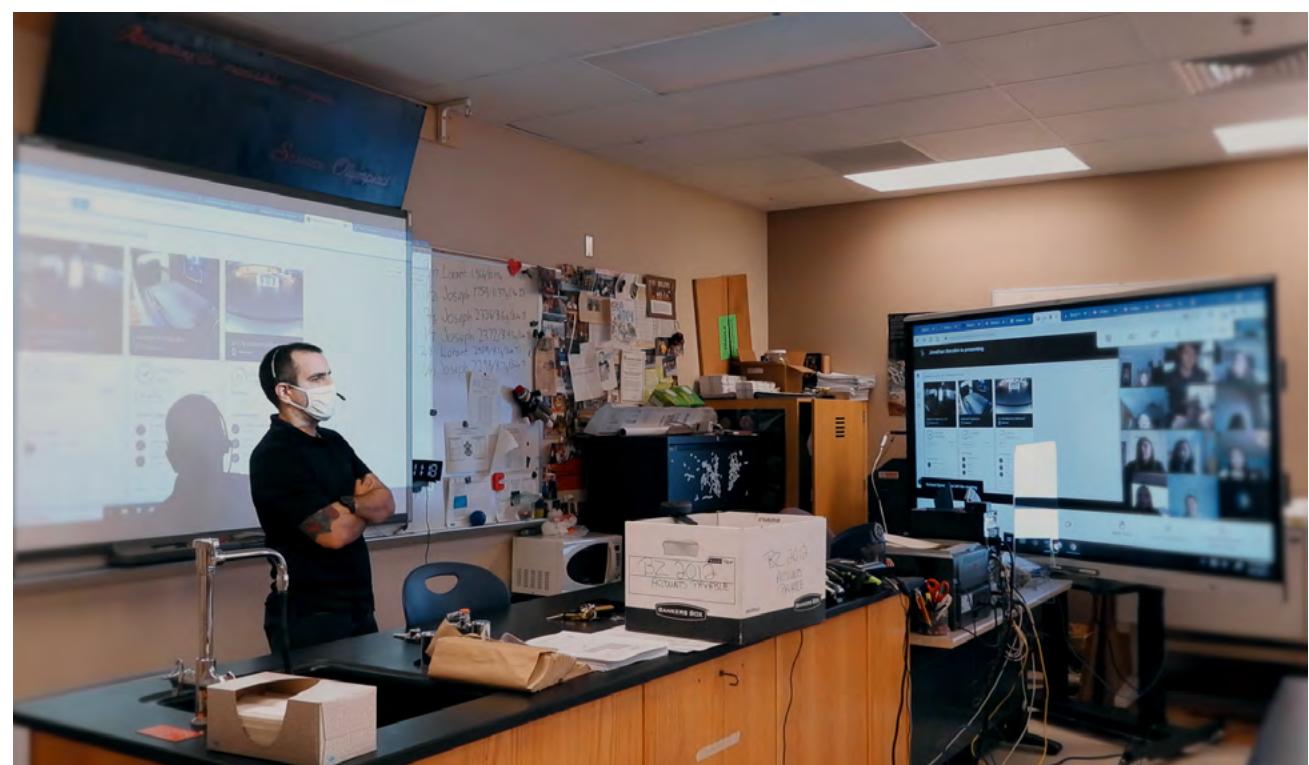


STEP 3 LIMITED INTERNET ACCESS

The elements of 3D printing can still be started at this level, even without the printer or the internet.

Start with a Sketch

- Have students sketch and outline the components of what their 3D design would look like or what elements they would like to test with 3D printing. Remember to have students include details that we learned earlier to help make their sketch a stronger idea.
- Outline specific components of the design to test
- What materials can they use around them now to start testing out the rough shape of their design?
- What are the backup plans if something goes wrong with the design?
- Once 3D Printing is available: How will the design be oriented on the build plate if this were to be printed?



Using MakerBot CloudPrint (our cloud-based classroom printing software) is a great way to make 3D printing accessible to students - even when they're not in the classroom.

STEP 4**COLLABORATING ON STUDENT'S CAD DESIGNS**

Collaboration is a key component to design thinking and especially for designing with 3D printing. Create 'Breakout' rooms during online classes to discuss students' design and gather their classmates input.

This is a process that typically happens after a student's design is first printed, however collaboration before a design is printed can still provide valuable input that can then be implemented into the design.

**DESIGN THINKING WITH 3D PRINTING**

Design thinking requires us to design a solution for a problem - to design a solution we have to put ourselves in the shoes of someone else, define a user's pain points, and create a solution through an iterative process of asking, sketching, brainstorming, and prototyping. This process is non-linear and it's expected and encouraged to go through this process multiple times before coming to a final solution.

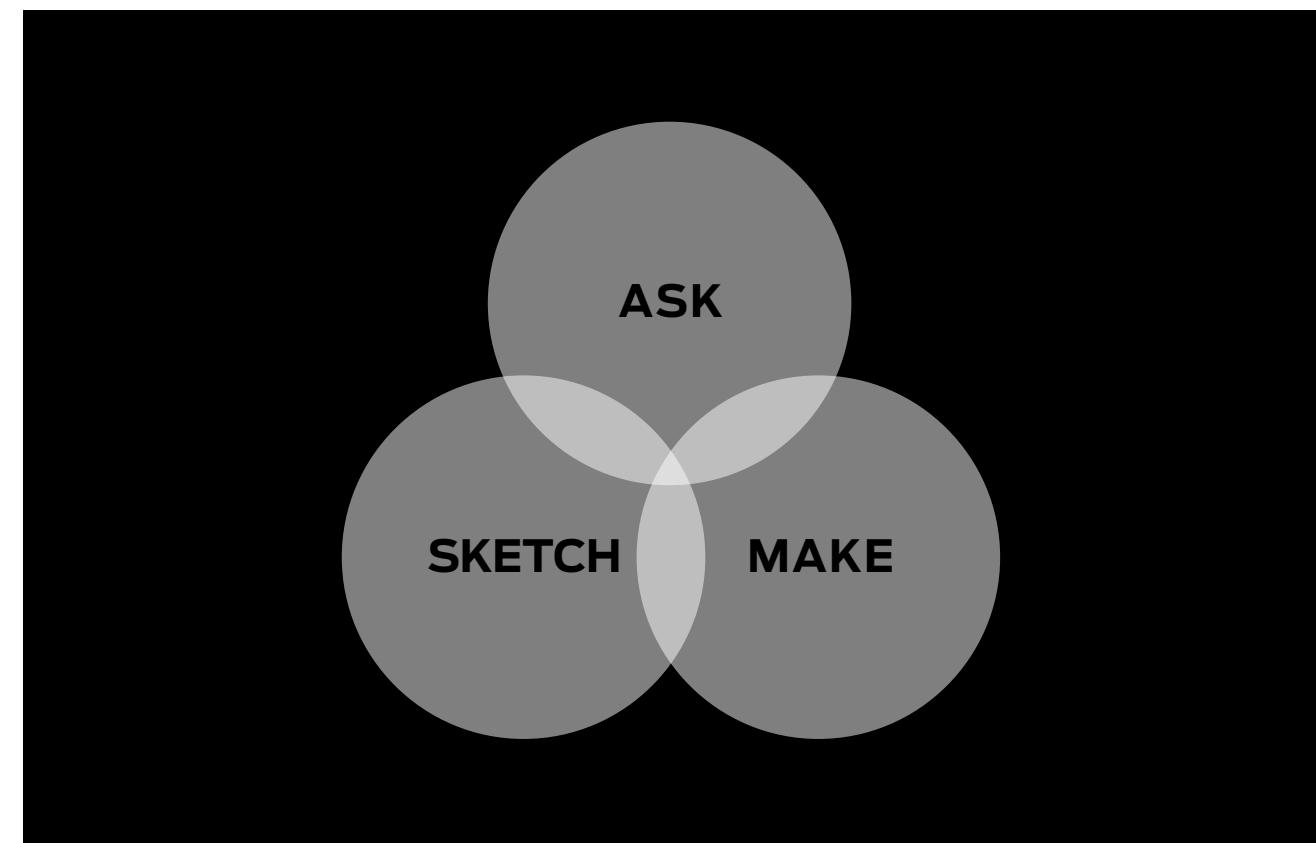
Getting Started with Design Thinking

Design Thinking is one of the best ways for students to leverage everything 3D printing has to offer. We've broken down the design thinking cycle into 3 steps. You may find other design thinking cycles with more steps but most will stress the 3 steps we've categorized below:

ASK: Empathize with the user and define the problem at hand

SKETCH: Ideate and Brainstorm solutions that resolve the user's pain points

MAKE: Print and Test Prototypes to better refine the solution



Step 1 ASK

How Asking Enables us to Define the Problem



Design is all about solving problems for people. It is crucial to actually talk to the subjects we are designing for and get to know their needs deeply before being able to design the right solution for them.

Ask means thinking from someone else's perspective, or being empathetic to a person's needs. Without empathy we will not be able to design and solve problems effectively.

Through **Asking** we can also define **pain points**. Pain points help us define a user's needs and gives us focus areas to design around.

1. How to Ask a Good Question

- Pick a topic, object or pain point you're interested in improving, such as designing a headphone stand for a student.
- Develop a list of questions to ask people about that topic:
 - > Where do you currently store your headphones?
 - > What do you like and dislike about how your headphones are stored?
 - > How often do you use your headphones?
 - > Where do you use your headphones most often?

Questions like these can lead to a deeper and richer understanding of how a particular student may use and store their headphones.

QUESTIONS TO AVOID

Be sure to avoid questions that lead the user to specific answers, or answers that you may want them to say. Always aim to ask questions as neutrally as possible and to allow the interviewee to answer freely:

Example:

✗ "Do you like your headphones because of its bright color palette?"

This is a leading question because it shifts the focus away from the interviewed user's actual experience with the headphones and onto the student designer's potentially preconceived idea of what they want to do for the user's headphones.

✓ "What features on your headphones do you enjoy using the most?"

This is a neutral question and allows the interviewed user to answer freely without implicit bias from the interviewer. Now the user can say what they like most about their headphones and better give the interviewer/designer an idea of what's most important to them when it comes to their headphones.

2. Dig Deeper

Always follow up with why, how, where or who questions to increase your understanding for the topic on hand. Remember that your subject is the expert in their own experiences and that your primary goal is to listen.

Example:

- **First Question:**
Where do you keep your headphones?
- **Answer:**
I keep my headphones in my backpack

- **Follow up with:**
 - > Why do you keep it in your backpack?
 - > Where in your backpack do you store it?
 - > How long is it in your backpack?
 - > Have you found issues keeping it in your backpack?

Ask Everyone

Follow up by doing additional interviews with experts on your topic and researching what people have to say online about similar topics - such as those who sell headphones in a store or those who use headphones daily

3. Putting it together

Once you have completed your research, identify the problems that are similar across the users you interviewed, as well as problems that may be unique to the person you are designing for. These will be the pain points used to define a problem statement to be solved in the next steps.

4. Keeping in mind...

The audience's thoughts aren't the only thing that needs to be considered when creating a solution. A solution will live somewhere, take up space, and may be interacted with often - that means we also have to consider the physical constraints, *where it will be located, if it will fit in its intended location, etc.*

These constraints along with the user's input and pain points can then be compiled into **Design Considerations**.

Step 2 SKETCH

Making An Idea More Powerful



Sketching and brainstorming is crucial to both the design thinking cycle and the 3D printing process. Through this phase you can brainstorm and take ideas out of your head to share with other people while also thinking of how potential designs could realistically be printed in a 3D printer.

- Think of creative solutions for each pain point
- No sketch is a bad sketch - be creative!
- Work through ideas to communicate them to other people

1. Organizing Pain Points & Brainstorming

Using pain points that were identified in the ASK phase students can start creating possible solutions to address pain points they've identified.

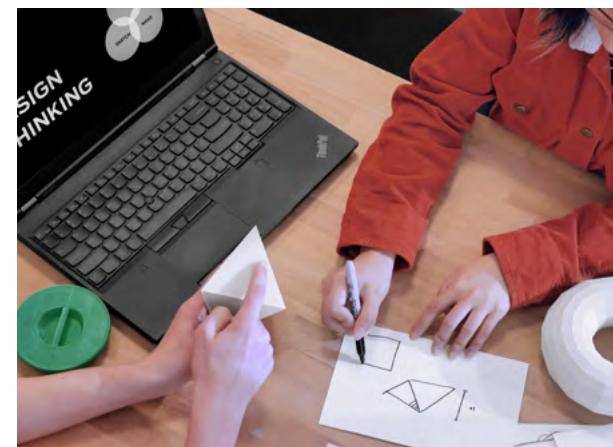
Taking everything that students learn from identifying pain points, students can then brainstorm as many solution-based concepts and begin sketching them out. In this phase, no idea is ever a bad idea - it's important that students do not limit their ideas and that they have fun with the process.



HOLD COLLABORATIVE BRAINSTORMING SESSIONS

A single person or student can only come up with so many ideas, so it's always important to brainstorm with other classmates to inject new creative energy, ideas and additional diverse opinions and perspectives.

2. How to Create a Successful Sketch



Brainstorm Ideas:

Take a pain point and think of as many creative solutions and begin sketching them out. Make sure to think as widely as possible, no idea is ever a bad idea.

Take all that you learn from asking questions and make as many concepts out of these pain points as possible. Remember, be loose, fun and creative!

3. Drawing a Powerful Sketch

We can have the best idea in the world, but if it's not presented in a powerful or strategic way it's very easy for an idea or sketch to get lost in the mix. Let's explore how we can make the presentation of our ideas stronger to help them go further.

Sketching Methods:



Orthographic: An orthographic sketch is a sketch drawn in one perspective. This means that an orthographic sketch can only communicate a fraction of a proposed idea. These sketches will typically be drawn either from a straight-on view, top view, front view or side view.



Three-point Perspective: A sketch drawn in a three-point perspective is similar to the image one sees when looking into a horizon and seeing a road converge into a singular point. These sketches tend to be more powerful because it is able to show multiple sides of a proposed idea from one sketch alone.

4. Combining Methods to Make A Powerful Sketch

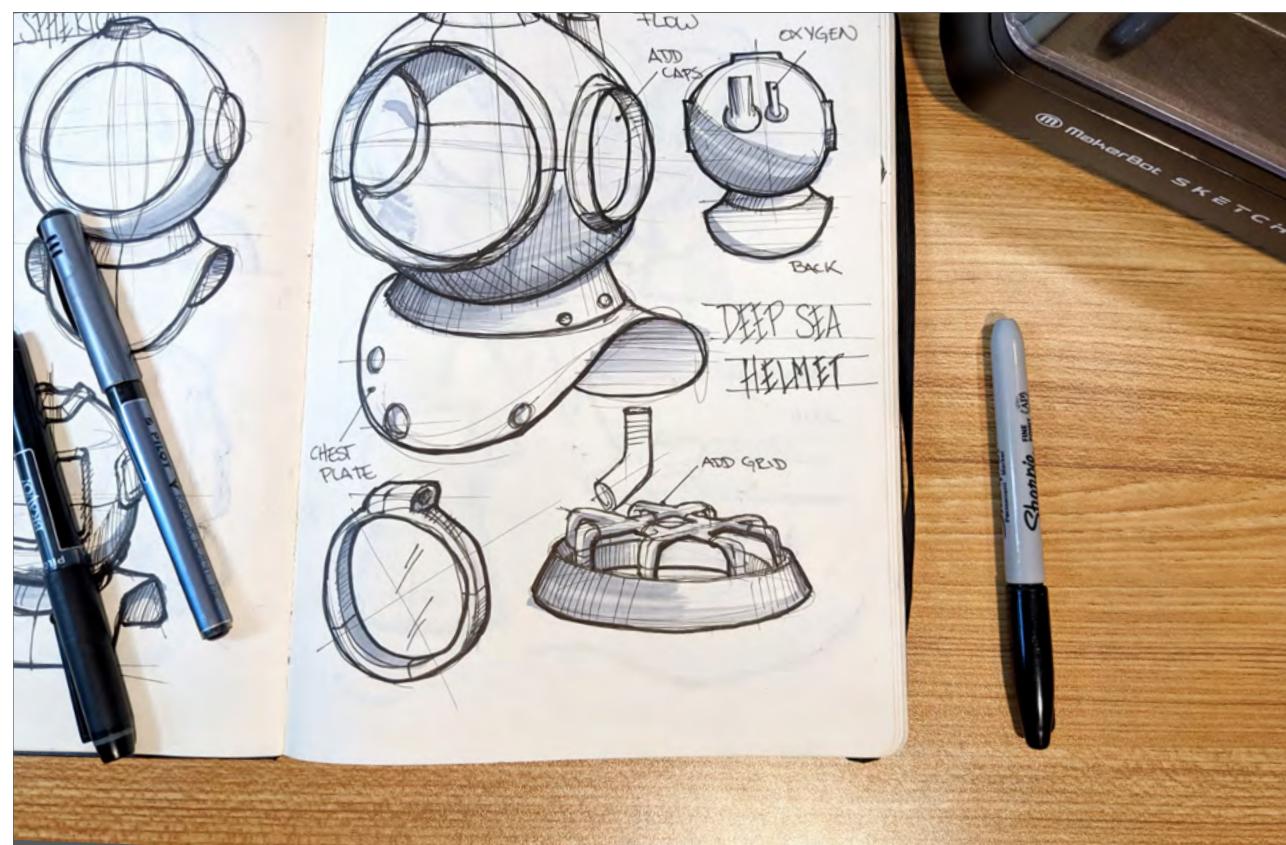
Using both orthographic and three-point perspectives, a student can leverage both methods to create a stronger sketch that shows overall what a proposed solution might look like, and different angles that show features that are not immediately apparent. Here's how it's put together:

Capture the General Idea

Using a small piece of paper, draw a three-point perspective representation of your proposed idea. Be sure to choose an angle that best captures what the whole solution would look like.

Name the Concept

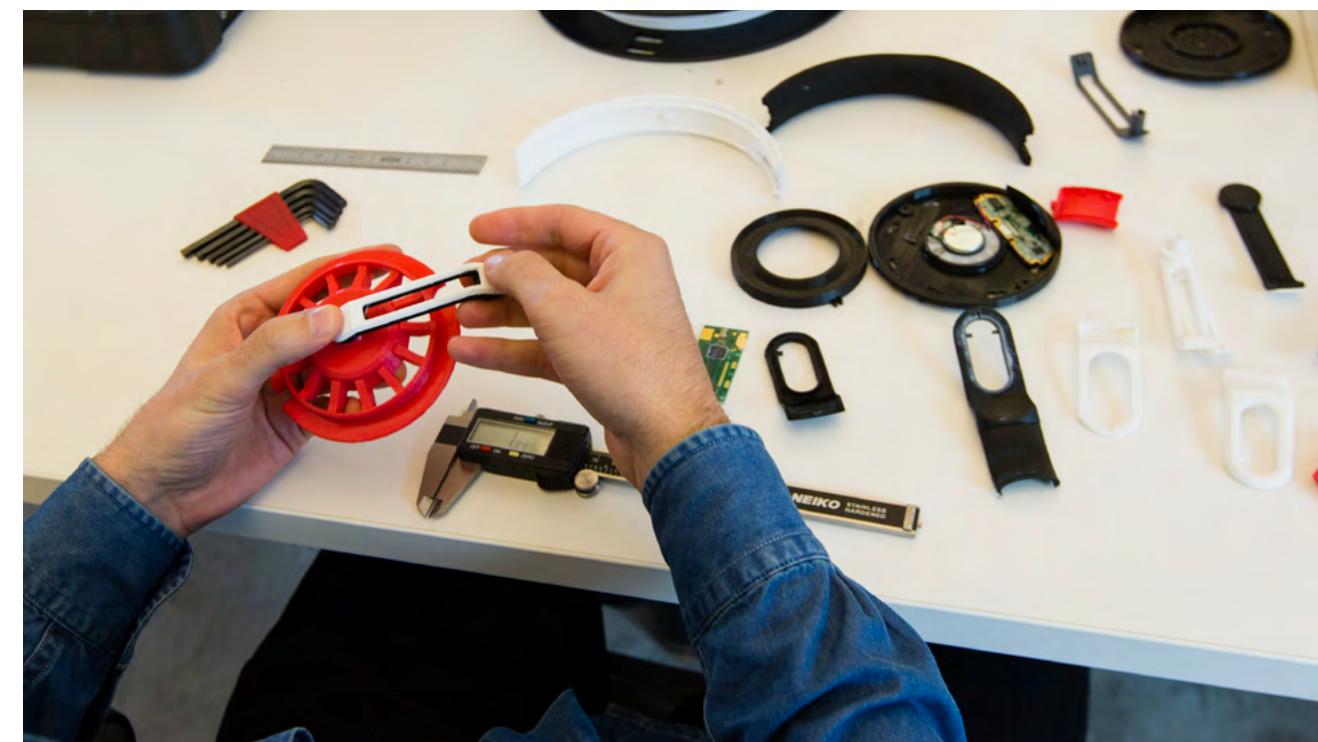
A concept with a name is much easier to remember and better solidifies the existence of a potential solution.



Now we have a concept that has a whole idea, speaks for itself and can be presented to someone else to effectively present the depth of a student's idea. Now it's time to further validate this idea with 3D printing.

Step 3 MAKE

Bringing Solutions to Life with Prototypes



Sketching out thoughts and ideas out can help us better grow the breadth in our solutions and get better visibility on the problems at hand but they still can't tell us everything we need to know. To combat this, we use 3D-printed prototypes to develop a better understanding of how a proposed solution will work in real life and to determine if the solution is as strong as was originally thought.

1. Iterating with 3D Printing

3D-printed prototypes allow us to leverage the most important part of the design thinking process - iterative design. With iterative design and 3D printing a student is able to develop their idea, execute on it by way of 3D printing, make observations on their printed design and determine changes that need to be made, print again, make observations and so on and so forth - it's a cyclical process that helps to further refine an idea and get it to a stronger state.

2. Using 3D-Printed Prototypes to Improve Designs

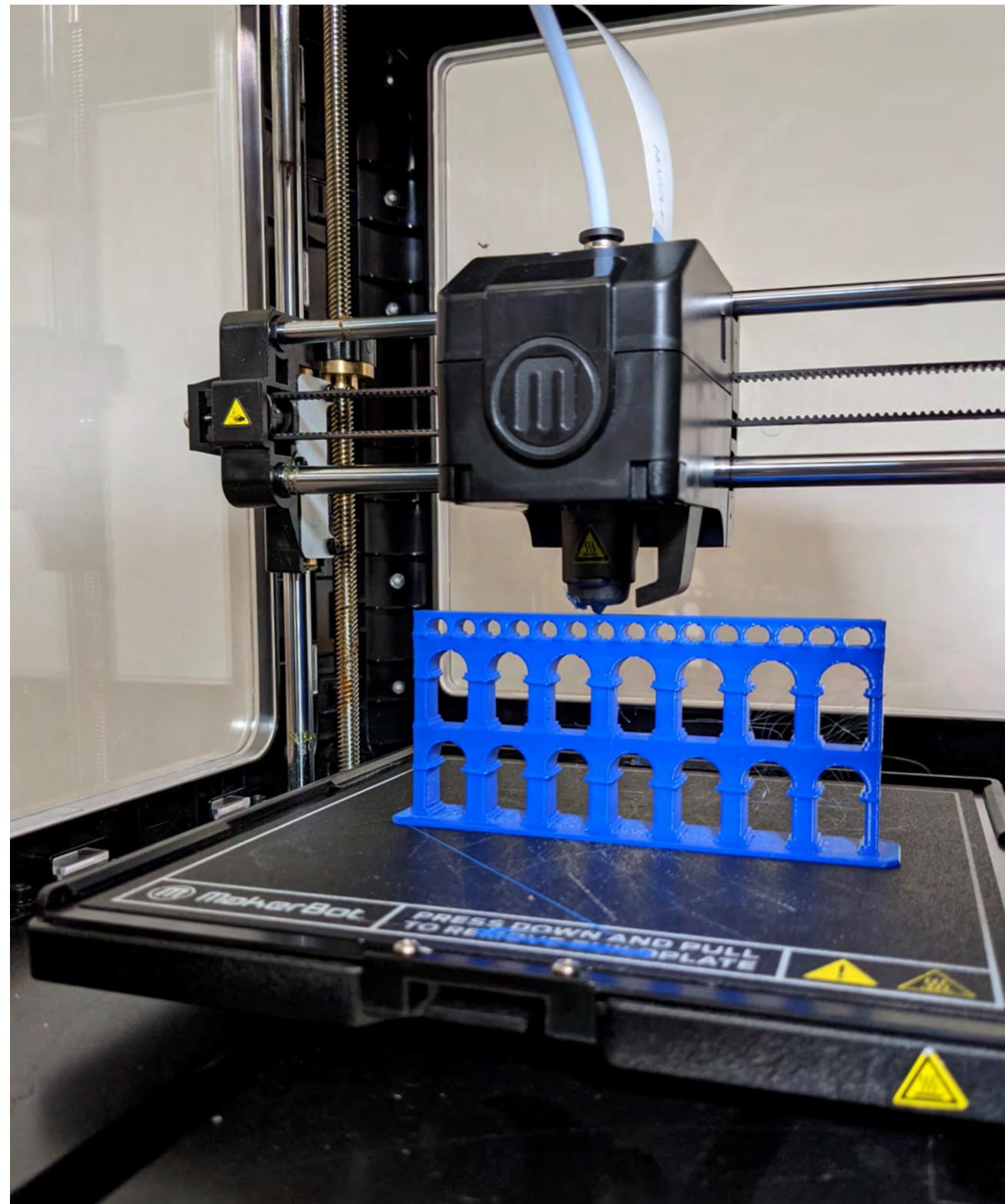
No matter if it's the first or eighth prototype - when evaluating whether or not the first or latest prototype meets the design requirements that were set in place, it's important to collect notes on our success and failures and ask ourselves the following:

- Are there pain points we overlooked?
- Was the prototype used by the subject as intended?
- Do small adjustments need to be made?
- Do we need an entire redesign?
- Do we need to gather more input?

These questions are essential to allowing us to better adjust our original design to better answer the pain points identified in the ASK phase.

**NOTE:**

Missing the mark or not getting it right on the first prototype is to be expected and even encouraged - failures allow us to further see what didn't work and how we can improve. Ultimately, this gets us closer to a stronger solution since we're able to analyze both the things that worked in our concept as well as understanding the reasons why other things did not.

**CHAPTER
TWO****THE X, Y, Zs
OF 3D PRINTING****Reflecting on Design Thinking**

The design thinking process is never done because our ideas can be continuously improved. Just because we've asked questions, sketched and made prototypes it does not mean that you are finished. These steps can be used cyclically, starting wide and slowly refining until we truly create solutions that are worth putting out in the world.

In conclusion:

ASK: We ask our audience questions to help empathize with their problem, situation and environment and help us define the problem at hand through pain points.

SKETCH: Putting our pain points and design considerations together we can start brainstorming through different ideas to see what best answers our pain points.

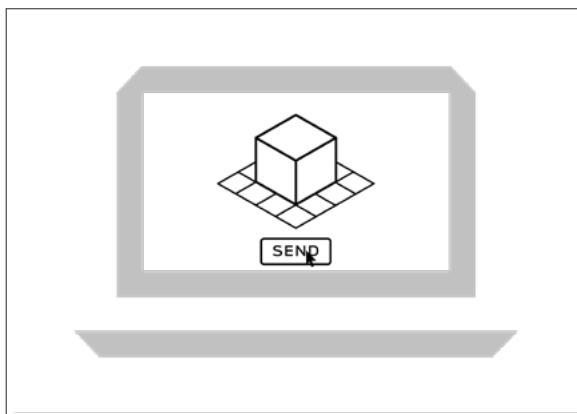
MAKE: With our chosen ideas, we can then prototype our designs through 3D printing and test them out with our audience to see if it answers their needs.

3D printing at a glance can seem like a technology that can be difficult to master - but like any new technology, machine or skill set, it starts with laying down a foundation of knowledge and growing on it. In this chapter, you'll learn the overall process of how to go from a digital model to a physical print, how 3D printing actually works to create a physical, tangible object, what modeling programs students can begin using - no matter their skill level.

SECTION 2.1

From Digital Model to Physical Print

How does a 3D printer know what to create and how? The process at first glance can seem like magic happening in front of our eyes, but like any technology there's a series of steps that have to be followed before we get to a finished 3D-printed model:



1. DESIGN

3D printing starts with a digital model, most often generated from a 3D modeling program. A digital model can be obtained in the following ways:

Design a model to print in a 3D design software or computer-aided design (CAD) program.

Find a model online from [thingiverse.com](#)

Scan an existing physical object with a 3D scanner or 3D scanner app like the Qclone® app.

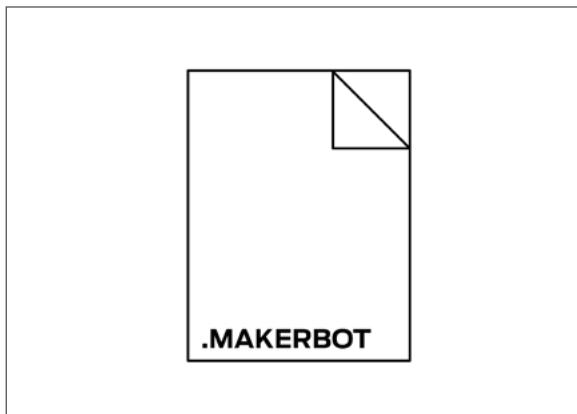


2. SLICE

Before a model can be printed it has to be sliced - slicing is the process of translating a digital model into a language, or series of steps, that the 3D printer can understand and follow. Slicing a model for 3D printing can be compared to sliced bread.



TIP:
Go to page 54 to learn how to prepare a 3D model to print.



3. PRINT

Once the 3D model is sliced a .makerbot file will be generated. The .makerbot file can then be sent to the MakerBot 3D printer, which will then read the file's directions and begin printing the 3D model.



TIP:
You can send the .makerbot file to your MakerBot 3D printer for printing through CloudPrint, Wifi, Ethernet, or USB jump drives.

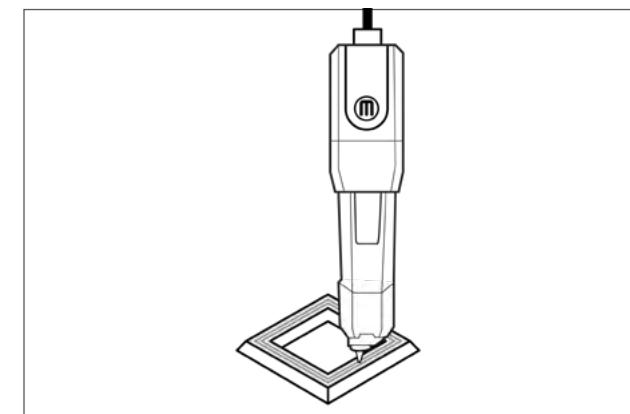
SECTION 2.2

How Does It Work?

Now that we know how a digital model is taken to the printer to be 3D-printed, let's take a look at how the 3D printer makes it possible for that sliced model to take its physical shape. All MakerBot 3D printers work in nearly the same way and use a technology called **Fused Deposition Modeling**, or **FDM** for short.

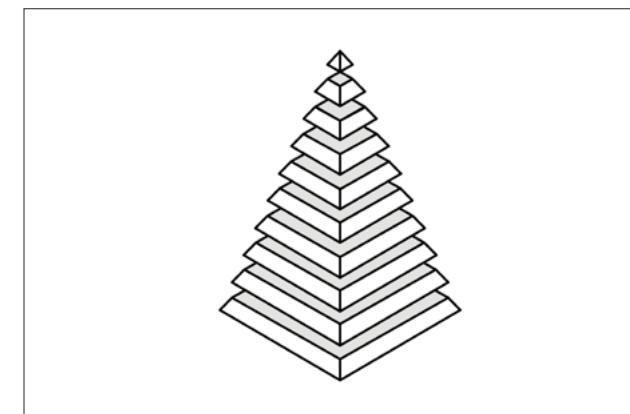
FDM is the process of extruding a molten material, usually a type of plastic, from the printer's extruder, similar to a hot glue gun onto a build surface that lowers as a new layer of molten material is extruded.

A Closer Look



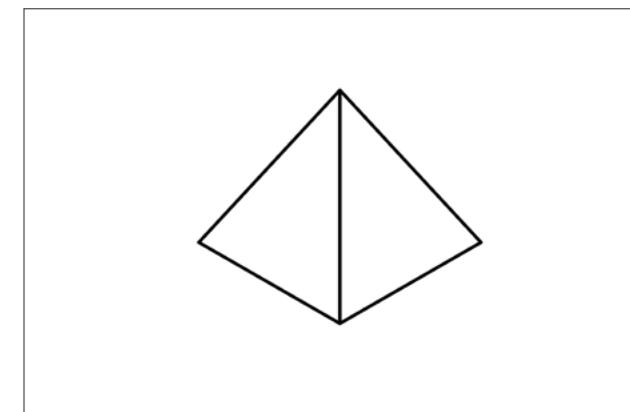
01

A printer's extruder moves around a set plane, usually in the XY plane. As the extruder moves around the build plate following a long list of coordinates, melted plastic is extruded from the extruder as it moves and completes the first layer of a 3D print.



02

This forms a layer of melted plastic that cools off and can then hold its shape. As a layer is completed, the printer's build plate will lower on the Z-axis and print another layer of plastic on the previously printed layer.



03

These layers then fuse together and the process continues over and over until a final 3D shape is produced.

BEYOND THE BASICS

Breaking the process down into three steps helps to see how the overall process works - but as you and your students grow more comfortable with 3D printing, you'll find yourselves asking more about the mechanics of a 3D printer. Having more knowledge about the inner workings of a printer can help later in the process when creating more complex models and designs.

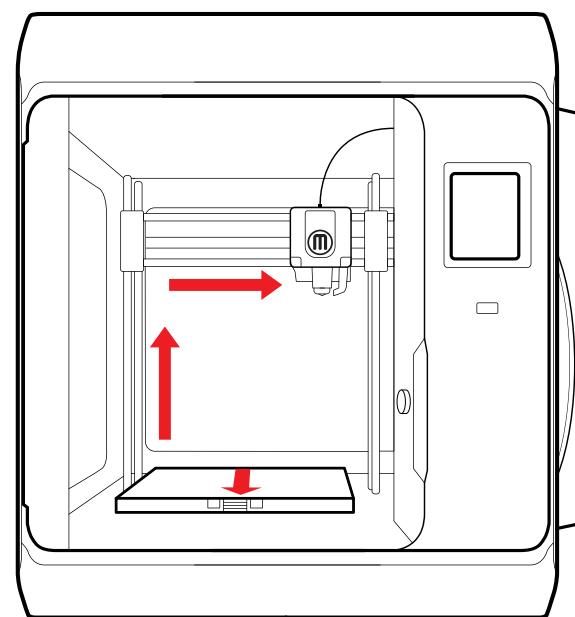
With FDM 3D printers, the extruder and the build plate work together to move across the X, Y and Z axes. With this movement, the printer is able to "draw" any type of design because it is able to move left and right on the X-axis, forward and back on the Y-axis, and up and down on the Z axis. These 3 axes can work together to make both geometric and organic shapes, essentially allowing the user to create any design needed.

X-Axis Left and Right direction

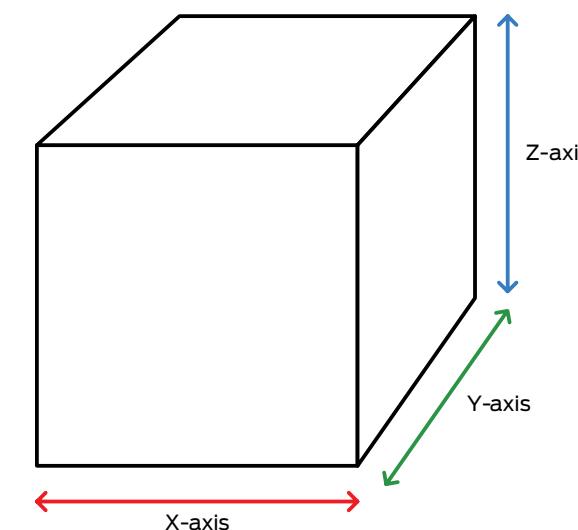
Y-Axis Forward and Back direction

Z-Axis Up and Down direction

On most MakerBot printers, the extruder travels left to right on the X axis, front to back on the Y axis and up and down the Z axis. On a MakerBot SKETCH® 3D printer, the build plate moves front and back on the Y and the extruder moves both in the X and Z axes, left to right and up and down, respectively.



Graphic of a SKETCH printer movement

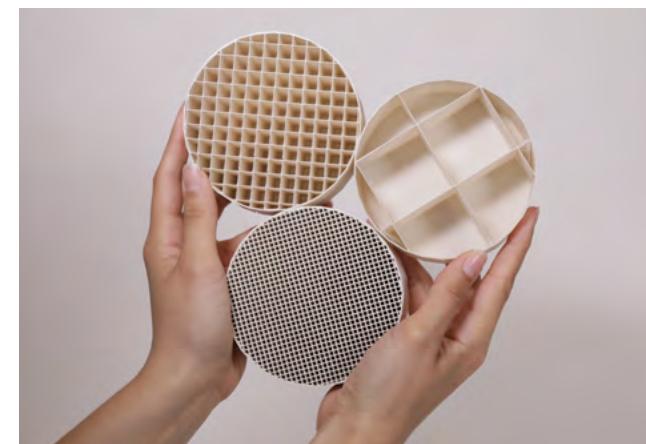


Graphic of a METHOD printer movement

SECTION 2.3

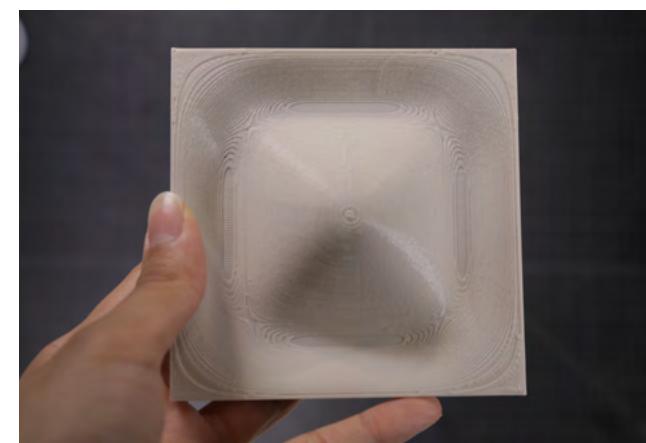
Components of a 3D Print - Bringing It All Together

There are different components that make up a 3D print, all these components work together to provide you with a successful 3D print.



Infill

The internal support structure that helps a 3D object hold its shape and increases the objects durability, measured in density.



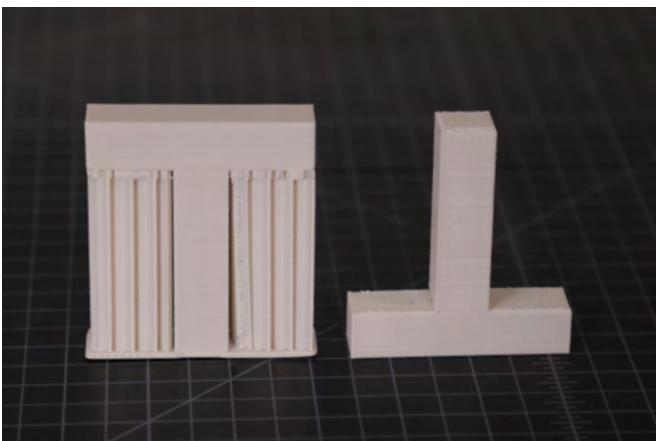
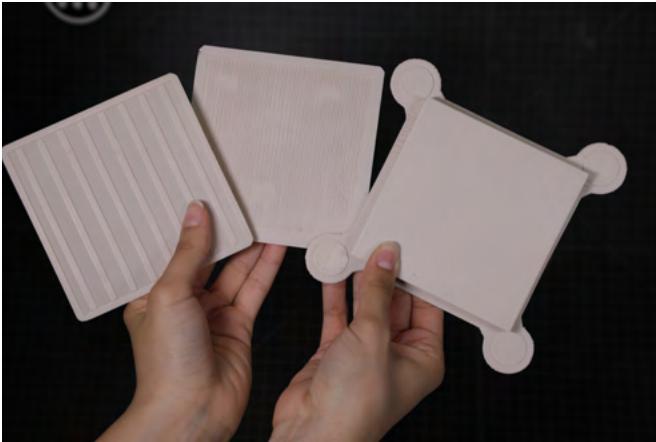
Layers

The layers make up the shape of the 3D print, think of each layer as a unique slice of bread that when stacked creates a 3D model. Layers are often measured by the layer height, or vertical thickness of each layer.



Shells

Outside walls that make up the perimeter of printed parts or the perimeter of each printed layer, sometimes referred to as the 'skin' of a print.



Rafts

Typically the first component that is printed, a raft helps models adhere to the build surface of a printer and provides a level surface for the first layer of the 3D model.

Supports

Removable scaffolding-like structures that print with your 3D model for any areas that have severe overhangs. Supports help you print components of a 3D model that may be in 'mid-air', similar to the wings of the letter "T".

Overhangs

Layers that have little contact with the previous layers. Overhangs that typically exceed 68 degrees from the Z-axis will require supports.

Bridges

The underside of a print that is supported at both ends but not in the middle. Usually a 'bridge' that is longer than 50mm will require supports to avoid filament "drooping" from the print.


TIP:

Designing with overhangs and bridges in mind can enable students to print without the use of supports.

SECTION 2.4

3D Design

3D design, or 3D modeling as it will be referenced here, 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 the 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(s) that fits your design the best.

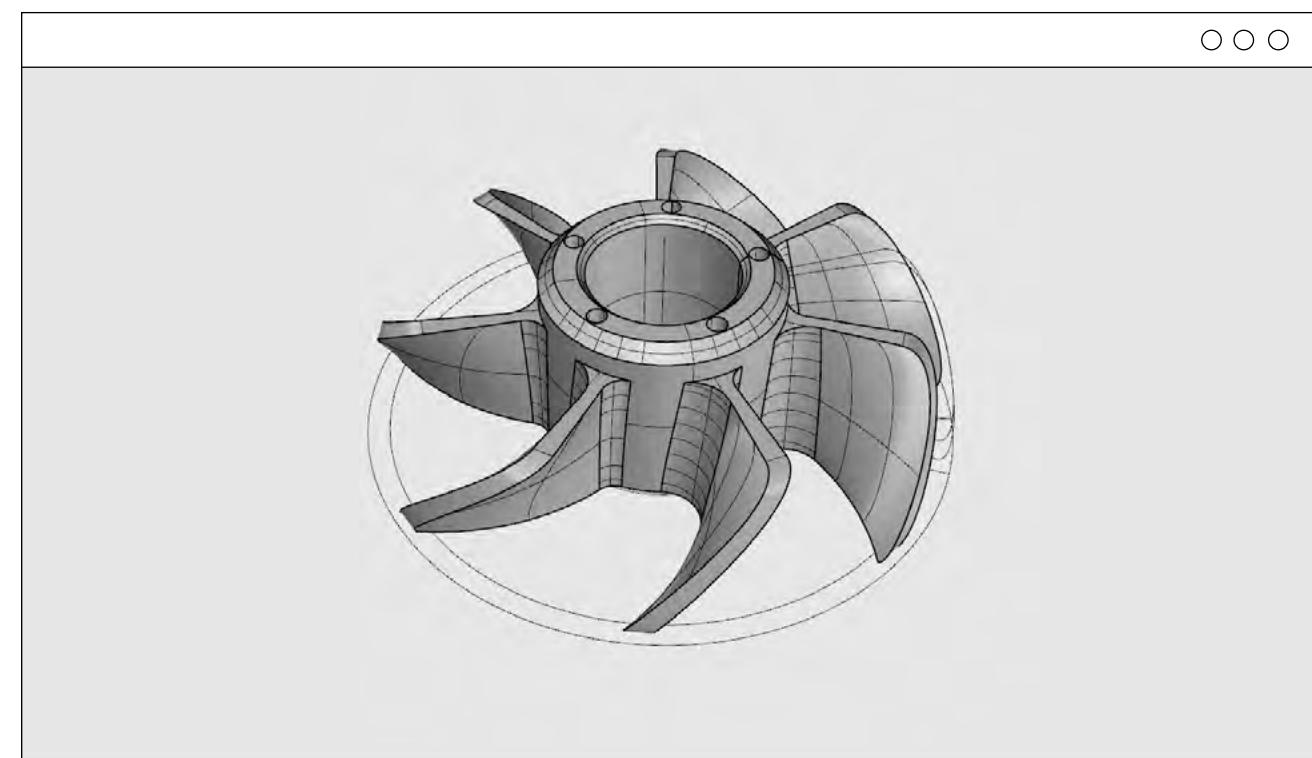
TYPES OF MODELING PROGRAMS

There are a lot of 3D design programs available, all with different strengths and weaknesses. When looking at 3D modeling programs, you'll find that all of them fall into three major categories:

- Solid Modeling
- Digital Sculpting
- Polygon Modeling

1. Solid Modeling

The easiest and most widely available type of modeling program to start out with. Solid modeling works well for creating models with real-world dimensions and is typically used to make functional parts.



Ideal for

STEM-integrated projects, as well as design-thinking, engineering and problem-solving centered initiatives.

Strengths

Creating mechanical structures with real-world dimensions, building assemblies, simulating real-world physics, editable design history

Program to Start with: Tinkercad
 Autodesk® TINKERCAD®
<ul style="list-style-type: none"> • Free • Cloud-Based • Integrated with Google Classroom

Used by

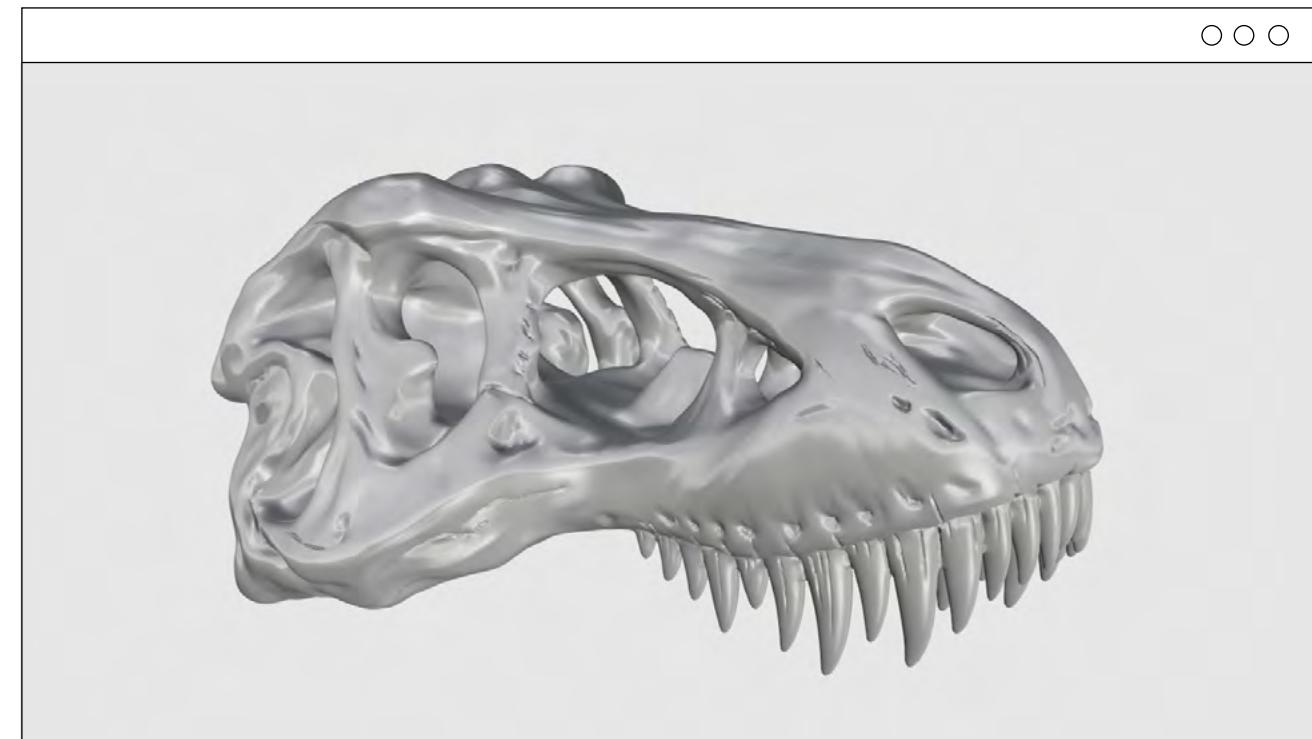
Engineering, Industrial Design, Architecture, and Medical industries

Weakness

Difficult to create organic shapes, detailed surfaces and patterns

2. 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.

**Overview of Applicable Modeling Programs**

	 Autodesk® TINKERCAD®	 AUTODESK® FUSION 360™	 onshape®	 SOLIDWORKS
Difficulty				
Cloud Based	Yes	Yes	Yes	No
Cost	Free	First Year Free	Free	\$99+
Phone App Available	No	Yes	Yes	No
	Available as Web-Based Tool	Works in conjunction with desktop counterpart		
Chromebook Compatible	Yes	Yes	Yes	No

Ideal for

Testing rough shapes for art projects, sculpture and projects where organic models are needed such as faces, plants, etc.

Strengths

Highly detailed models, organic shapes, digital painting, ability to “undo” mistakes

Program to Start with: ZBrushCoreMini
(Previously known as Sculptris)

- Free
- Easy to use
- Simplified Interface

Used by

Films, Video Games, Jewelry Design, Animation and Automotive Design industries

Weakness

Creating functional parts is difficult, often requires a drawing tablet, and a steep learning curve for advanced programs.



TIP: While we have a list of recommended programs below there are many other programs available that can be used with both tablets and smartphones. We recommend going to either the Google Play™ store or Apple® App Store® to find more options.

Overview of Applicable Modeling Programs

				
Difficulty	<div style="width: 15%;"></div>	<div style="width: 20%;"></div>	<div style="width: 25%;"></div>	<div style="width: 30%;"></div>
Cloud Based	No	No	No	No
Cost	Free Free for Non-Commercial Work	Free	Monthly Subscription Model	\$99+
Phone App Available	No	No Available as Web-Based Tool	No	No
Chromebook Compatible	No	Yes	No	No

Ideal for

High resolution 3D models and for editing STL files, also used in Animation and video game design classes

Strengths

Useful for creating highly detailed, intricate models; direct control of the mesh, and a preferred tool for animation.

Program to Start with:

Autodesk® Meshmixer
(Previously known as Sculptris)

- Free
- Versatile Use
- Can help repair problem STL files

Used by

Animation, Architecture, Visualization, Film, and Video Game industries

Weakness

Steep learning curve. Intended for on-screen and virtual environments - extra consideration must be taken while modeling for 3D printing.



TIP:
Polygon Modeling is not optimized for 3D printing, we recommend trying polygon modeling once a solid understanding of 3D modeling and 3D printing has been established.

3. Polygon Modeling

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



Overview of Applicable Modeling Programs

					
Difficulty	<div style="width: 15%;"></div>	<div style="width: 20%;"></div>	<div style="width: 25%;"></div>	<div style="width: 30%;"></div>	<div style="width: 35%;"></div>
Cloud Based	No	No	No	No	No
Cost	Free	Free	Free	Monthly/ Annual Subscriptions	Monthly/ Annual Subscriptions
Phone App Available	No	No	No	No	No
Chromebook Compatible	No	No	No	No	No

GET TO KNOW YOUR MAKERBOT 3D PRINTER

Both the MakerBot SKETCH Classroom™ and MakerBot METHOD® 3D Printers offer different capabilities that can enhance different steps of the design thinking process. The section below details the main components of each of the MakerBot 3D printers today. Refer to the diagrams for guidance on each printer's major components like the build plate, gantry, extruder(s), and more.



SECTION 3.1 SKETCH 3D Printer

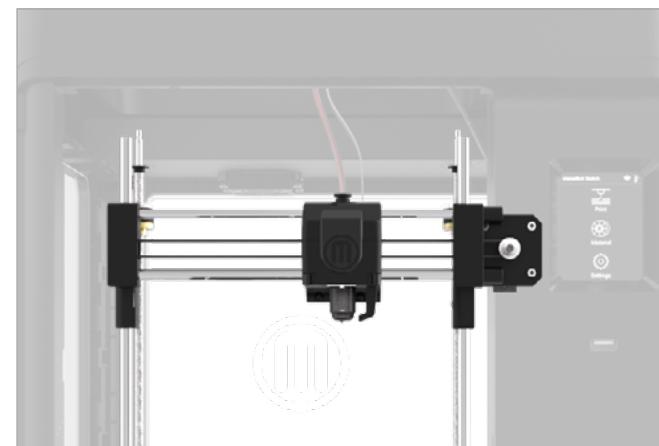
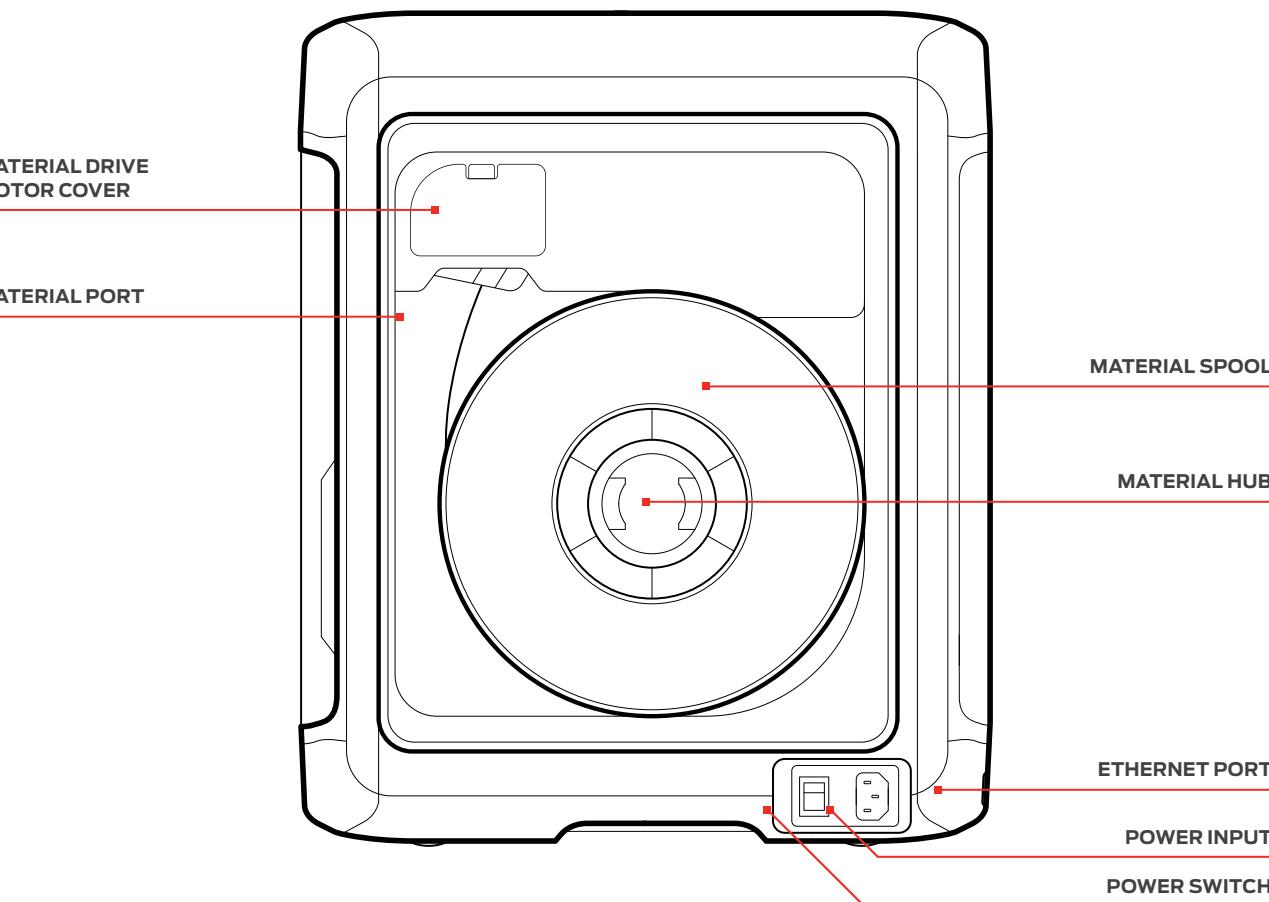
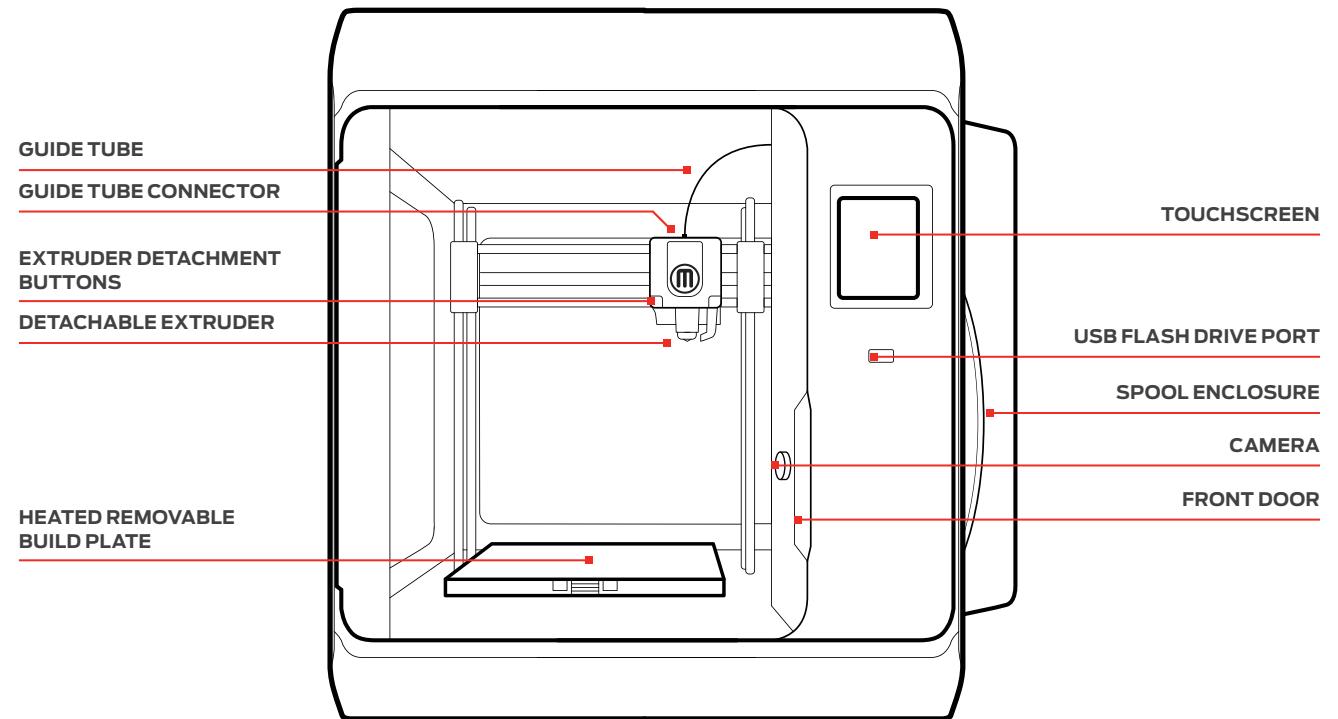
The first time you turn on your MakerBot SKETCH 3D Printer, you will be guided through the initial setup via the onboard touchscreen. This guided setup will walk you through connecting the printer to an internet connection, authorizing your printer, running calibration, loading material, and running your first test print.

Use the diagram below to familiarize yourself with the main components of the SKETCH 3D printer.

GENERAL FEATURES:	IDEAL FOR:
<ul style="list-style-type: none">• Single Extrusion• Breakaway Supports• Heated Build Plate• Fully Enclosed Print Chamber• Automated Material Loading• Remote Monitoring	<ul style="list-style-type: none">• Users Not Familiar with 3D Printing• Getting Started with 3D Printing• Exploratory Printing• Teaching Aids• High-Volume Printing• Rapid Prototyping



PARTS & FEATURES



01 Touchscreen

The touchscreen allows you to start prints, change settings and view status information.

02 Extruder

The extruder draws the material from the spool, melts it, and pushes it through a nozzle onto the Build Plate

03 Heated Removable Build Plate

The flat plate on which the MakerBot SKETCH 3D printer builds an object. This plate is removable and bending the plate allows you to remove objects.

04 Gantry

The apparatus that allows the carriage and extruder assemblies to move in the X and Z axes. (The build plate moves in the Y axis)

SECTION 3.2

METHOD Series 3D Printers

The first time you turn on your MakerBot METHOD, you will be guided through the initial setup process using the MakerBot METHOD user interface. This guided setup will walk you through connecting the printer to an internet connection, authorizing your printer, attaching Performance extruders, running calibration, loading material, and running your test print.

GENERAL FEATURES:	IDEAL FOR:
<ul style="list-style-type: none"> • Dual Extrusion • Dissolvable Support Material • Open Materials Platform • Heated Printing Enclosure • Auto-Calibration • Dimensional Accuracy Within +/-0.2mm 	<ul style="list-style-type: none"> • Users Familiar with 3D Printing • Advanced Prototyping • Complex Geometries • Engineering, Manufacturing, & Industrial Design Applications • Material Research



05 Build Volume

The maximum build volume for this printer is 150mm x 150mm x 150mm [5.9in x 5.9in x 5.9in]



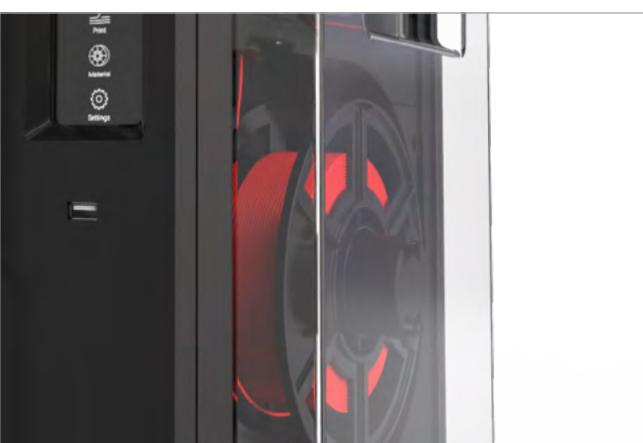
06 Material Guide Tube

The plastic tube that guides the MakerBot material from the material spool to the extruder.



07 Camera

Use camera to monitor prints remotely

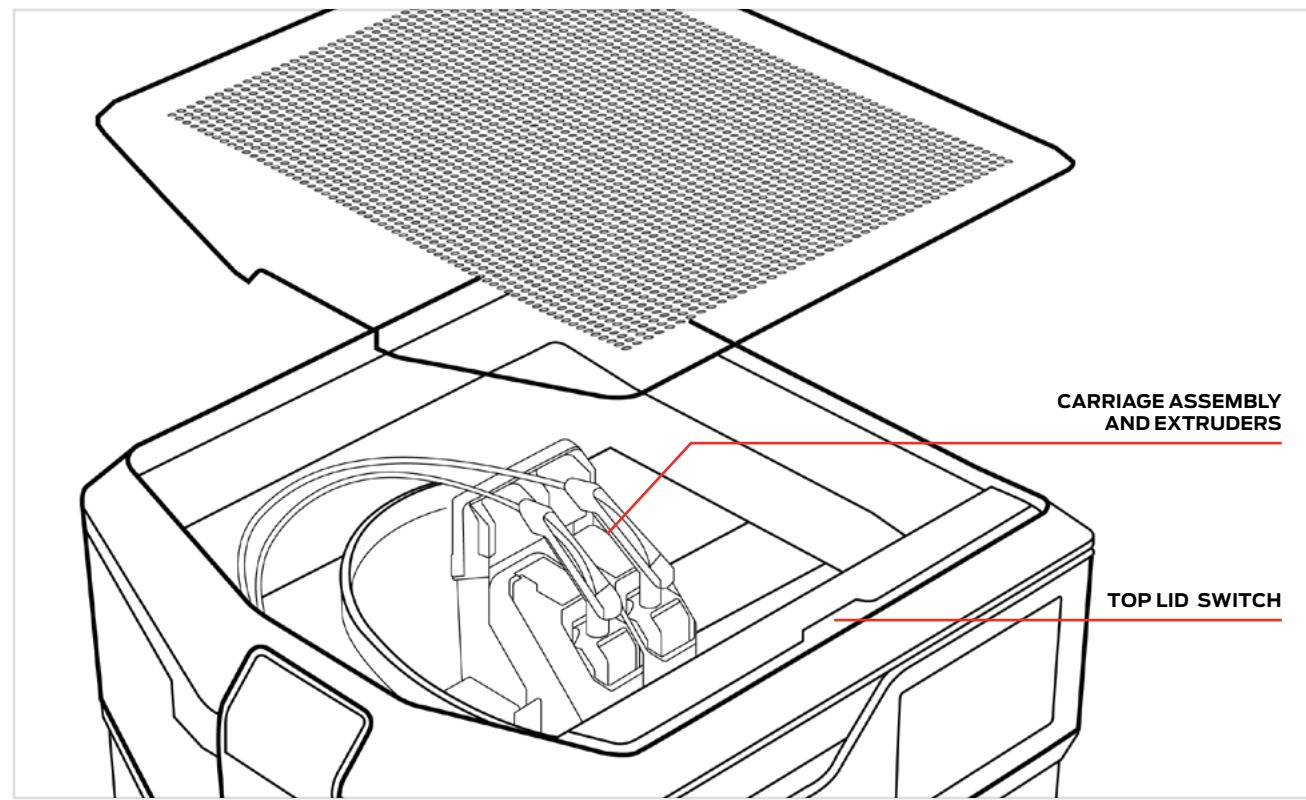
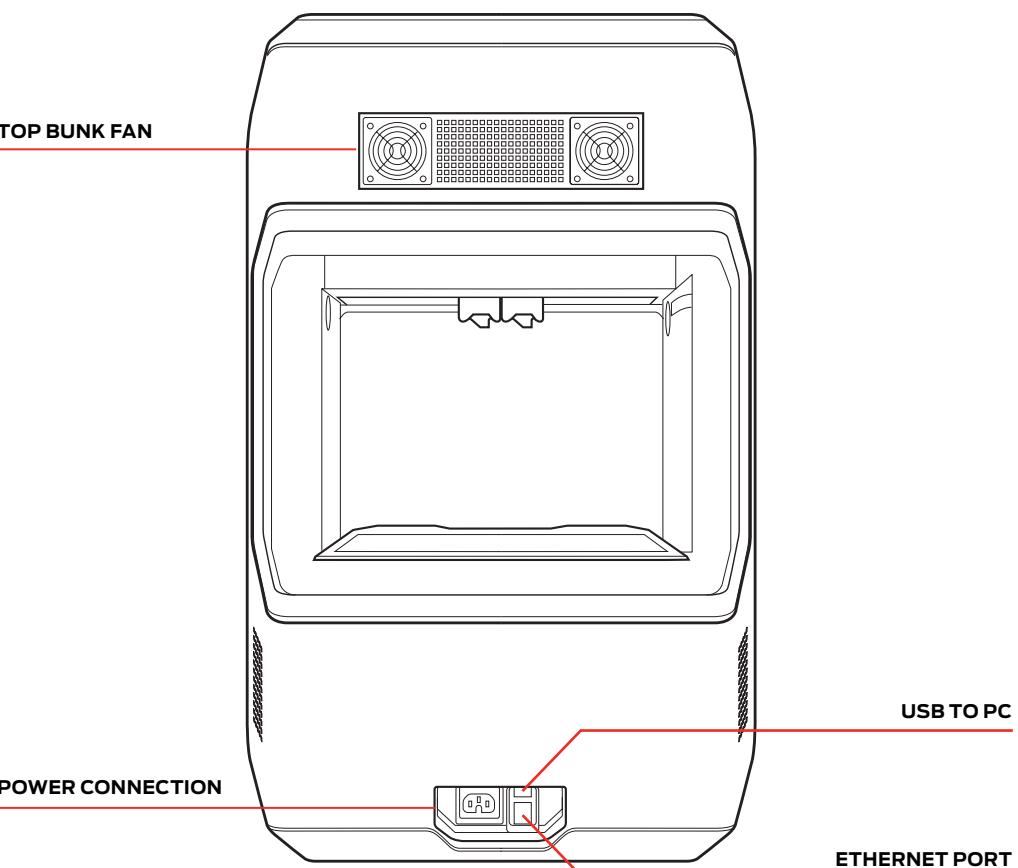
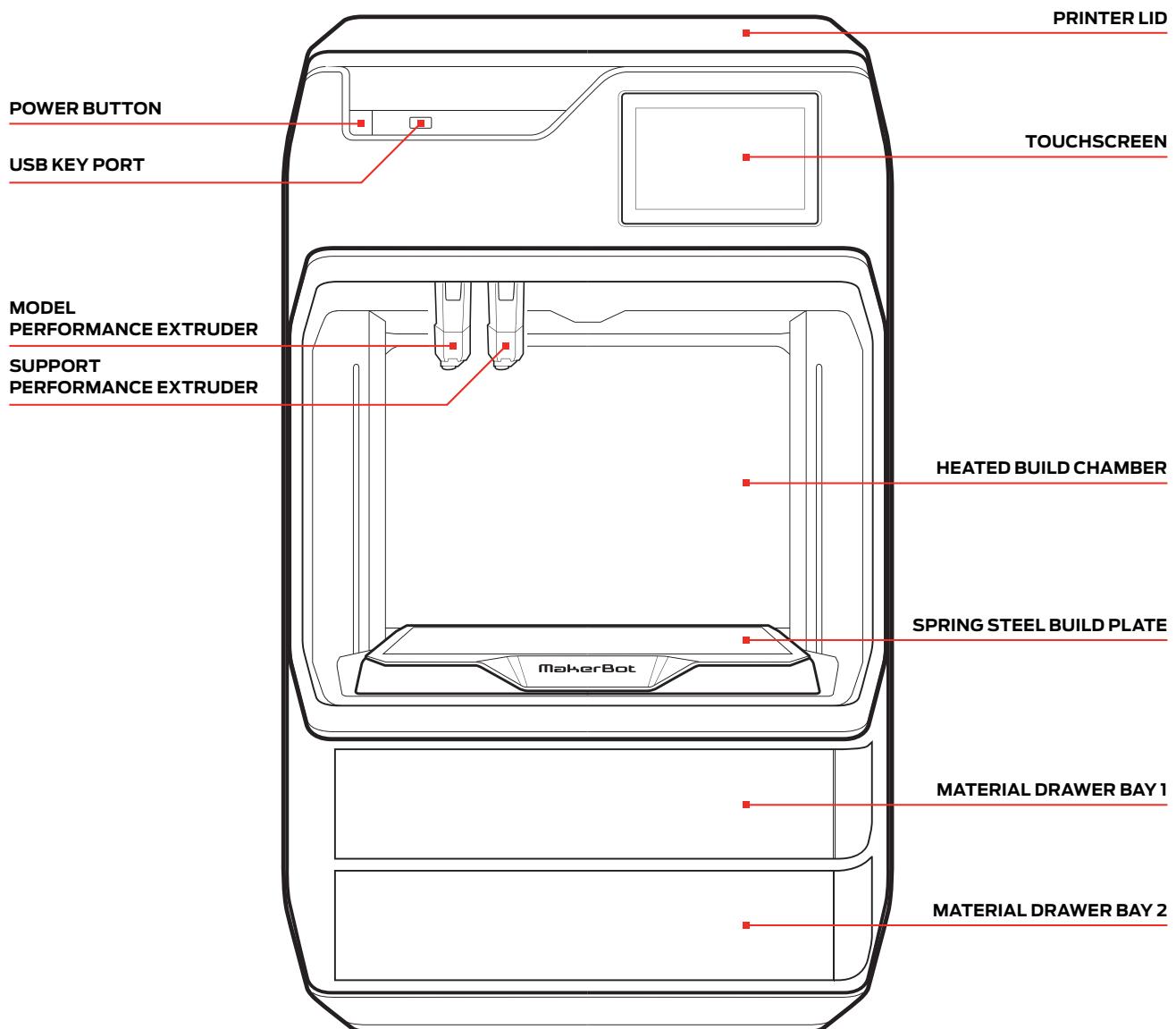


08 Spool Enclosure & Material Hub

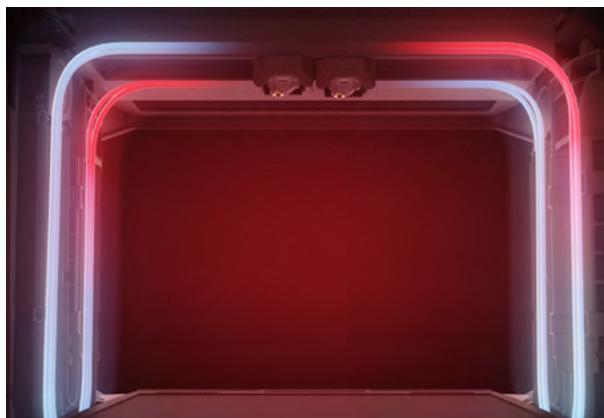
Used to store print material during the printing process. Spools are inserted in a clockwise manner.



Use the diagram below to familiarize yourself with the main components of the METHOD 3D printer.



PARTS & FEATURES



01 Printer Lid

Allows for heat to escape, preventing the printer from overheating



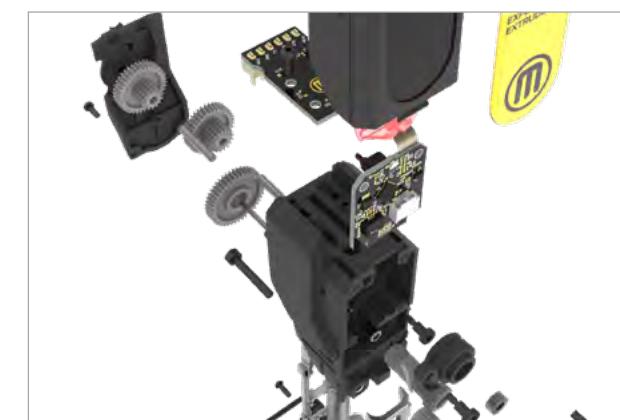
02 Heated Build Chamber

Temperature-controlled chamber allows for active heat immersion and allows the extruded material to cool slowly, minimizing warping and curling.



03 Build Platform

The support for the build plate. The build platform's underside contains adjustable hex bolts for use during assisted-leveling.



04 Material Drawer Bays

Two sealed drawer bays located at the base of the MakerBot METHOD, where both the model and support material spools are stored during the printing process and kept safe from humidity, environment and dust.



05 Performance Extruder

The Performance Extruder draws filament from the spool, melts it, and pushes it through a nozzle onto the build plate. There are two types of performance extruders, the Model Performance Extruder is responsible for printing the 3D model, while the Support Performance Extruder prints any support material that the 3D model might need to ensure a successful print.

06 Spring Steel Build Plate

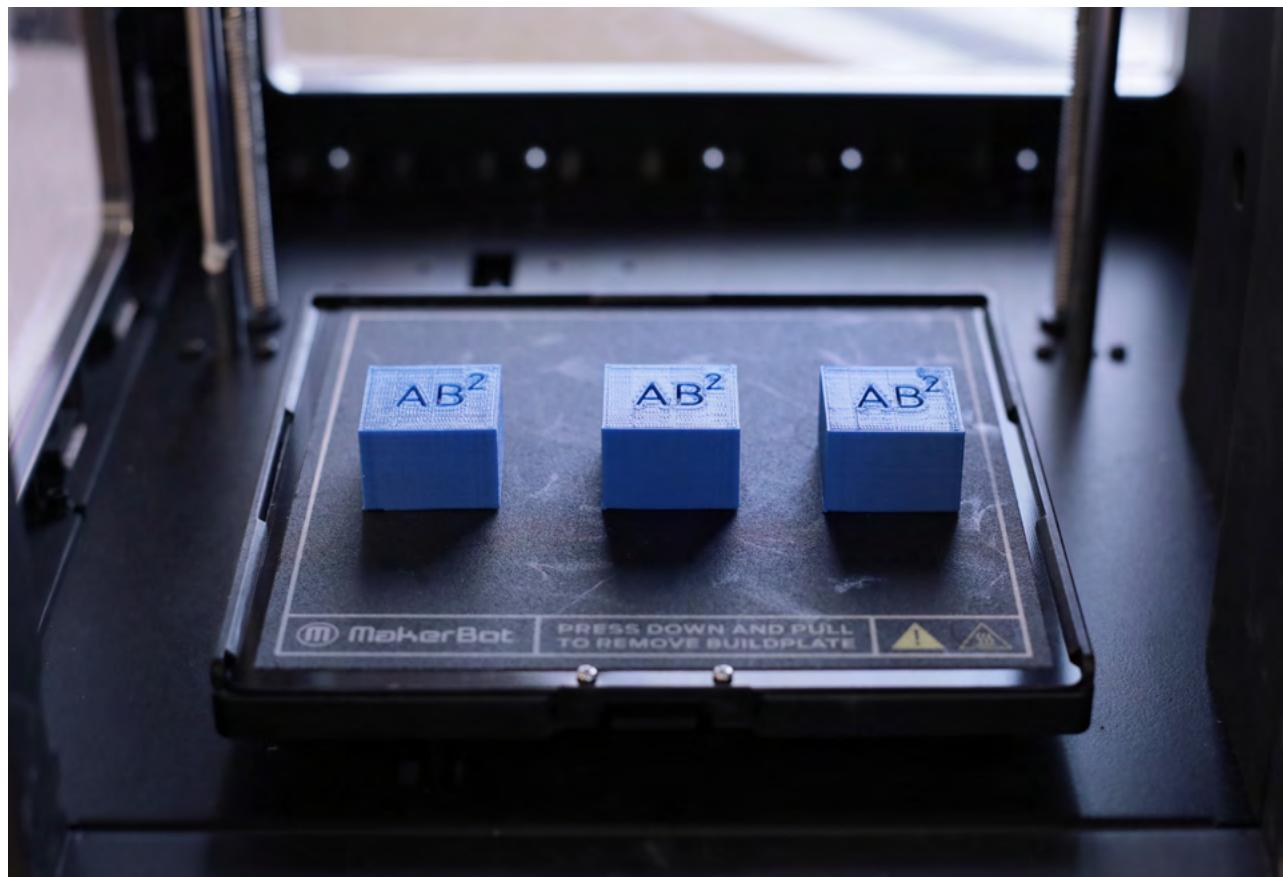
The flat plate on which the MakerBot METHOD 3D Printer builds an object. This plate is removable and bending the plate allows you to remove objects.

07 Extruder Assembly

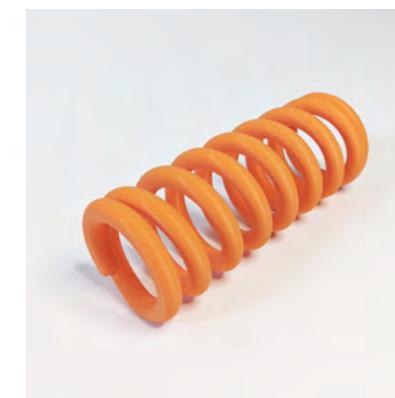
The swappable Performance Extruders which contain the sensors, drive gears, hot end, and nozzle.

08 Gantry

A pulley and belt system that allows the carriage and extruder assemblies to move along the X and Y axis.

SECTION 3.3**Material Compatibility****SKETCH MATERIALS****PLA**

Extruder Standard
Printer SKETCH

TOUGH

Extruder Standard
Printer SKETCH

METHOD MATERIALS

The chart below shows what sort of materials are compatible with these printers - from the tried and true types of printing material like PLA, TOUGH™ and ABS to newer materials like Nylon Carbon Fiber, SEBS and even Metal. Below you'll find a collection of some of the materials METHOD series printers can print with.

**MODEL MATERIALS****PLA**

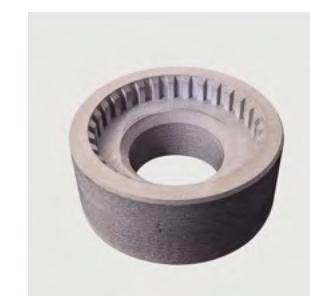
Extruder Standard
Printer METHOD, METHOD X

TOUGH

Extruder Material Extruder 1
Printer METHOD, METHOD X

NYLON

Extruder Standard
Printer METHOD, METHOD X

METAL

Extruder LABS GEN 2
Printer METHOD, METHOD X

NYLON CARBON FIBER



Extruder Material Extruder 1C
Printer METHOD, METHOD X

N12 CARBON FIBER



Extruder Material Extruder 1C
Printer METHOD, METHOD X

PETG



Extruder Material Extruder 1
Printer METHOD, METHOD X

ABS



Extruder Material Extruder 1XA
Printer METHOD X

SECTION 3.4

MakerBot Legacy 3D Printers - Replicator Series



Replicator+ Mini +

Replicator+

Replicator Z18

Have a MakerBot Replicator® 3D Printer? Download our previous MakerBot Educators Guidebook book (2017) to learn all about your printer's features and how to use them in the classroom. Keep reading this book to learn more on 3D modeling, projects and tips that can also be used with your MakerBot printer

SUPPORT MATERIALS

SR-30



Extruder Material Extruder 1XA
Printer METHOD X

PVA



Extruder Material Extruder 1
Printer METHOD, METHOD X

**TIP:**

MakerBot is constantly testing new materials that can work with the METHOD series printers - looking to see what the latest additions are to the materials platform? Visit us at www.makerbot.com/3d-printers/materials/method-materials/

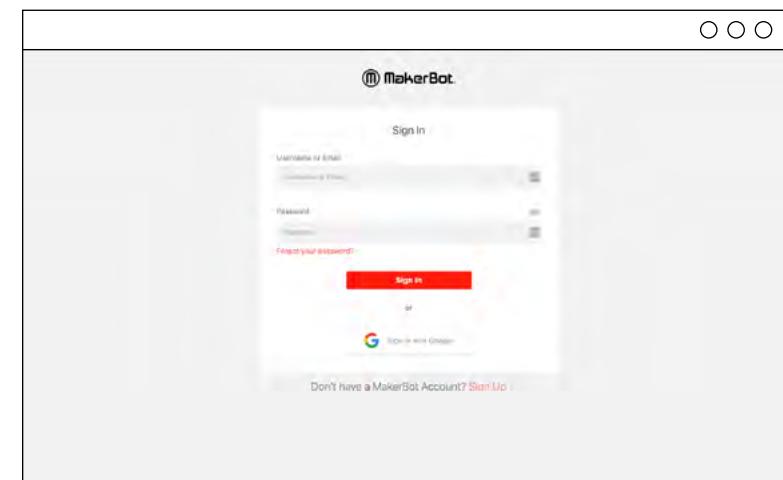
SECTION 3.5

Printing Remotely - MakerBot CloudPrint

Often, bringing new software and technology into the classroom can be a massive challenge for educators - that's why we created a cloud-based platform that requires no software to download and install, with no student account creation necessary. Students in class, or in remote-learning, can submit files to be queued and printed by the instructor, and the instructor can combine student-submitted files into a single submission to the printer. A streamlined and simplified 3D printing process in classrooms.

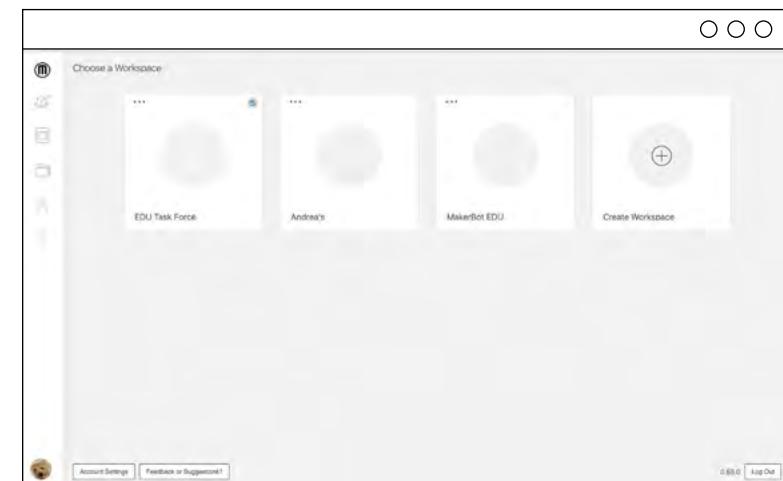
GETTING STARTED WITH CLOUDPRINT

To get started, go to cloudprint.makerbot.com & log in. If you don't already have a MakerBot account, click "Sign Up" to create one.



CREATING A WORKSPACE

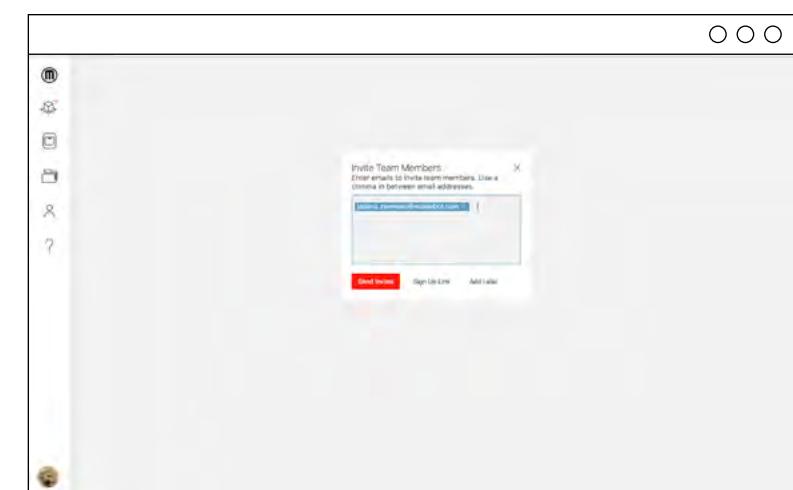
The first step in monitoring multiple printers across multiple classrooms at once is by creating a workspace. Workspaces can be used for different classes, teachers, clubs, groups of printers, and projects.



ADDING MEMBERS TO A WORKSPACE

After naming your workspace, you'll be asked to add members to your workspace. We recommend adding fellow faculty members & students that you are comfortable with managing the printers & printer queue.

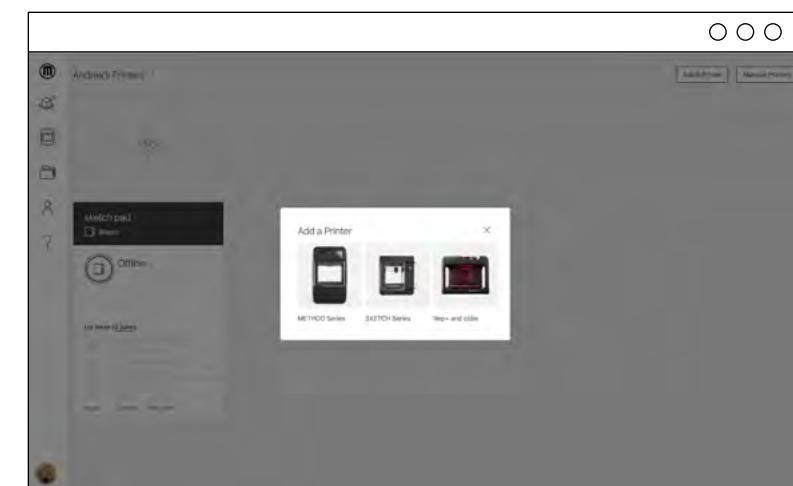
If adding multiple members to your team, make sure to include a comma after every email address.



ADDING PRINTERS TO A WORKSPACE

Next, you'll be asked to add printers into your workspace. To add printers they must already be authorized to your account and connected to a WiFi network. By clicking **Share with Workspace**, you'll be sharing access to this printer with all members of the workspace.

To authenticate a printer to your account, connect your printer to a WiFi or Ethernet connection and login to your MakerBot account from your printer.



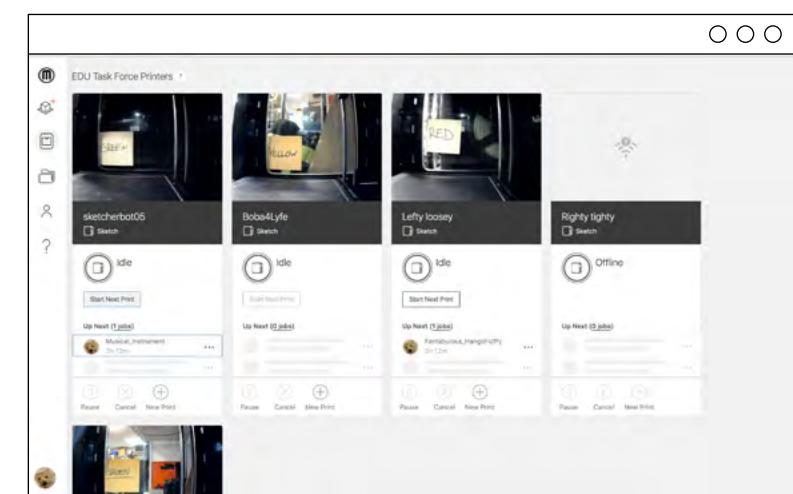
SELECTING A PRINTER FOR PRINTING

Go to the Workspace Printers page by clicking on the Workspace Printers printer icon on the left hand side of the screen. Locate the printer you'd like to use from this workspace and on that printer's module click New Print. This will take you to a new page to start preparing your file for printing.



TIP:

If there are no printers currently setup in your "Workspace" click the Start a New Print button on the left hand side.



STARTING A PRINT

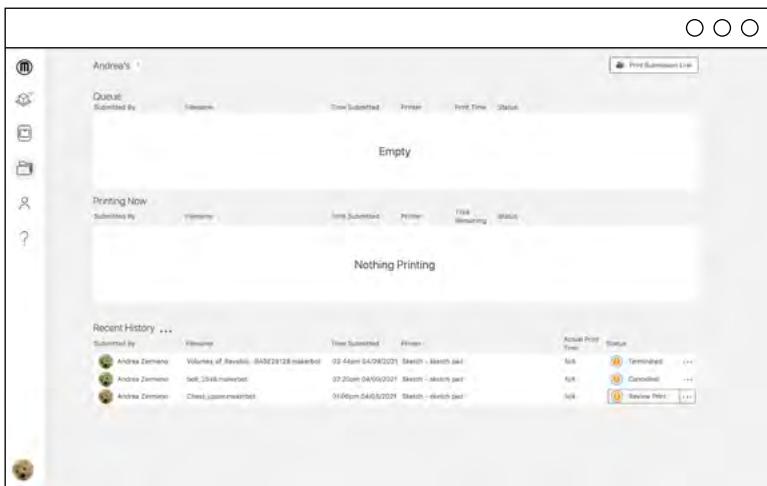
After you've selected which printer to print to, you'll be taken to the CloudPrint's slicer. Here you can import .stl file(s), select a print mode, and adjust any settings needed to print the 3D models. When ready to send your file(s), click "Queue" to add the prepared files to your printer's queue.

This will close the window and add the model to the selected printer's queue. Once back in the **Workspace Printers** page, click **Start Next Print** to begin the print.

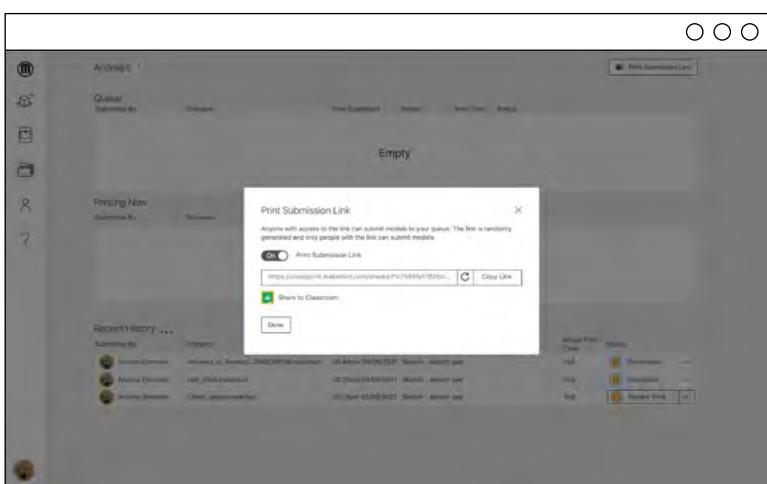


ENABLING STUDENT FILE SUBMISSIONS

To allow students to submit their files to your workspace, you can generate a **Print Submission Link** from your workspace by clicking on the top right corner of the **Workspace Print Jobs** tab to allow students or colleagues to submit files to your queue - without needing a MakerBot account.



A unique link will be generated for your workspace. This link allows your students and colleagues to submit their .stl files to your workspace without creating an account. Click "copy" to copy onto your clipboard and share via email, Google Classroom, or your preferred method of sharing files.

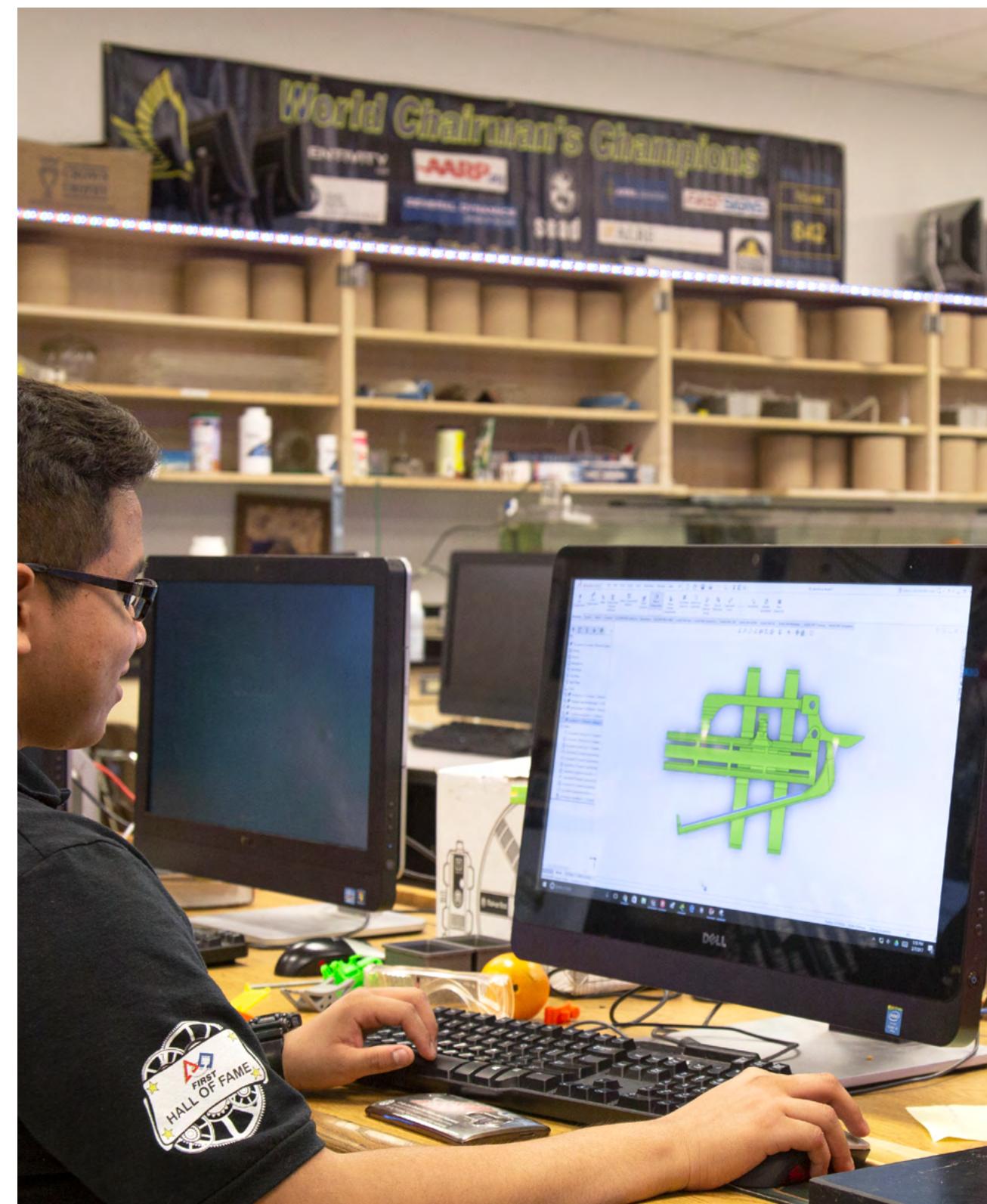


TIP:

Go to cloudprint.makerbot.com to see the latest updates and features for MakerBot CloudPrint.

CHAPTER FOUR

CURRICULUM PROJECT IDEAS



There are thousands of ways to integrate 3D printing into the curriculum - from kindergarten to higher education the possibilities are endless. The projects collected in this book aim to help give both new educators a better idea of how to start using 3D printing in the classroom and to give seasoned 3D printing educators ideas of how to integrate 3D printing even further into the curriculum. The projects collected in this book have been grouped by **Natural Sciences, Math, Engineering, Robotics, and Art, History & Music.**

Ready to dive into some projects?

Before you do we recommend you read the section below to help guide you as you read through each group of projects. These projects will provide both new and seasoned 3D printing educators ideas that will help them boost 3D printing in their curriculum.

HOW TO USE

PROJECT CATEGORY

If you remember from **Part 01: The Ins and Outs of 3D Printing in the Classroom** we define the way 3D printing is used in education using four categories:

Exploratory Print

Part of the Lesson

Teaching Aids

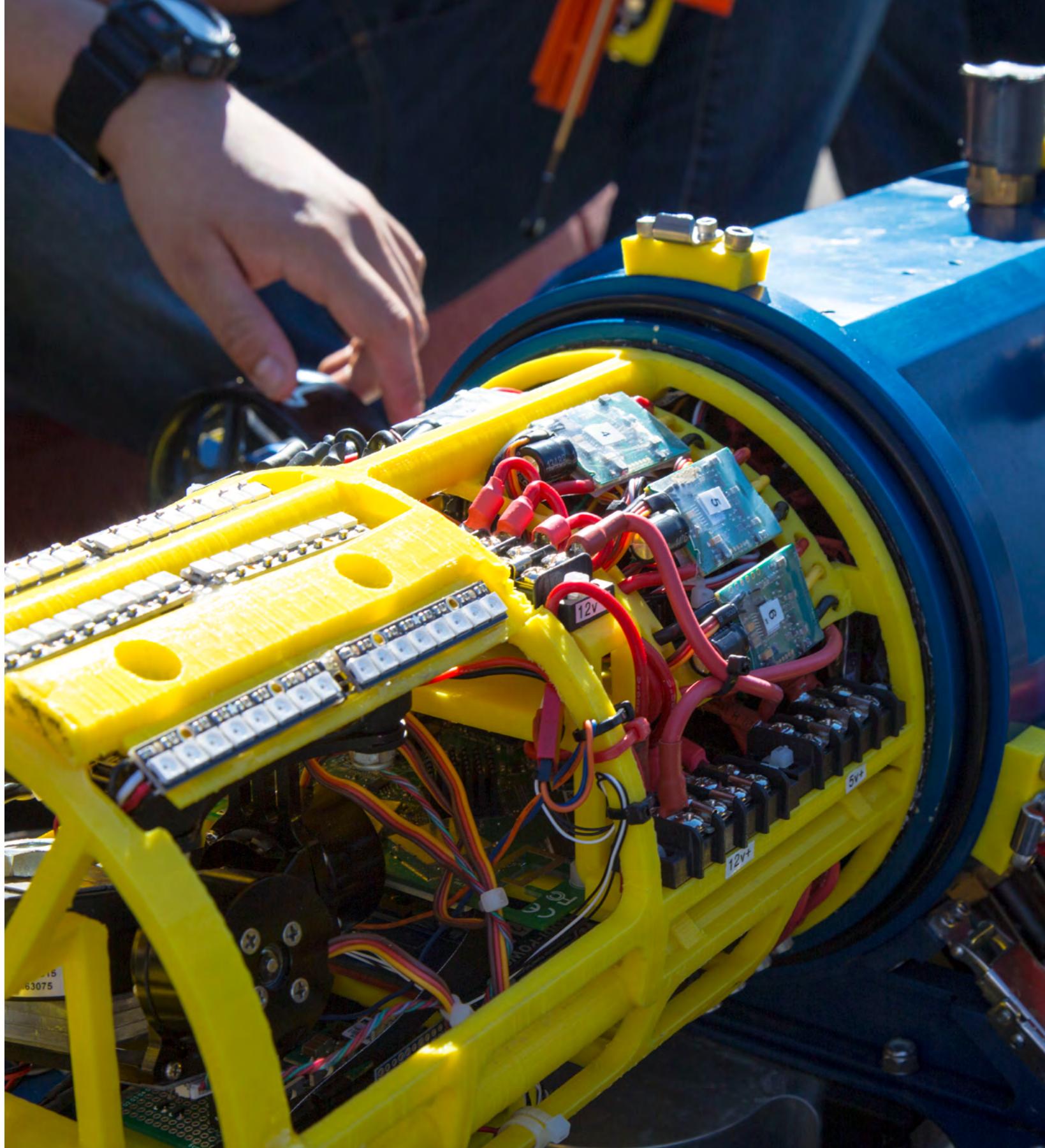
Student-Led, Student-Created

The project ideas in these next pages use the last 3 categories (Teaching Aids, Part of the Lesson and Student-Led, Student-Created) to signal the ways in which these project ideas can be used. You'll find that many projects can be used as teaching aids and that small steps can be taken to further involve students in the concepts taught.

HOW TO USE

DESIGN DIFFICULTY

Students are quick learners - especially when it comes to 21st century technology. Though many model files can be found on Thingiverse - we welcome students to challenge and familiarize themselves with designing models for 3D printing. Our **Design Difficulty** meter represents a scale made up of 5 STARS, the higher the STARS the more complex a model can be to design, the lower the amount of stars the easier it should be to start designing.



READY TO DIVE-IN?

SECTION 4.1

Natural Sciences

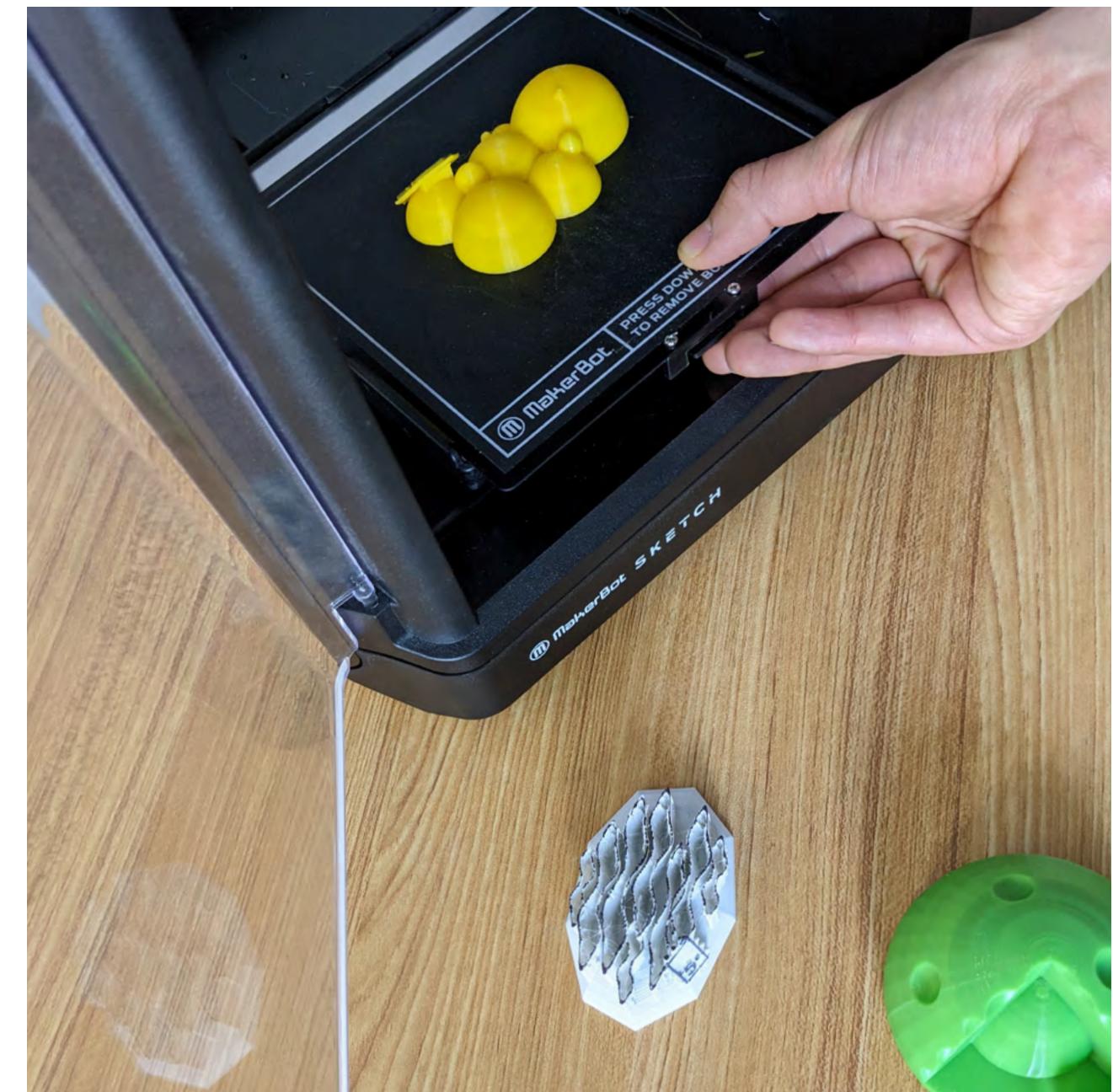


Scientists are working together to break 3D printing barriers in various fields of science - from 3D printing organs with live tissue, to printing scans of brain tumors, to 3D printed reefs to aid in marine restoration. We're only scratching the surface of what's possible when 3D printing is part of a scientist's tool belt.

Students, too, can use 3D printing as part of their tool belt to better engage and grow their understanding of the different branches of natural sciences. Students can get a hands-on look at the components that help a skeleton have movement, how extinct organisms may have functioned and how 3D printing can be used to study meteorology today.

[NATURAL SCIENCES PROJECTS TO GET STARTED ON →](#)

Project: Build a Cell City



Project Category

Part of the Lesson

Design Difficulty



LEARNING OBJECTIVES

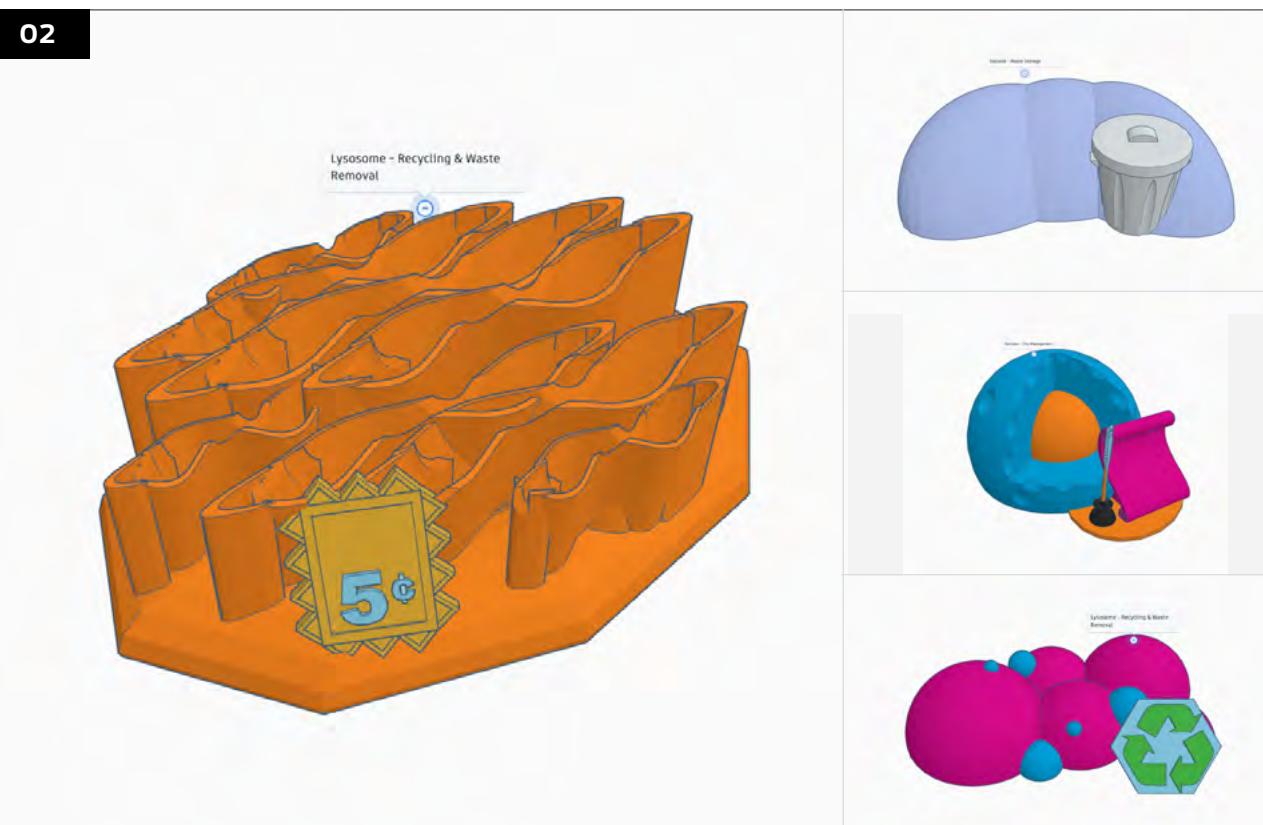
- Identify the organelles that make up an animal cell and their functions
- Understand how each organelle relies on each other to properly function
- Describe how a cell and its organelles are similar to how a city functions

01

Example:

Organelles	Job in the City
Nucleus	Regulates and controls the city
Mitochondria	Power plant and/or energy provider
Golgi Body	Postal delivery service
Vacuole	Waste storage
Lysosome	Recycling center and waste removal

Discuss this analogy with students, and together, come up with a cohesive list of organelles and their city counterparts.

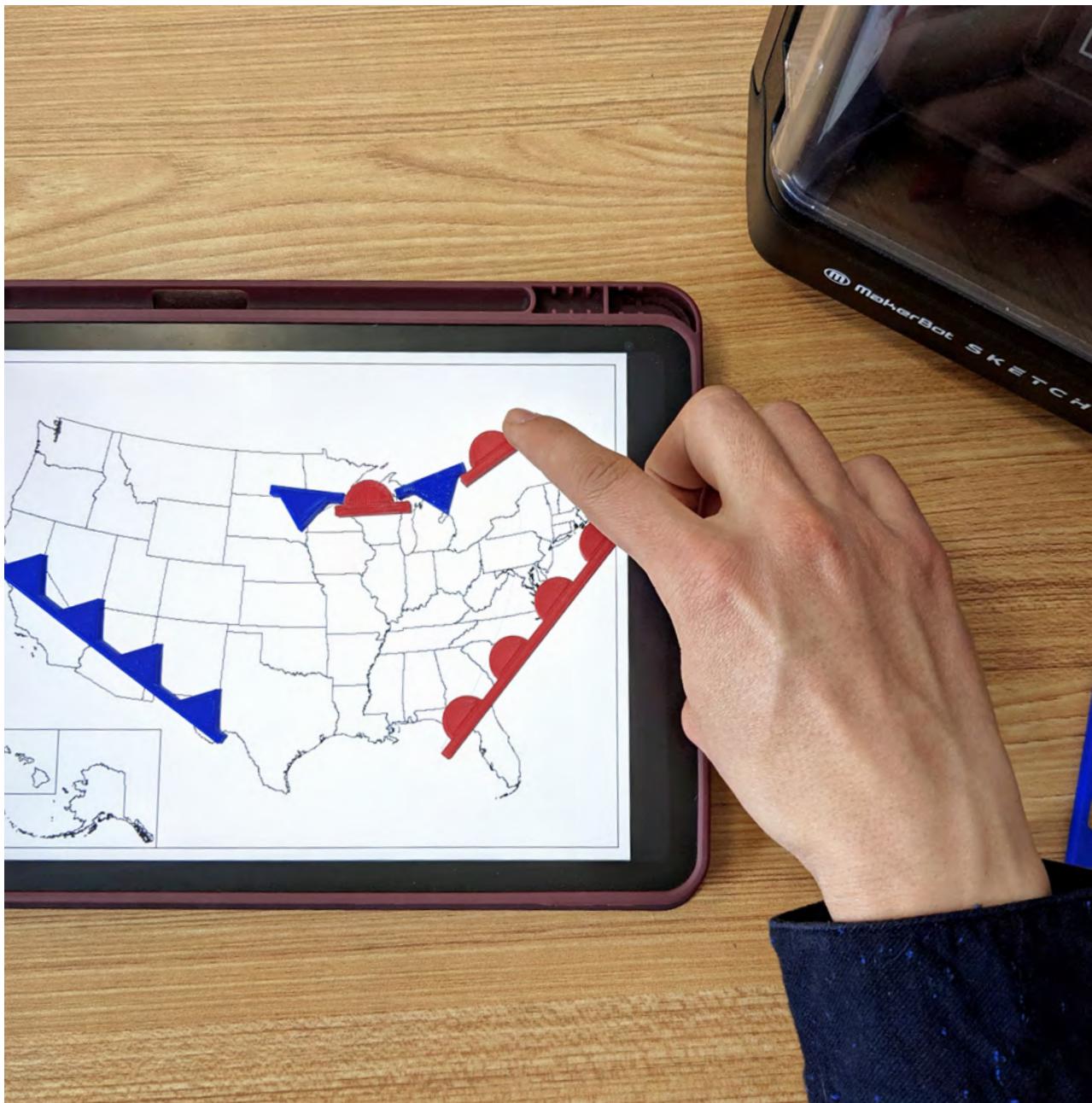


Putting students into teams, assign them each an organelle to redesign in Tinkercad.



Groups can then put all the printed organelles together and show how the cell itself functions like a city.

Project: Classroom Weather Map



Project Category
Part of the Lesson

Design Difficulty
★ ★ ★ ★

LEARNING OBJECTIVES

- Understand the factors that lead to cold and warm fronts
- Track different weather conditions over an area for a period of time
- Recognize the type of symbols used to show different types of weather conditions

Use a large bulletin board, posters, or even a blank wall as a classroom weather map, print weather symbols to track the weather through a week and document changes in weather conditions.

01

Sunday

High: 80°F | Low: 55°F
Cloudy skies, slow wind speed



Thursday

High: 66°F | Low: 47°F
Cloudy sky, no wind



Monday

High: 71°F | Low: 51°F
Sunny sky, low wind speed



Tuesday

High: 63°F | Low: 47°F
Sunny Sky, higher wind speed



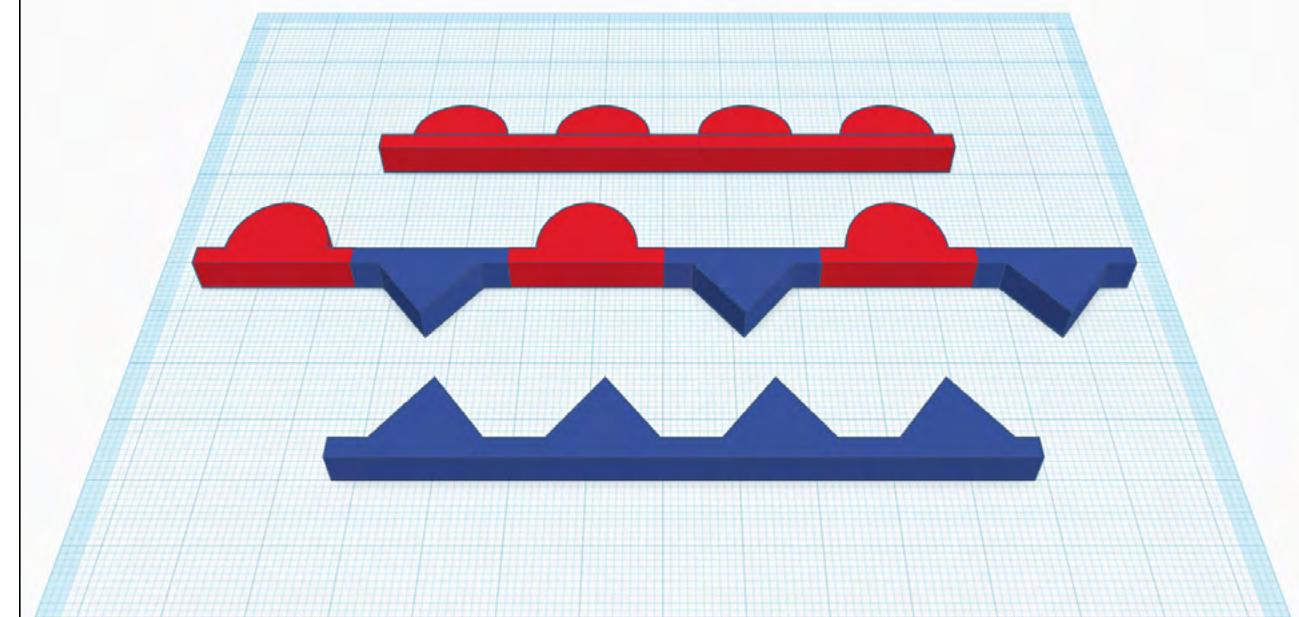
Wednesday

High: 55°F | Low: 46°F
Cloudy Sky, Slow wind speed

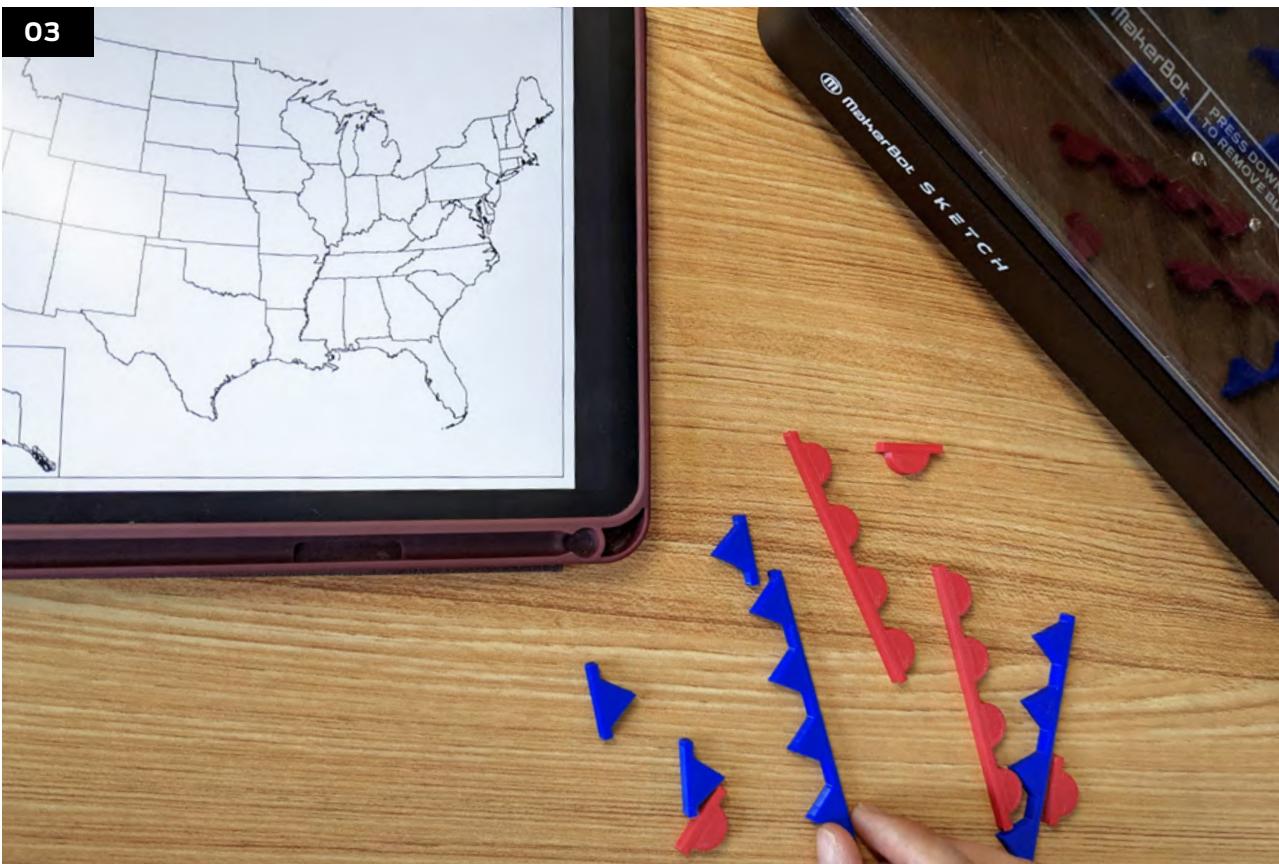


Track weather data over a specific period of time (example: weather in the United States throughout a week).

02



Have students use Tinkercad to design weather symbols to 3D print, such as cold fronts, warm fronts, hurricanes, wind speed flags, high and low pressure systems, and many others.



After printing, add tape to the back, and move the symbols on the classroom weather map daily to display how the weather changed throughout the week.

Explore More

There are a lot of ways to incorporate 3D printing into projects and lesson plans - below are some examples of how to integrate various topics in different branches of natural science (you'll find other project suggestions for the other subjects included in this book). Depending on your comfort level, many of these projects can serve as teaching aids or be incorporated as a part of a lesson - all these project ideas can also be incorporated into Student-Led, Student-Created type projects with a few adjustments.

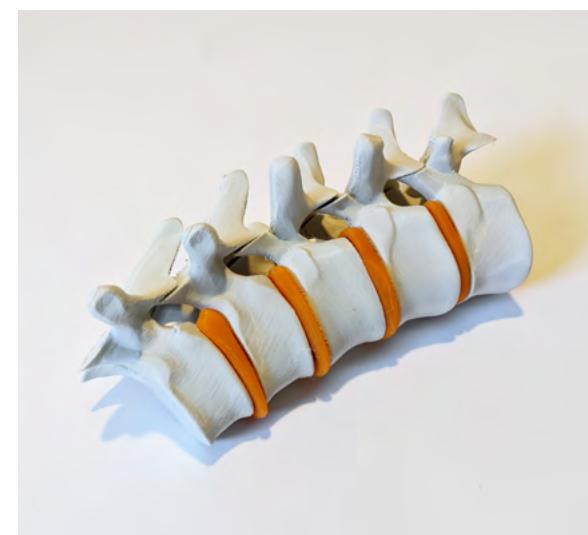


FROG DISSECTION

Thing #: 258112
@MakerBot

Students will research their frog and its habitat, dissect the frog, and consider how its anatomy adapted to its environment. They will consider how observations made provide evidence for evolution.

Licensed Under: CC BY 4.0



SPINAL ANATOMY

Thing #: 1855444
@TeamEpidural

Present the components that make up spinal anatomy and compare these vertebrae using 3D-printable cervical, lumbar and thoracic models.

Licensed Under: CC BY 4.0

**WEATHER TOOLS**

Thing #: 1907023
@mfritz

Weather Tools for meteorology are at students' fingertips! Students can monitor and track wind speed by printing an anemometer and determine the direction of the wind using a wind vane.

Licensed Under: CC BY 4.0

**DNA TRANSCRIPTION**

Thing #: 1259352
@Eagleknot

DNA Transcription Students can build a model of DNA with a given sequence of chemical bases and demonstrate the process of DNA transcription.

Licensed Under: CC BY-NC 4.0

PLANT & ANIMAL CELLS

Take the diagrams out of the textbook. Students can assemble the components that make up a plant cell and animal cell and examine the differences in cell structures as well as the organelles that make up each cell.

**WHAT DOES IT LOOK LIKE?
WHERE DID IT LIVE?**

Students can experiment with different print infills to see if modifying density and internal support structure of the print will change the efficiency of the wedge. This design can also be used to discuss differences in inclined planes and wedges.

SKELETAL SYSTEM & ARTICULATION

Explain how different joints in the skeletal system make motion possible with 3D-printable joint structures.

BUILD A DNA DOUBLE HELIX MODEL

Discuss the structure of the DNA molecule and how specific features, such as the sequence of chemical bases and the rules of base pairing, allow the molecule to carry and pass on information related to the inheritance of traits.

SECTION 4.2

Engineering



The development of analytical and problem-solving skills are no longer confined only to the professional world. Students gain critical knowledge by experimenting with technologies that allow them to test their abilities, build their technical expertise, and develop their cognitive skills. Visual learning allows students to better understand the mechanics of their projects and, ultimately, improve their approach to real-world challenges.

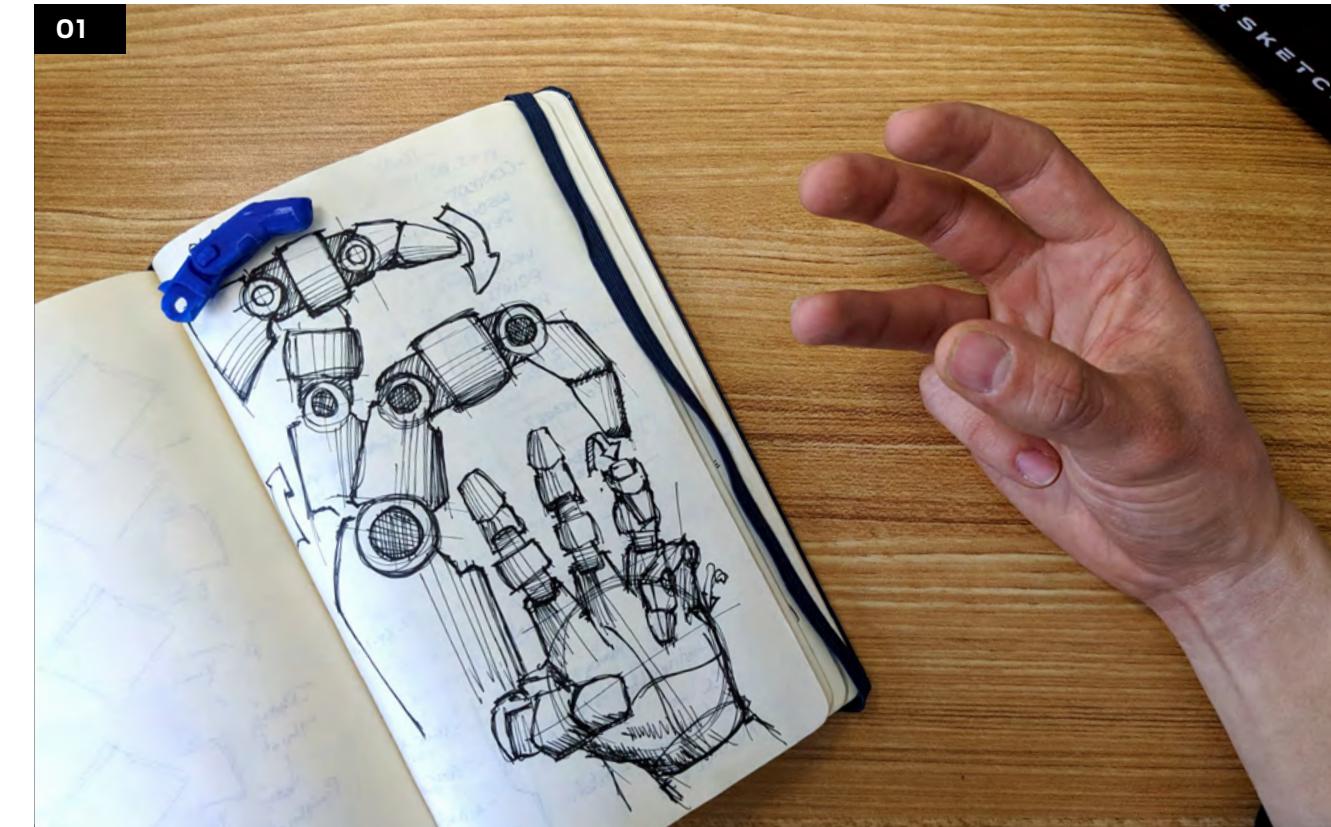
ENGINEERING PROJECTS TO GET STARTED ON →

Project: Mechanical Gripper



Project Category	LEARNING OBJECTIVES
Student-Led, Student-Created	<ul style="list-style-type: none"> Observe how the shape of the gripper determines the amount of force it can exert Understand how print orientation and print settings affect the strength of the printed parts Determine what design considerations are important when designing parts meant to fit together
Design Difficulty	★★★★★

Students will work in groups and study the elements needed to make a mechanical gripper. Each group will then design and create their own mechanical grippers using only 3D printing to make all the needed parts.



STUDYING HAND MOVEMENT

Working in groups, students will study the movement of their hand as it goes to pick up an object. Students should keep the following questions in mind:

- How do the fingers bend around an object?
- Is it possible to pick objects up without bending one's fingers?
- What is allowing the fingers to bend? How can that be replicated mechanically?
- What areas of one's arm are engaged when picking up items similar to a claw?
- How does a hand look when it's at rest as opposed to when it is picking something up?

02**List of items that need to be designed****Gripper Fingers**

Interact with objects and is capable of picking up and dropping objects.

Actuator

Element that moves in a fixed up and down direction, and drives movement to the phalanges.

Trident Housing

An element that acts both as housing for the gripper and works with the gripper fingers and secures the gripper fingers in place.

Phalanges

Responsible for expanding and retracting the gripper's fingers.

Core Connector

Center element that joins the phalanges to the actuator.

Nuts and Bolts

Used throughout the design to keep parts in place.

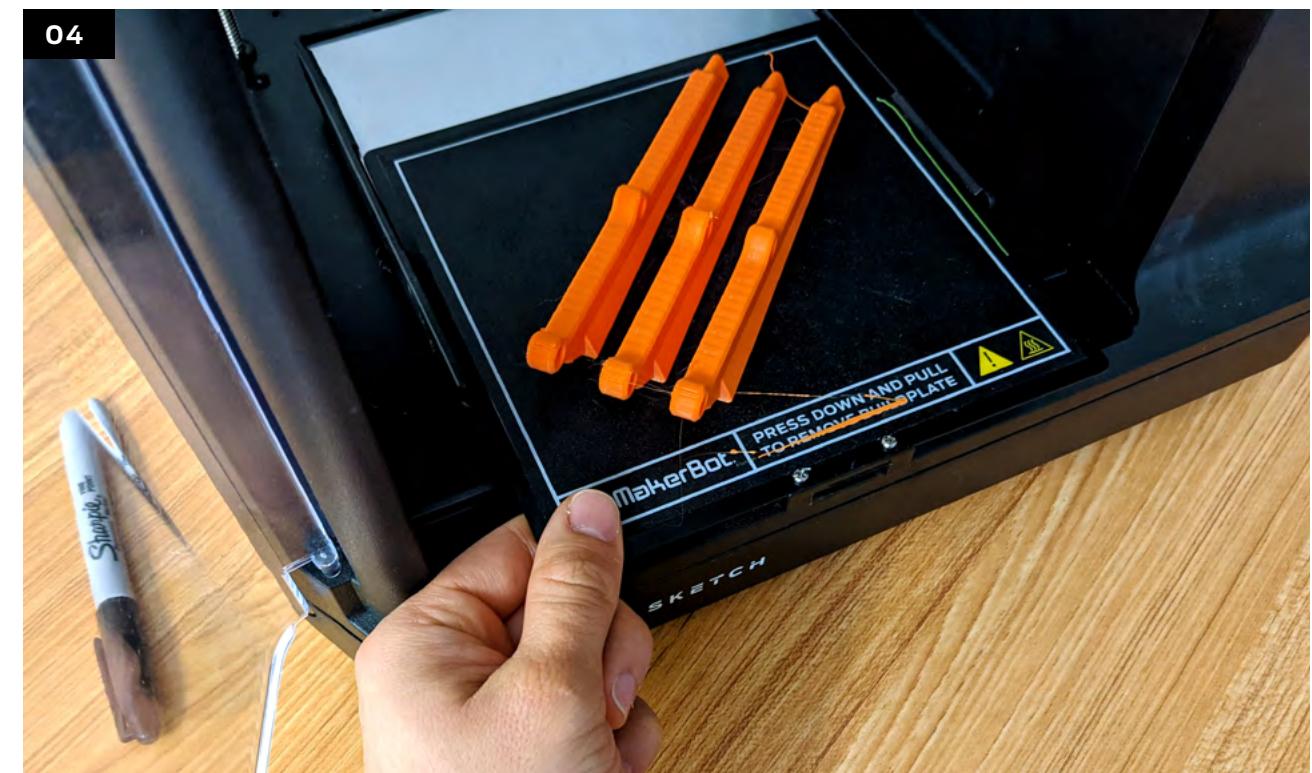
PLAN AND DESIGN

Using a preferred 3D modeling program (beginner-friendly modeling programs will work for this, too), begin thinking about how you will start designing the mechanical gripper. Will the actuator be designed first or the housing for the gripper? Is it best to start designing the biggest component first?

Keep in mind there is no linear path for designing a prototype. It's a cyclical process that develops over a period of time.

**TIP:**

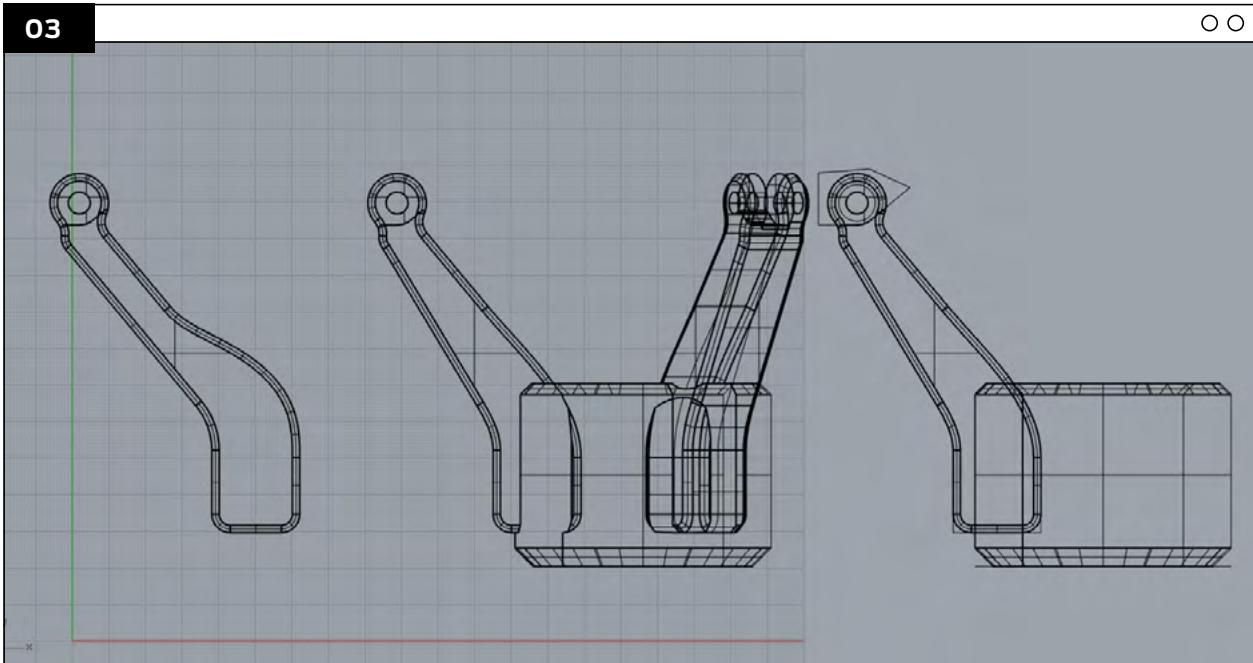
A good rule of thumb when designing something complex or with multiple parts is to break the designs down into simple shapes first, this will allow you to add design complexities later on.

04**PRINT, REDESIGN AND PRINT AGAIN**

A mechanical gripper will require multiple printed parts. When preparing files to print, be sure to keep in mind how you orient the different parts on the build plate and if the orientation of parts will lend to stronger or weaker parts. The printing part of the process is where you'll most likely find areas that need improvement - are the gripper fingers too long? Is there too much tolerance between the bolts and the parts? Keep these things in mind for the next iteration of this prototype.

BREAKING DOWN THE MECHANICS OF HAND MOVEMENT

Begin sketching out and breaking down parts of the human hand and arm that are in play to better define what elements are essential to replicating hand movement when picking up an object. Then create a list of what elements need to be designed to make a mechanical gripper possible.

03



REFLECTING

It's important we reflect on the wins and losses we encountered in this activity: What worked well? What did not go well? What is an area we want to dive deeper into? What new methods and techniques did we learn from modeling this gripper? Can we use that knowledge in future projects?

Project: Fidget Spinner Science

Design by: Ken Hackbart

Thing: 2341019



Project Category

Part of the Lesson

Design Difficulty



LEARNING OBJECTIVES

- Determine whether or not angular momentum is conserved or lost
- Learn if adding new forms of angular momentum reduces the original amount of angular momentum
- Discuss how the results of the experiment validate the Law of Conservation of Angular Momentum

Through this Fidget Spinner Science activity, students learn about the Conservation of Angular Momentum and use a practical method for validating the concept using a modified fidget spinner and an angular momentum isolation rig. These files can be found by typing **2341019** on thingiverse.com.

MATERIALS NEEDED:	3D PRINTED COMPONENTS NEEDED:	SUPPORT POSTS:
<ul style="list-style-type: none"> • 6 x 8mm Chrome Ball Bearings • 2 x 608ZZ 8x22x7 Skate Bearings • 1x Stopwatch • 1x Superglue 	<ul style="list-style-type: none"> • 1x Rotor Base • 1x Rotor • 1x Fidget Spinner Print • 2x Support Caps 	<ul style="list-style-type: none"> • 1x 35mm • 2 x 40mm • 1x 55mm • 1x 60mm

**01**

Working in partners, assemble the fidget spinner by first pressing in the skate bearing using a mallet or blunt object to help insert the bearing into place. Then, insert the six ball bearings into each cavity on the fidget spinner.

**02**

Insert the support caps into the fidget spinner and glue the support arms onto the support caps. Then Insert the second skate bearing into the rotor's base, lastly insert the rotor on top of the skate bearing.

03
Set up the rotor and fidget spinner so that the fidget spinner is being supported by the two 40mm support posts. When inserting the post, place your finger behind the rotor to counter the pressure of inserting each post.

For easier assembly, always insert the longest support arm first and into the tallest point

**04**

One partner will hold the rotor in place with one hand and apply a consistent rotational force on the fidget spinner each time. Immediately after spinning the fidget spinner in place, release the rotor being careful to avoid applying a sideways force.

The other partner will record how long the spinner spins before stopping completely. Observe whether the rotor spun at all.

**05**

Change the post heights by removing the spinner in the opposite order it was assembled in and increase the difference in height with the following measurements:

- Increase the difference in height by 15mm using the 40mm and 55mm posts
- Increase the difference in height by 25mm using the 35mm and 60mm posts



Record how long the spinner spins before stopping completely for each change in height, be sure to observe the movement of the spinner as well as that of the rotor.

Explore More



WHEEL & AXLE

Thing #: 258112
@Rosynthal

Put students' engineering design skills to the test, as you guide students in exploring the concept of a wheel and axle. Challenge students to design and print their own axles, as well as different size wheels to determine how it affects their cars' performances. Push this project further by having students create different front and back wheel axles to design their own RC cars for different terrains.

Licensed Under: CC BY 4.0



BALANCING BIRDS

Thing #: 1179531
@mled90

Demonstrate how balancing an oddly shaped object on its center of mass can show how the center of mass allows the object to be balanced on a point. Open a conversation to the classroom to bring up how center of mass is used in a variety of fields such as automotive, ship building, space travel and more.

Licensed Under: CC BY 4.0

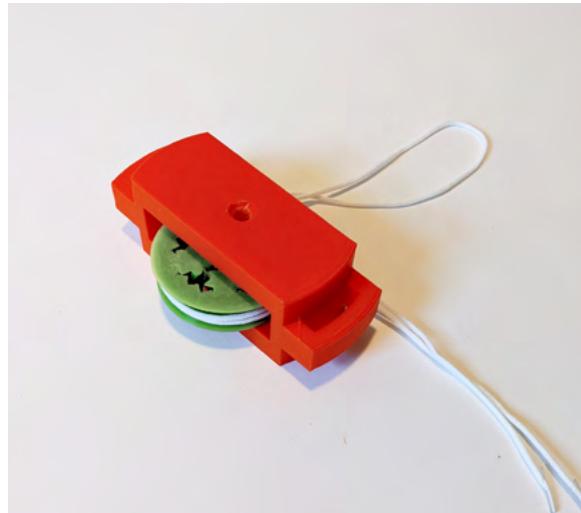


CATAPULTS - POTENTIAL ENERGY

Thing #: 1524194
@TRAPPKING

Students can design and print their own catapults and test how the potential energy changes with different tension sources.

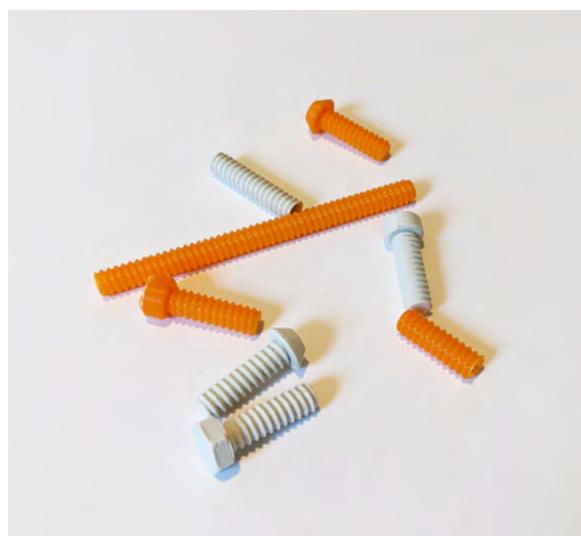
Licensed Under: CC BY 4.0

**PULLEY**

Thing #: 1713315
@xfanta

Demonstrate the components that make up a pulley and have students create their own pulley system to show how pulleys can be used together.

Licensed Under: CC BY 4.0

**SCREW**

Thing #: 193647
@mike_mattala

Students can investigate a variety of screws and determine how a screw's lead and pitch allow it to convert a low rotational force into a greater linear force.

Licensed Under: CC BY-SA 3.0

CENTRIFUGAL AND CENTRIPETAL FORCES

Can you turn a drink upside down without spilling it? Try using the Spill-proof Drink Holder to illustrate differences between centrifugal force and centripetal force.

GRAVITY AND AIR RESISTANCE

Explore how gravity acts on objects with different masses. Challenge students to use Tinkercad to design an object to print with varying amounts of infill, such as 10% vs. 50%. After printing, drop the objects from the same height, at the same time, and make observations regarding the result. Next, have students create a "featherweight" object - one that will fall at a different rate due to air resistance, similar to how a feather floats down when dropped.

TENSEGRITY TABLE

Test different variables as you explore tensegrity and floating compression by creating a tensegrity table with some string and 3D printing.

WEDGE

Students can experiment with different print infills to see if modifying density and internal support structure of the print will change the efficiency of the wedge. This design can also be used to discuss differences in inclined planes and wedges.

SECTION 4.3

Mathematics



Understanding abstract concepts within mathematics can be challenging to students. Creating manipulatives and teaching aids helps students develop a better understanding of mathematical theorems with tangible examples. From 3D visualizations of Sine and Cosine waves, to showing how Volumes of a Solid Revolution are calculated, to exploring geometric shapes through physical models, 3D printing opens new learning possibilities and turns ideas into reality.

MATHEMATICS PROJECTS TO GET STARTED ON →

Project: Fractionate Your Creation



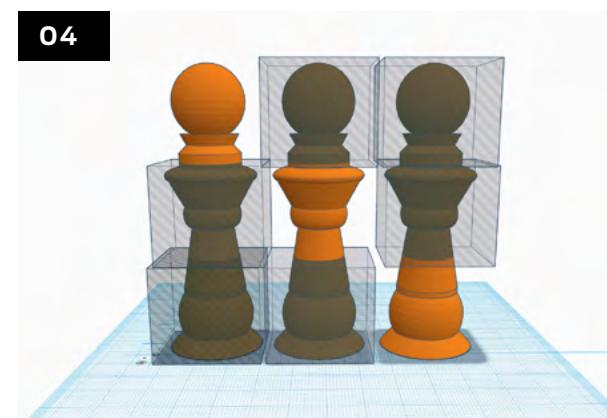
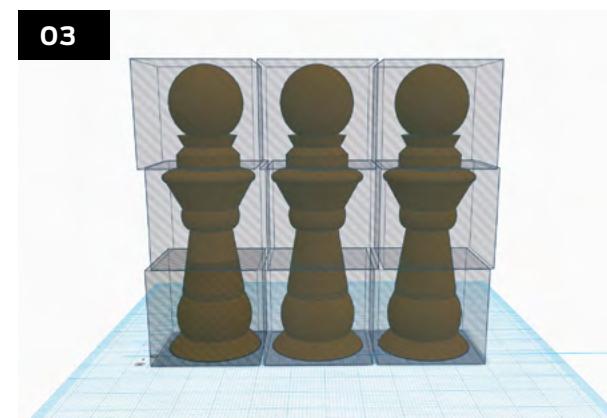
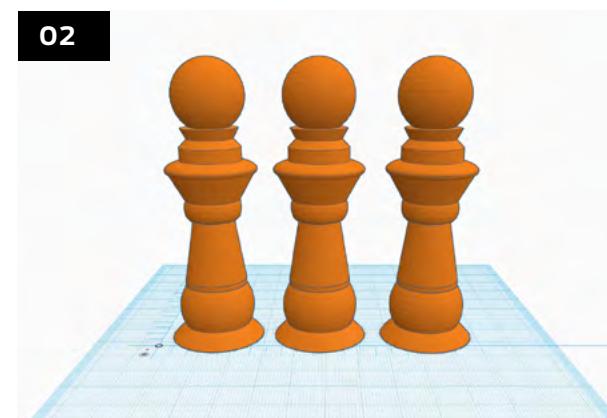
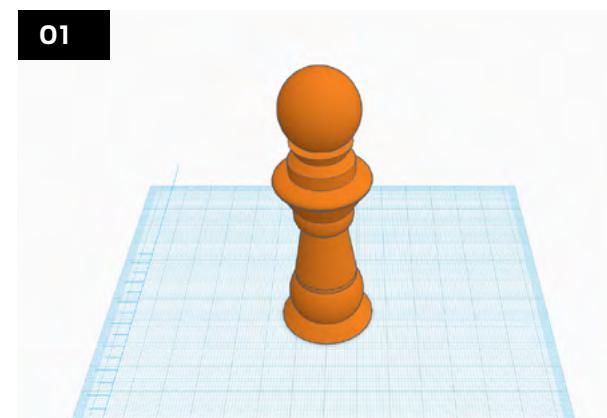
Project Category
Part of the Lesson

Design Difficulty
★★★☆☆

LEARNING OBJECTIVES

- Understand how a number or object can be split up into a number of equal parts
- Design an object and divide it into equal halves, thirds, quarters
- Understand how expanding and simplifying fractions can be used to better solve math problems

How many parts can students cut their design into? Have students design or download a model to bring into Tinkercad to “fractionate” and break into an equal number of parts.



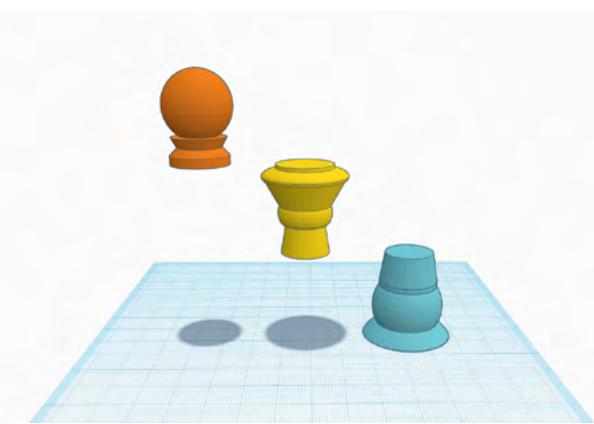
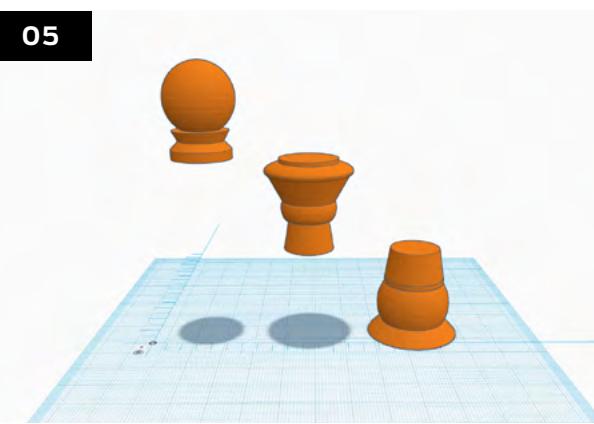
Import the STL into a workplane in Tinkercad, and lay the object flat. For this example we use a pawn that was previously designed in Tinkercad.

Determine the amount of parts the model will be split into and duplicate the model the same amount of times. In this example we want to divide our model into 3 equal parts therefore we will duplicate (or copy and paste) the model 3 times.

Think about how the object can be split into equal parts. This pawn is designed at a height of 90mm, that means we can divide this model into 3 equal parts vertically. To do this we will need to drag 3 empty boxes that are each exactly 30mm in height for each pawn model, like so.

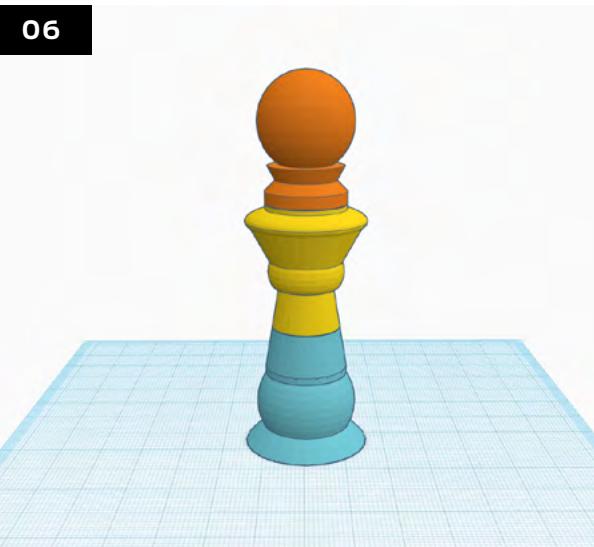
To successfully create three equal halves, we'll need to remove one empty box from each column such that each pawn has a unique section exposed.

To remove a box, click on the box and press the ‘Delete’ key.



Next, we'll group each pawn and their respective empty boxes one at a time. We'll then be left with only the exposed sections of the models.

*You can then change the colors of each part to highlight that they are individual pieces that can now fit together.



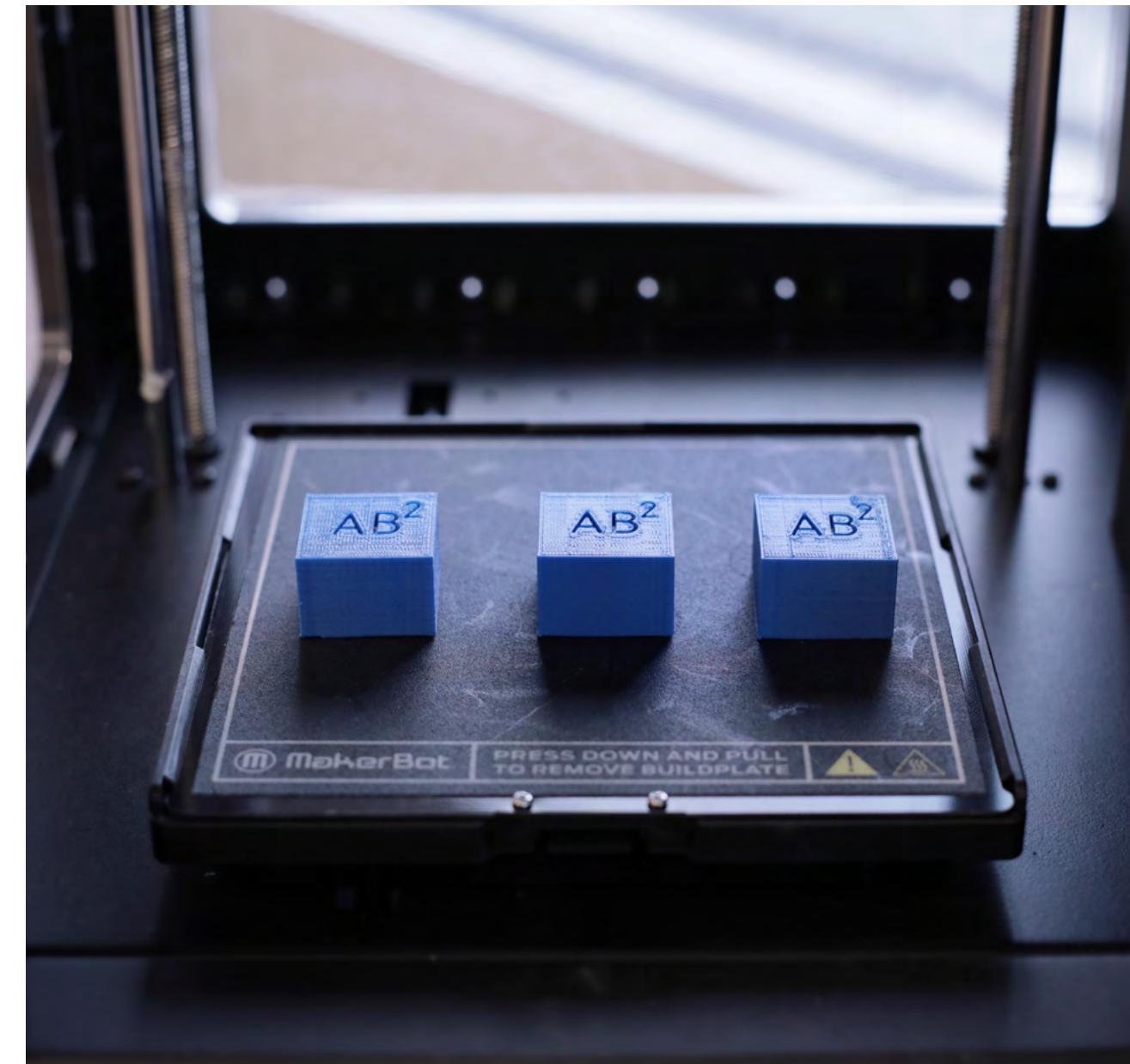
Align the separate pieces back together using the Align (L) key, press the L key and select the center dots on the X and Y axis.

Before exporting the fractionated pieces, be sure to Drop (D) each part so that it sits on the workplane, this will allow for easier printing later on.

08 **Take it further:** Students can further divide their STL model into a higher quantity of equal parts to work with more advanced fractions.

Project: Math Expression ($A+B$)³

Design by: Venkateswaran
Thing: 2517916



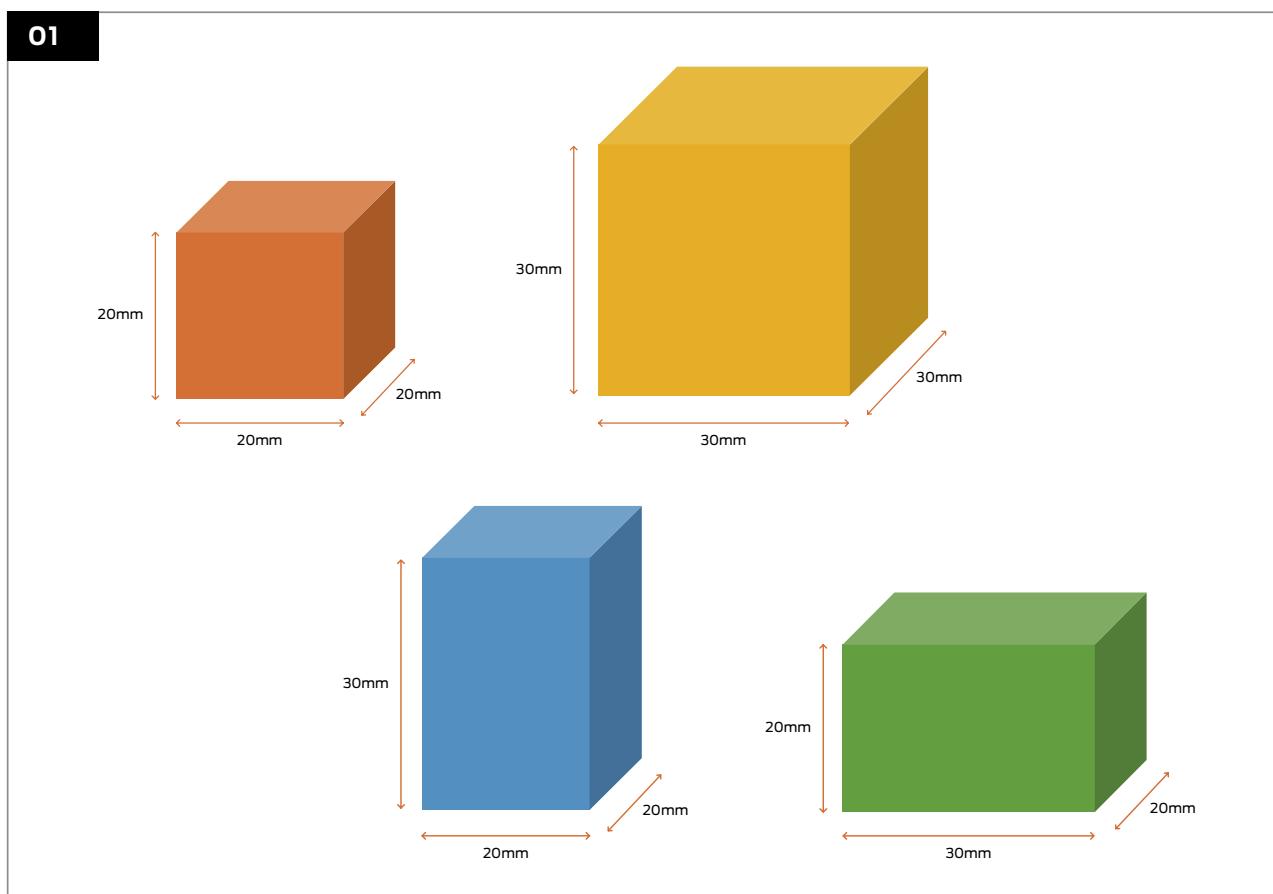
Project Category
Part of the Lesson

Design Difficulty

LEARNING OBJECTIVES

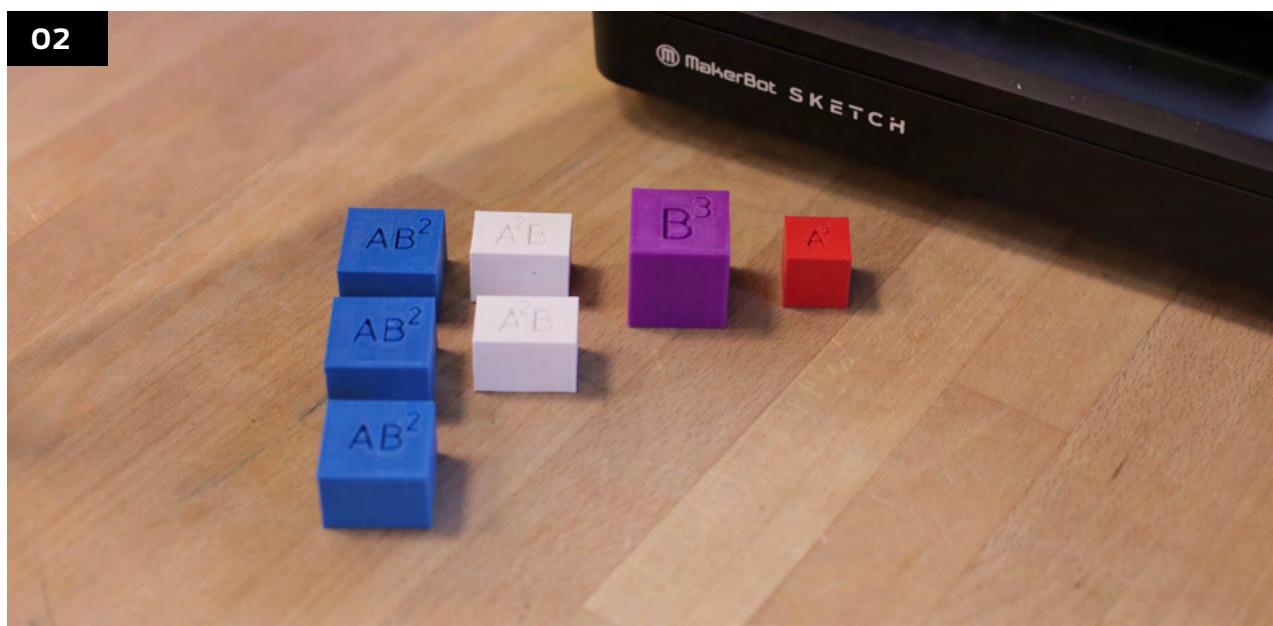
- Apply the knowledge of modeling primitive shapes using Tinkercad
- Utilize physical measurement and modeling technique to other complex mathematical expressions and formulae
- Understand the concept of Pascal's Triangle in an intuitive and novel approach

Verify $(A+B)^3$ as a mathematical expression based on physical measurement by modeling and 3D printing.



Use Tinkercad to design the cubes that make up the math expression. For this example, Side A was designed with 2cm and Side B was designed with 3cm. The rest of the calculations follow as per the equation:

$$(A+B)^3 = A^3 + 3A^2B + 3AB^2 + B^3$$



The A^2B and B^2A models need to be printed in quantities of 3 each. The A^3 and B^3 models need one quantity each.

03

$$(a+b)^1 = a + b$$

$$(a+b)^2 = a^2 + 2ab + b^2$$

$$(a+b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$$

Once everything is printed, students can then use the manipulatives to see a visual representation of how $(A+B)^3$ expands.

EXPLORING MORE**TOWER OF HANOI**

Thing #: 1620966

@NOP21

Students can design their own version of the famous mathematical game 'Towers of Hanoi' and write their own logic to solve the puzzle and move the tower from one side to the other. Take it further and have students write a proof for the logic they used to solve the puzzle.

Licensed Under: CC BY-NC-ND 4.0

**BINARY COINS**

Thing #: 957569

@falconphysics

Intended to help introduce the idea of binary numbers. Most students are only familiar with our normal base 10 numbering system and it is often helpful to have physical objects on hand to help students build the idea of other numbering systems.

Licensed Under: CC BY-SA 3.0

**VOLUMES OF REVOLUTION**

Thing #: 2604524

@ConnorMPrints

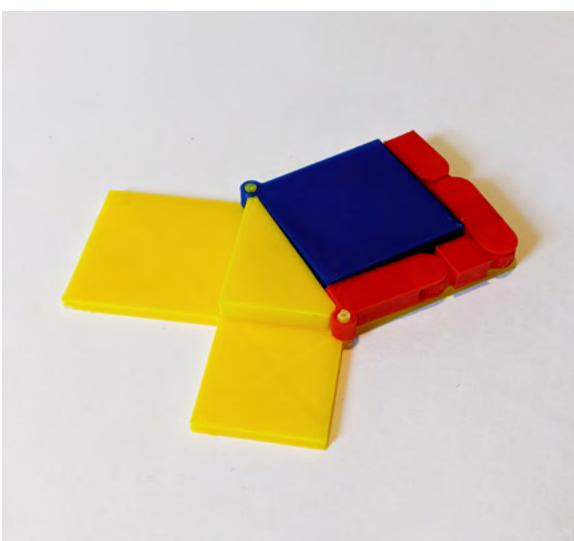
Students can visualize and interact with the volumes of different shapes in different dimensions using the Washer and Disc Methods.

Licensed Under: CC BY 4.0

**POLYHEDRONS**

@MakerBot

3D-printed polyhedrons that students can interact with. Students can also use these models to count the number of edges, planes and vertices.

**PYTHAGOREAN THEOREM**

Thing #: 245202

@mshscott

Help provide a visual example of the Pythagorean Theorem in motion. Students can use a 3D-printed model of theorem to actively manipulate the design to represent $a^2 + b^2 = c^2$.

Licensed Under: CC BY-SA 3.0

PART TO WHOLE

Fraction blocks can be used to not only show students a comparison between part to whole, but also as manipulatives to add and subtract fractions.

XYZ CARTESIAN PLANE

Allow students to better visualize coordinates in 3D space with an XYZ Cartesian Plane.

DEFINE THE ALGORITHM

Students can design their own version of the famous mathematical game ‘Towers of Hanoi’ and write their own logic to solve the puzzle and move the tower from one side to the other. Take it further and have students write a proof for the logic they used to solve the puzzle.

SINE AND COSINE

Help students develop a better understanding of trigonometric functions with 3D-printed stencils and manipulatives.

BRAILLE MULTIPLICATION TABLE

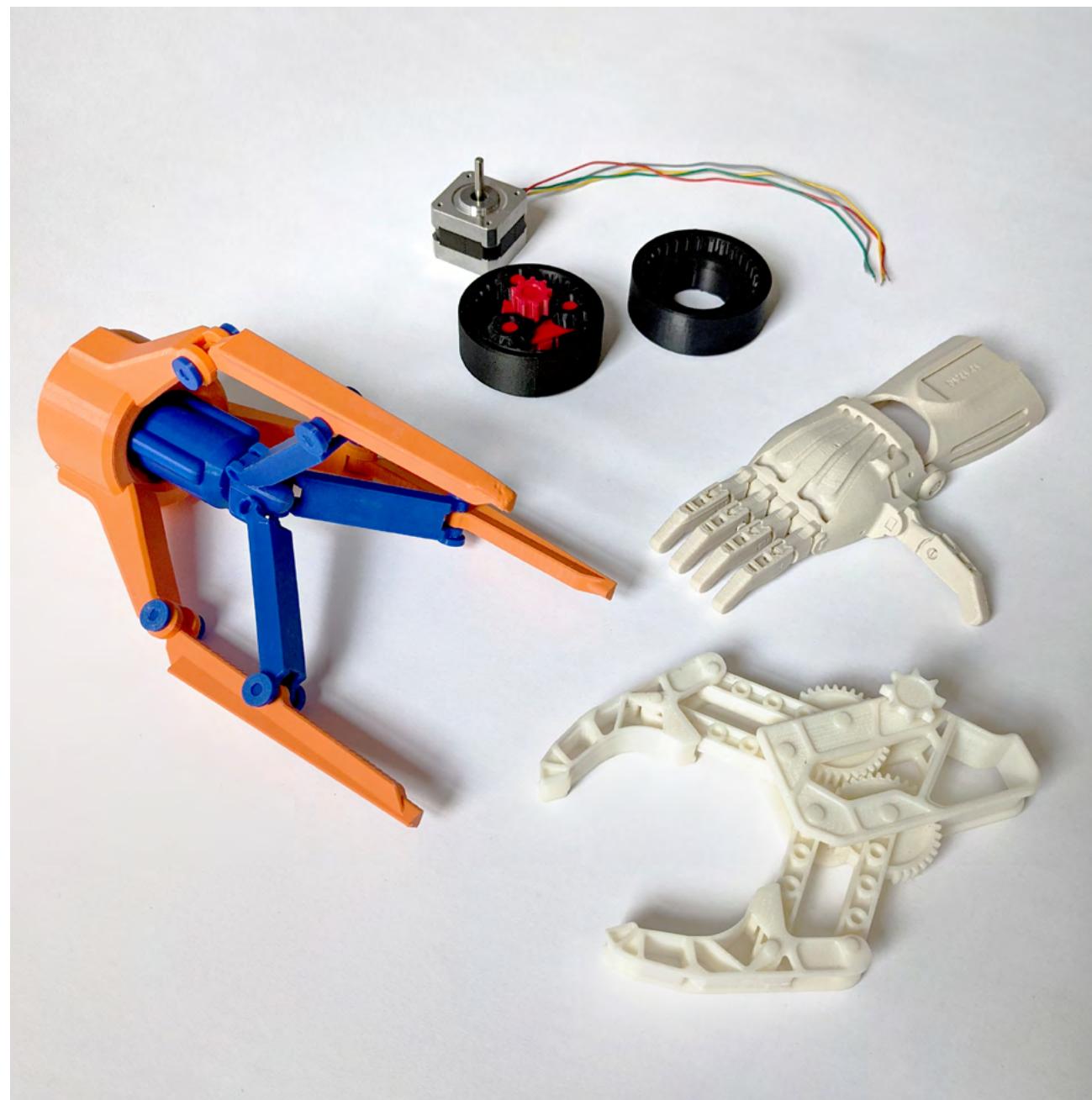
Assist visually-impaired students to review their times table with tactile multiplications table.

TANGENTS AND MATH THEOREMS

Explore the physical representations of tangents, Mean Value Theorem and Rolle's Theorem using 3D-printed manipulatives.

SPIROGRAPH

With colorful pens, a sheet of paper and 3D printed spirographs, students can start creating colorful geometric designs. Students can go further and explore how the geometries that the spirographs produce are mathematically significant and discern the differences between epitrochoids and hypotrochoid curves.

SECTION 4.4**Robotics**

The marriage of 3D printing and robotics is pushing the boundaries of STEM education. Learning how to build and maintain machines from the ground up offers students an incomparable experience that can be applied outside of the classroom. Through hands-on experience, students learn the basics of mechanical engineering and design thinking and further their understanding of the inner workings of different components and how they work together to function as a whole.

ROBOTICS PROJECTS TO GET STARTED ON →

Project: Planetary Gear System



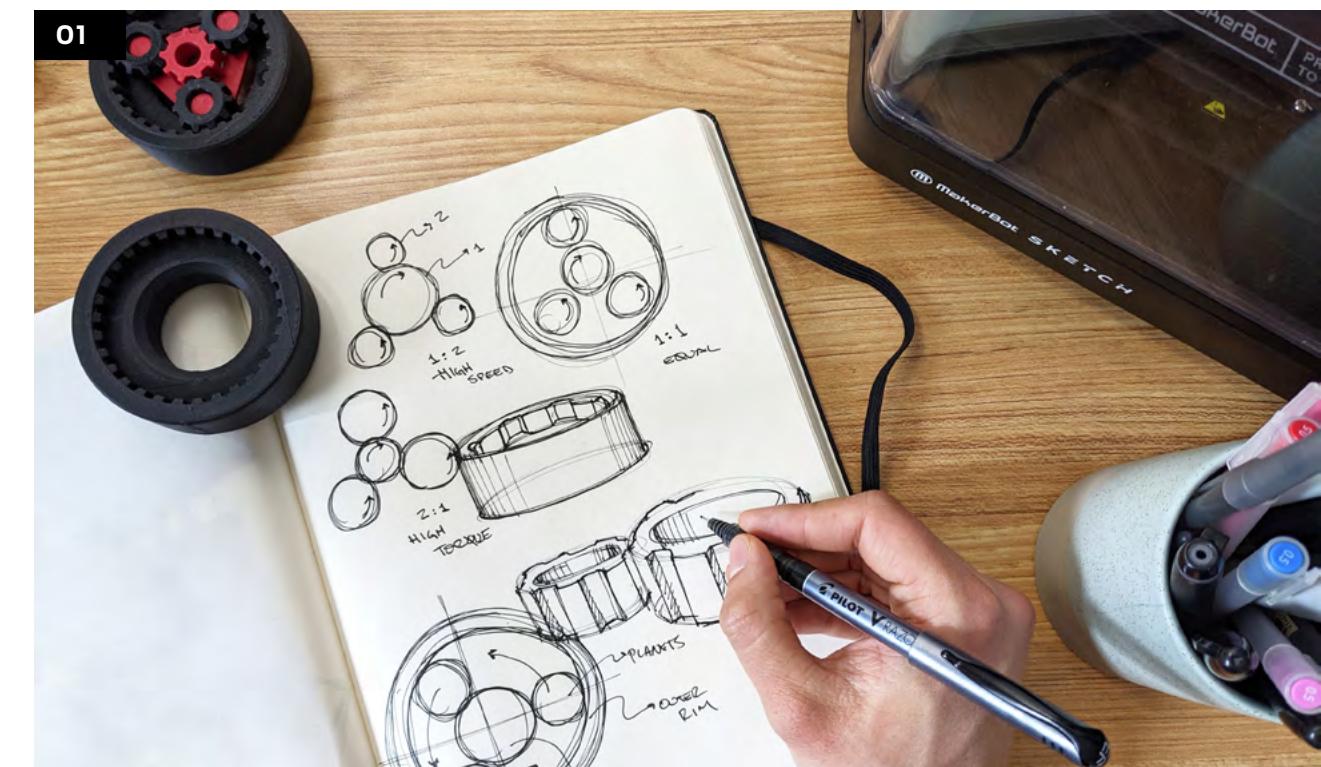
Project Category
Student-Led, Student-Created

Design Difficulty
★★★★★

LEARNING OBJECTIVES

- Identify the components that make up a planetary gear system
- Understand how changing the size of gears in a train affects the gear ratio
- Design a planetary gear system using 3D-printed parts

After completing a unit on how different combinations of gears work together to increase torque, students are tasked with identifying the necessary parts for a planetary gear system and designing their version of this type of gear train using 3D-printed parts.

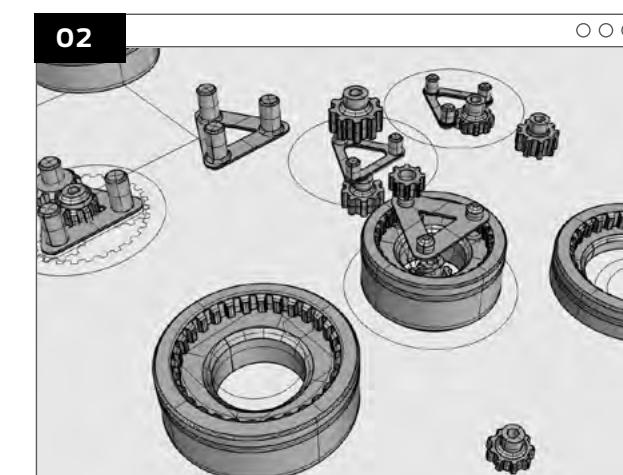


DESIGN CONSIDERATIONS

Sketch out the form that the planetary gear system may take. Are there any other design considerations that students should account for?

Possible Considerations:

- What gear ratio will the gear system be designed around?
- How many teeth should each gear have?
- How many planetary gears will be used? Will it affect the amount of friction produced?
- What size should the gears be? Should the sun gear be larger or smaller than the planetary gears?



3D MODELING THE DESIGN

Using a preferred 3D modeling program (Tinkercad can also be used for this), start building out the gears that are necessary for this planetary gear system. This system will require one sun gear, one outer gear, and at least two planetary gears.



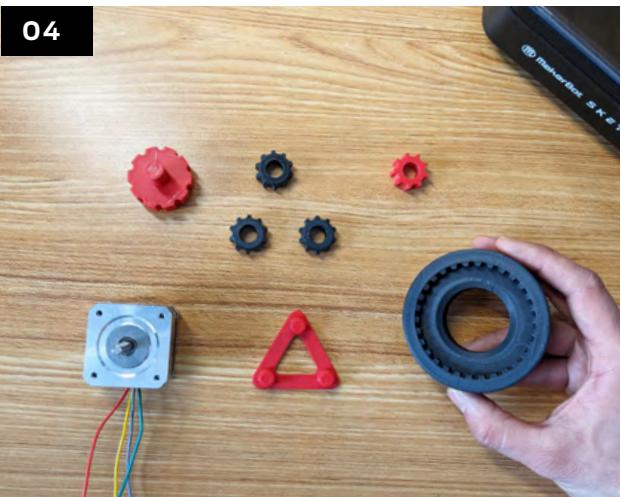
03

PRINTING AND TESTING OUT

Before sending the gear models to be printed, consider how the gears will be printed. Sometimes what looks to fit together well within a modeling program does not translate as well in the physical world. Is there enough tolerance between all the gears? Is there a possibility that the gears will fuse together when printed?

**TIP:**

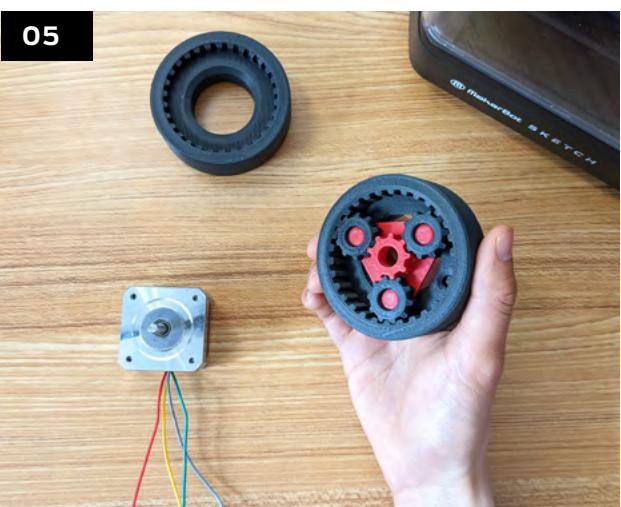
Before printing, identify areas in the design that might benefit from chamfered edges. Chamfered edges are edges that are beveled, usually at a 45 degree angle, and are at lower risk of warping.



04

ASSEMBLING

When putting together the 3D-printed gears be sure that the planetary gears are able to move around the sun gear without too much friction and that the fit of the gears aren't too loose.

**TAKE IT FURTHER**

Test how well the planetary gear system works when outfitted with a motor and determine if further changes need to be made to the design.

Project: Snap-Together Robohand

Project Category
Part of the Lesson

Design Difficulty

**LEARNING OBJECTIVES**

- Understand the mechanisms behind a robohand
- Recognize the role 3D printing is playing in bringing down the costs of 3D prosthetics
- Discuss how the existing design could be improved and what changes would be needed

See how 3D printing can help people all around the world by printing and building a snap-together version of the Robohand and develop a better understanding of the mechanics behind the robohand and how the robohand itself can expand and contract using one's wrist.

MATERIALS NEEDED:

- Elastic String (approx. 1mm in diameter)
- Nylon String (approx. 1mm or more in diameter)
- 5 x Short Screws

3D PRINTED COMPONENTS NEEDED:

- 1x RightKnuckleBlock.stl or 1x LeftKnuckleBlock.stl
- 1x Set of WristStructure.stl (*Made up of four 8-holebeams and 2 6-hole beams*)
- 1x Set of Fingers.stl (*Made up of 5 finger tips, 5 finger segments and 5 finger snap pins*)
- 1x Set of *SnapPins.stl

*There are four types of pins that print in the 'Snap Pins.stl' file. Two types of pins (long and short) are used to assemble the Knuckle Block. The remaining pins are divided into #2 and #3 pins. Generally, #2 pins are used when attaching two components and #3 pins are used when attaching three components.



TIP:

Parts in these plans are represented in two colors, blue and black. These colors correspond to the colors used in printed examples. In general, blue parts are movable or attachable parts, whereas black parts are static or structural.



ASSEMBLING THE FINGERS

Place one of the Fingertip prints on a table with the keyed side of the hole facing up and slide the Finger segment into the Fingertip. Make sure the segment is oriented with the cable slot on the bottom and the endstop at the back of the assembled finger. Use one of the small snap pins to pin the joint, you may have to use a mallet or heavy object to lock the pin into place.

A. Check Movement

The assembled finger should move freely around its joint and the back of the snap pin should be flush with the side of the finger. Repeat these steps to complete the other 4 fingers.

02

BUILDING THE HAND

Lay out the three printed parts of either the RightKnuckleBlock.stl or 1x LeftKnuckleBlock.stl on the table and attach the sides to the selected knuckle block using the two shorter pins (do not use the #2 or #3 snap pins) from the SnapPins.stl.

A. Install the First Two Fingers

Install the first two fingers into their slots (such that you're installing the fingers that would be the furthest away from the thumb). Use a mallet or heavy object to tap one of the longer snap pins into the hole, securing the fingers to the knuckle block.



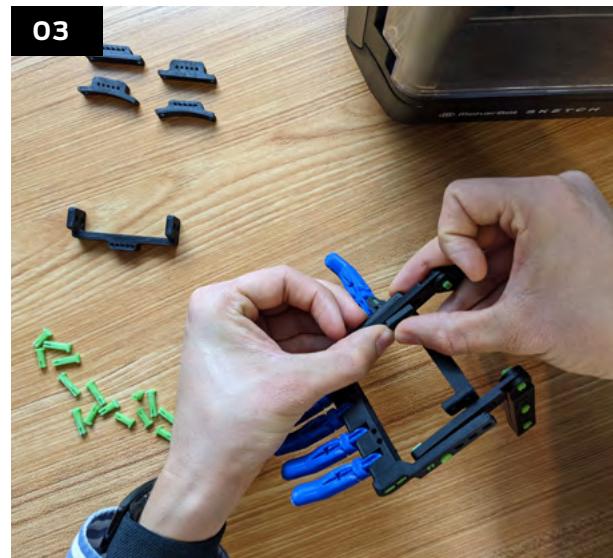
B. Repeat on The Other Side

Flipping the knuckle block over, install the other two fingers into the other two slots and secure with the second longer pin. Check the movement again and if there is a lot of resistance, move the fingers up and down again to loosen them up.



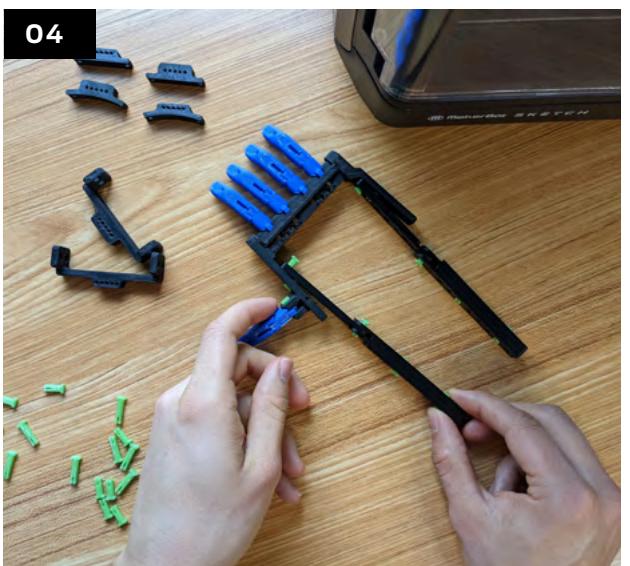
C. Installing the Thumb

Slide the thumb into place and use the last finger snap pins to secure the thumb to the hand. Move the thumb back and forth a few times until it loosens up if it does not move freely.



BUILDING THE WRIST

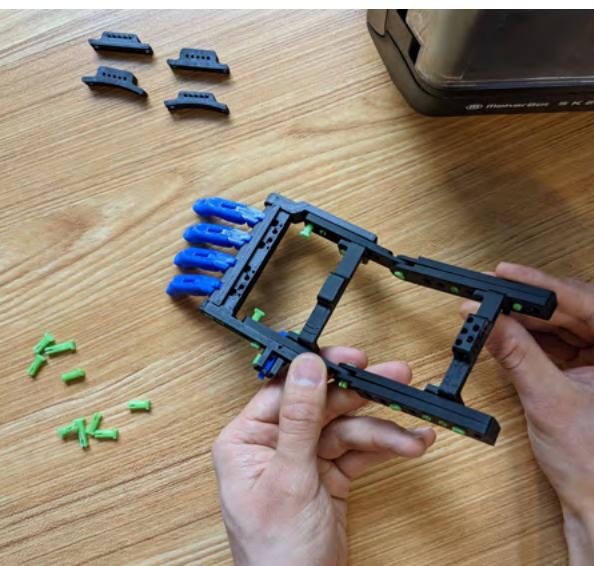
Place a wrist beam (one of the 6-hole beams) on the inside of the hand assembly and line the holes on the beam print to the knuckle block. Then insert two #2 snap pins into the front two holes (closest to the fingers) on opposing sides to attach the wrist beam to the hand. Next, line up the other wrist beam to the other side of the hand and secure them in place two more #2 snap pins.

**04****THE FIRST HINGE**

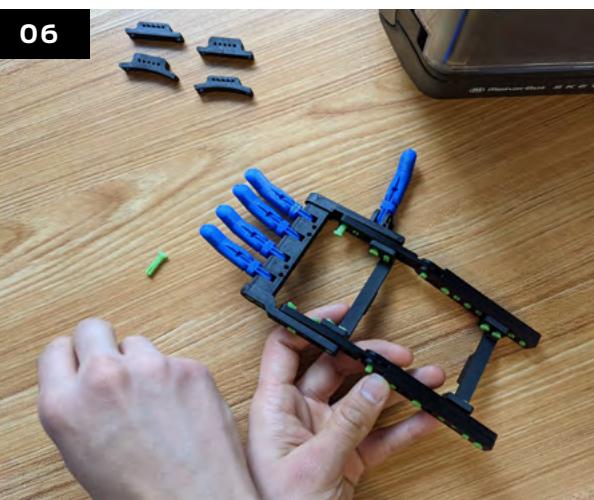
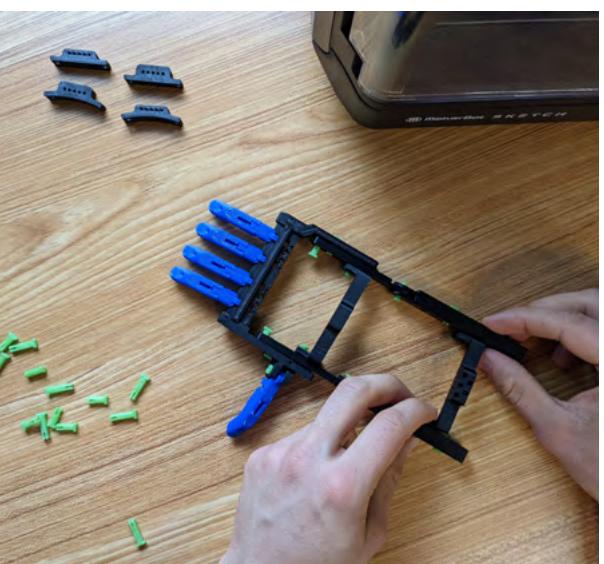
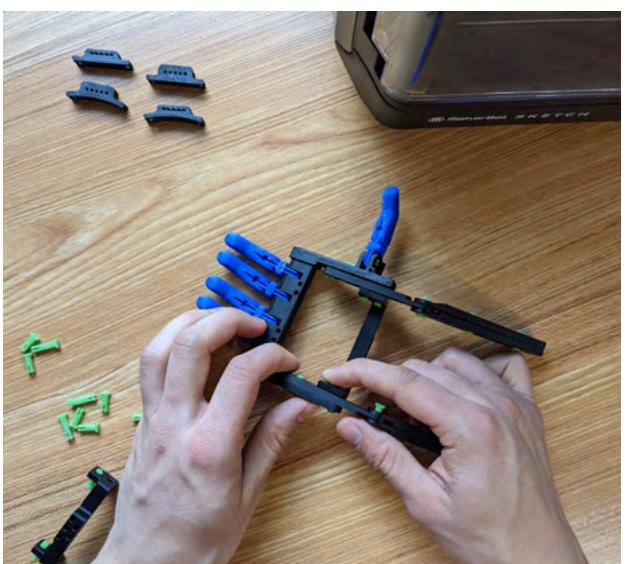
Using #2 snap pins, attach 2 wrist beams (two of the 8-hole beams) together. Once the two wrist beams are pinned together, take the curved end of these combined beams and slot them over the end of one of the wrist beams and secure in place and repeat on the other side like so:

Test the Hinges

Move both of the hinges back and forth. They should move freely with gravity. If they don't, force them back and forth several times until they loosen up.

**05****ATTACHING THE BRIDGES**

Using the wider of the two bridges, slide that bridge in between the wrist beams, being sure to line up the holes. Flip the robohand over onto its back and use a #3 snap pin in the hole that reaches through the outside of the hand and a #2 snap pin in the hole behind the thumb. Then secure the other side of the front bridge using two #3 snap pins.

**06****The Rear Bridge**

Flip the robohand right side up again and position the last bridge between the wrist beams and secure them in place with two #3 snaps on each side of the bridge.

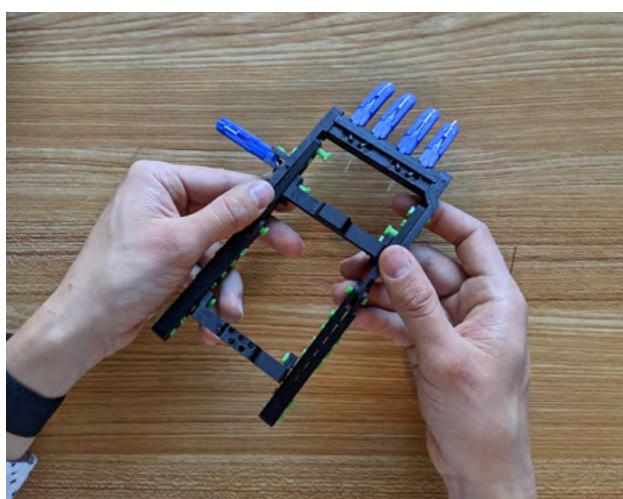
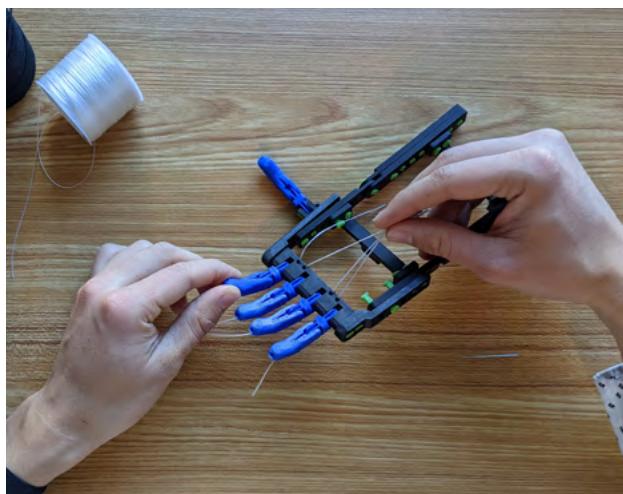
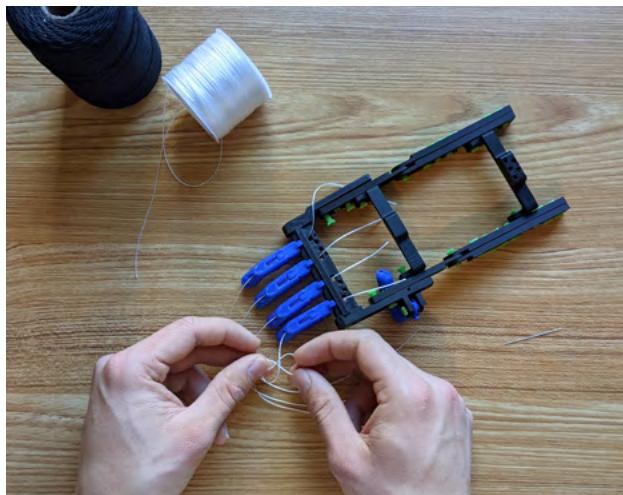
FILL IN REMAINING HOLES

Use any remaining #2 snap pins to fill in the open holes in the beams. Alternate the placement of the pins so that the top and bottom of the pins are staggered on the opposite sides of the beams. This will increase the robohand's strength and give it a more finished look.

07

INSTALLING THE ELASTIC

Thread the elastic string through the holes on the upper side of the index and middle fingers and out the top of the knuckle block. Then tie a figure 8 knot with the elastic string at the fingertip and pull back on the knuckle block end of the elastic. The knot should slide completely onto the finger.

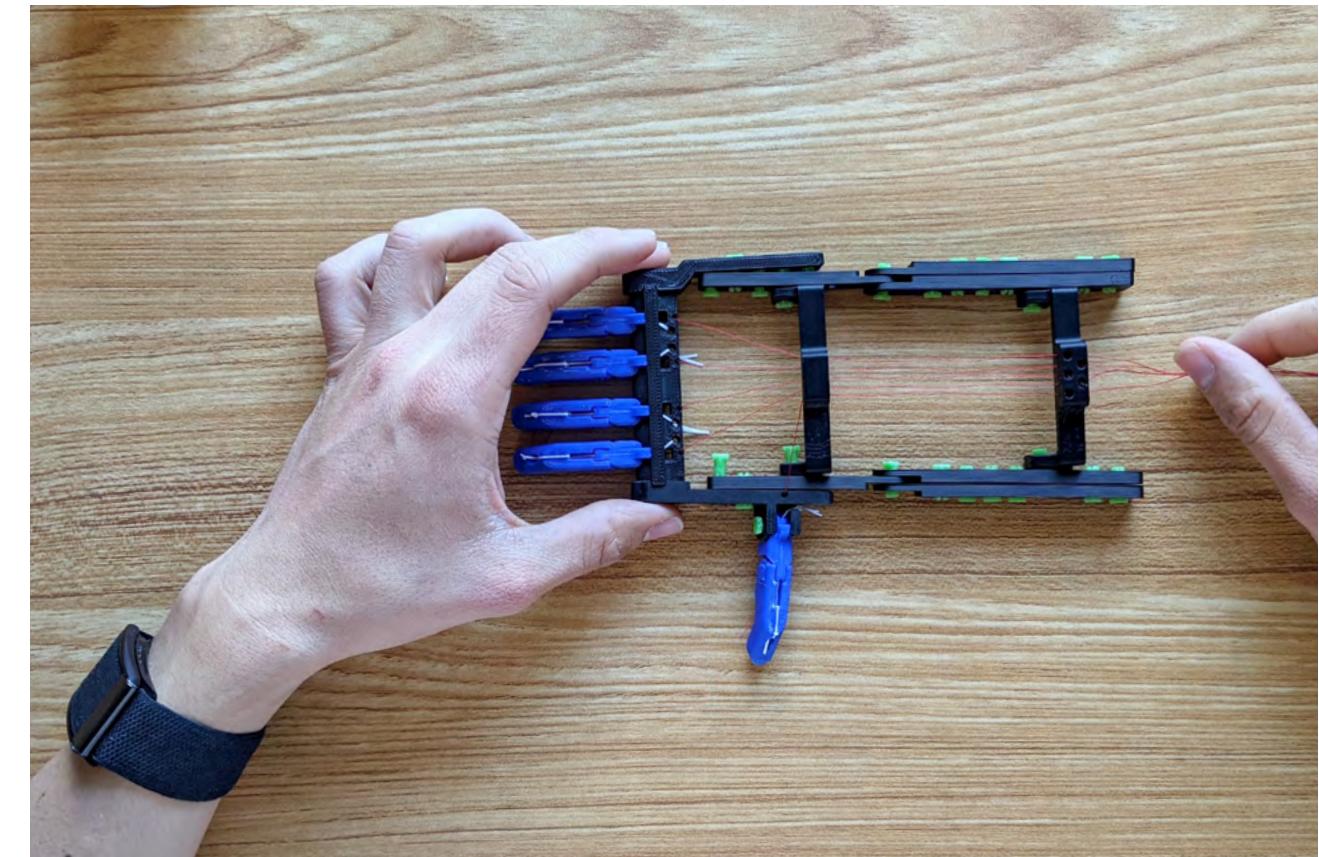
**Thread the Elastic Through the Knuckle Block**

Run the elastic down through the hole in the knuckle block and repeat this step for the second finger. Then, with the first two fingers threaded, flip the robohand over and tie the loose ends of the elastic together.

08

INSTALLING THE STRING

Pull a long piece of string through the hole and slot in the bottom of the finger. Tie a knot on the end of the string at the fingertip, pull on the loose end of the string until the knot slides inside the finger tip. Find the angled hole in the knuckle block behind the finger, run the thread through the hole and pull it through to the other side and flip the robohand over to run the string through holes in both the first and second bridge.

**A. Repeat**

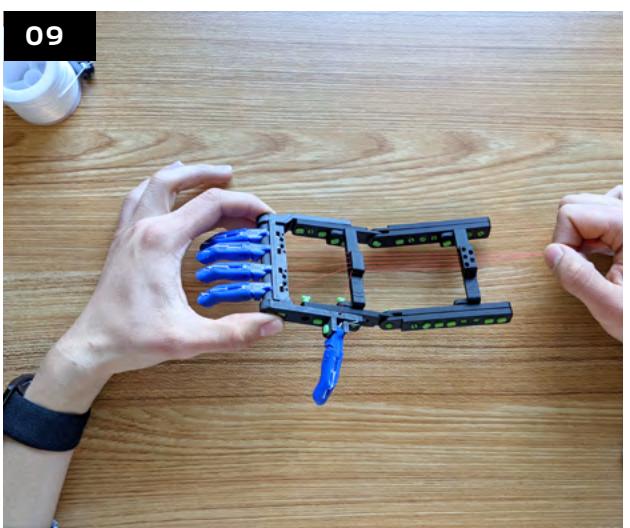
Follow the same steps to install the other four fingers.

B. Secure the Strings

Bend the wrist hinge to a 30 degree angle and install a short screw to clamp down on the first string. The screw will allow you to adjust the tension in each finger so that they all move in unison. Repeat for the other 5 strings.

**TIP:**

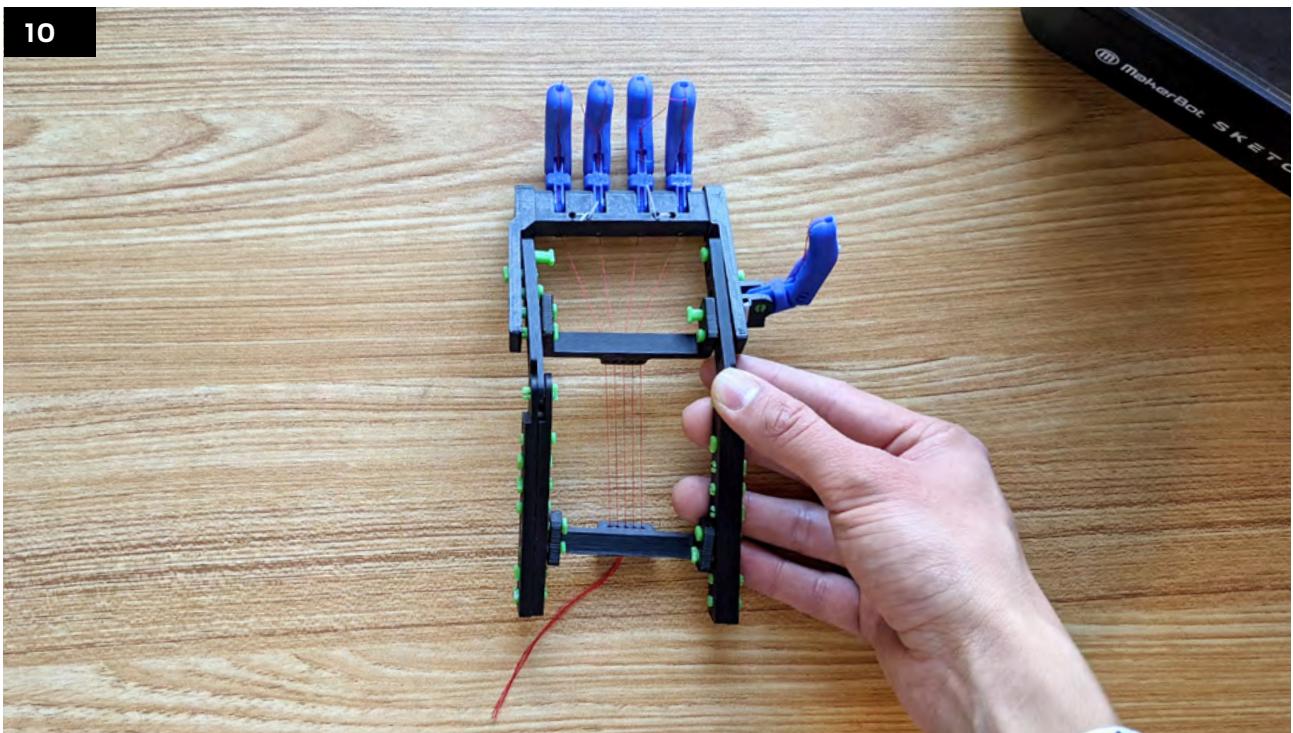
These screws are optional and can be omitted by tying the string to the rear bridge.

**TESTING**

Pushing down on the wrist will cause the fingers to grasp. Remember to adjust the screw tension so that the fingers close in unison.

Keep in mind

Most of the parts for the Robohand have been designed to attach to one another with snap-pins and that mechanical hands are a highly individualized piece of equipment that needs to be custom fitted to its user.

**IMPROVE THE DESIGN**

Discuss in groups how the robohand could be improved upon and changes that can be made if another robohand were to be printed.

EXPLORING MORE PROJECTS**PUMPKIN SPIDER TRANSFORMER**

Thing #: 3149456
@Sebastian_v650

Print the components of an articulated pumpkin spider and show students how 3D-printed ball-and-socket joints make it possible for the spider to turn itself into a pumpkin.

Licensed Under: CC BY-NC 4.0

**R. MAKER - MARK I**

Thing #: 11654
@Mr_MegaTronic

Design and develop a classroom robot that is representative of your classroom and is equipped with articulated features. Students will design their robot to have movement for the robot's head and limbs.

Licensed Under: CC BY-SA 3.0

**PRINT-IN-PLACE CLAW**

@MakerBot

Put students' experience with 3D printing together and test their ability to create complex and movable geometries all within one print. Use the METHOD series printers to allow students to print with geometric freedom.

**E-NABLE PHOENIX HAND V3**

Thing #: 4056253
@e-NABLE

Students can visualize the mechanics of finger movements by printing and assembling components of a prosthetic hand.

Licensed Under: CC BY 4.0

CREATING A ROBOTIC ARM

With servo motors, 3D-printed attachments and additional components, students can make a robotic arm and then program it to complete specific tasks.

A WALKING HEXAPOD

Build a mechanical vehicle that walks on six legs by using an arduino board and simple coding. Have students design the legs and holder for the arduino board and servo motors needed.

SIX-AXIS ROBOTIC ARM

Demonstrate the six axes that make up a six-axis robotic arm and how the X, Y, and Z planes, and roll, pitch, and yaw movements allow the arm to complete complex tasks.

AUTOMATA MACHINE

Build an automata of a person, creature or object demonstrating fluid motion by designing a system of gears to work together and make movement.

DRAWING WITH ROBOTICS

Students can create a robot with 3D-printed parts, a servo motor, and coding know-how to program the robot to draw specific shapes. Take it a step further and have the robot draw the robot's own wiring diagram.

CLIMBING ROBOT

Students can learn the mechanism in which a robot can climb up a rope, define the robot's movements and observe how tension affects the robot's ability to move up the rope and how movements change when a robot climbs horizontally across a rope as opposed to vertically.

SECTION 4.5**Art, History & Music**

The study and exploration of art, history and music is engrained in the physical. From seeing how light and shadows interact with the surface of a sculpture, to holding the replica of a cannon ball used in the American Civil War, to feeling the vibrations of a musical instrument form distinct sounds. Holding, touching and interacting with these items are integral to getting a true sense of what the artist, maker and historical figures would have thought and felt in those moments.

ART, HISTORY, & MUSIC PROJECTS TO GET STARTED ON →

Project: Curate Your Own Museum



Project Category
Part of the Lesson

Design Difficulty
★ ★ ★ ★ ★

LEARNING OBJECTIVES

- Identify three historical events that were critical to the development of associated cultures and explain why
- Understand how each other's cultural backgrounds, interests, and experiences play a formative role in how we develop as individuals
- Explore the history and development of civilizations that make up components of one's cultural background

Students take on the role of museum curator and take charge of creating an exhibit that represents them with items that narrate the diverse cultures and experiences that play a formative role in their lives.

01

Example:

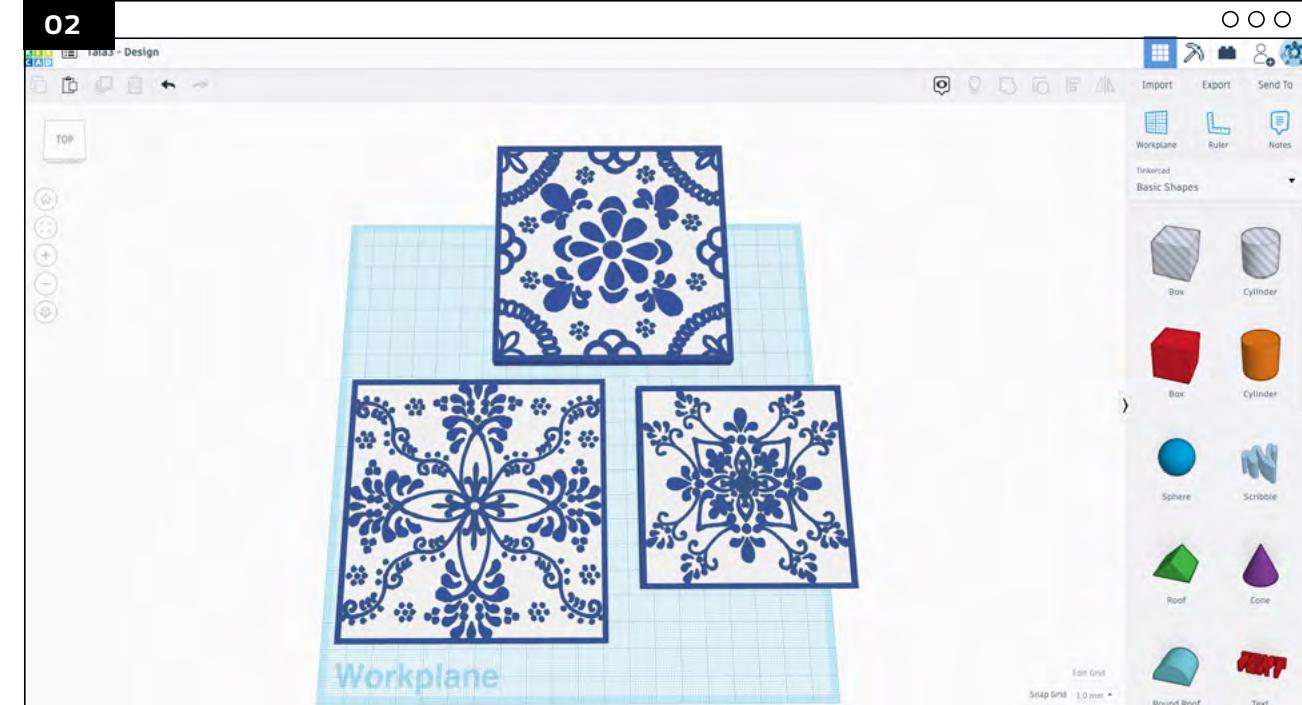
White and Blue Glazed Ceramics the sight of Talavera tiles and pottery in every relative's home as a child.

Mayan Pyramid representative of a deep love for Mexico's Pre-Colombian history

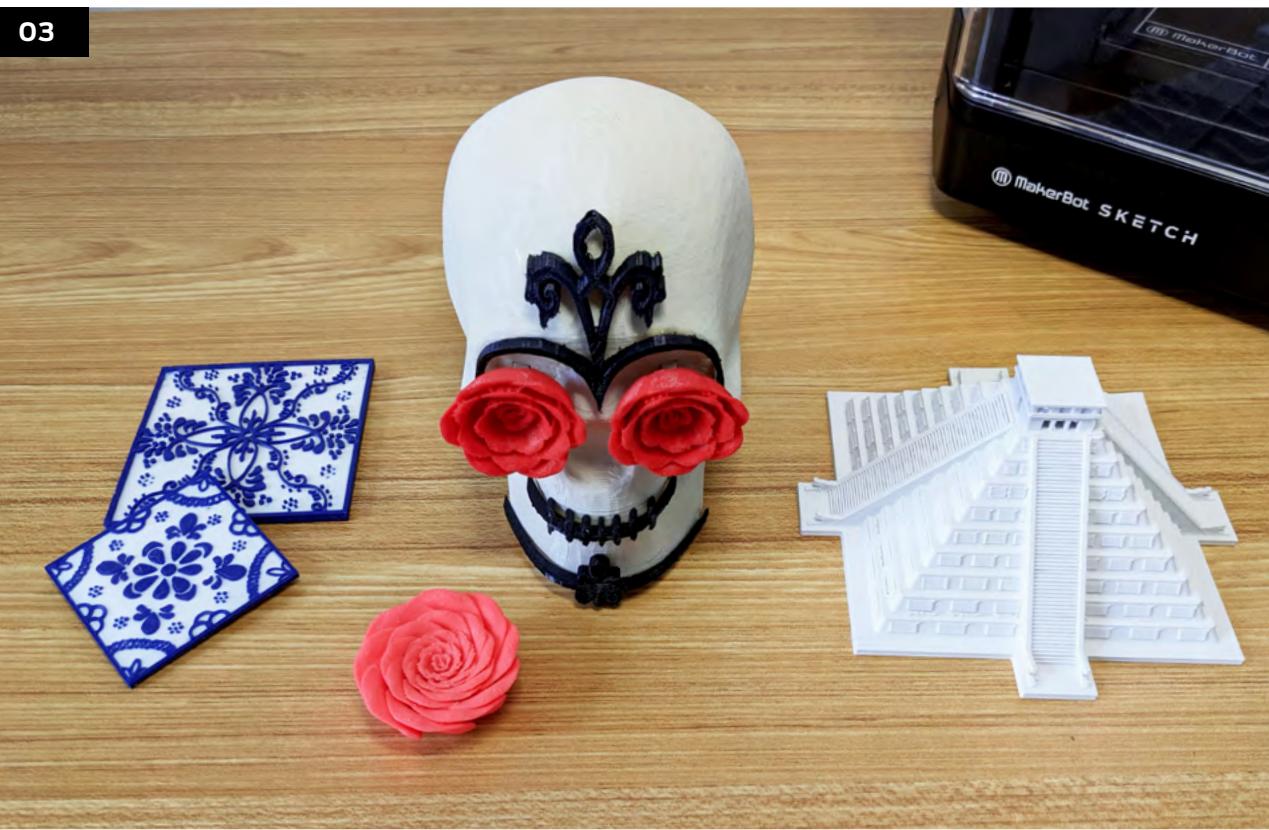
Dia De Los Muertos Skull representative of use of bright colors and connecting to those who've passed

Have students identify the cultures, experiences and ideas that they feel are representative of themselves. Then, brainstorm symbols or objects that can represent those cultures, ideas and experiences

02



Using 3D printing, students can design (or look on Thingiverse to start), create and print items that symbolize the cultures and experiences that represent them.



Students will then present their 3D-printed museum exhibit while supporting their exhibit with the history behind each object as well as the historical events that led to their unfolding.

Project: Two Faces and a Vase



Project Category
Student-Led, Student-Created

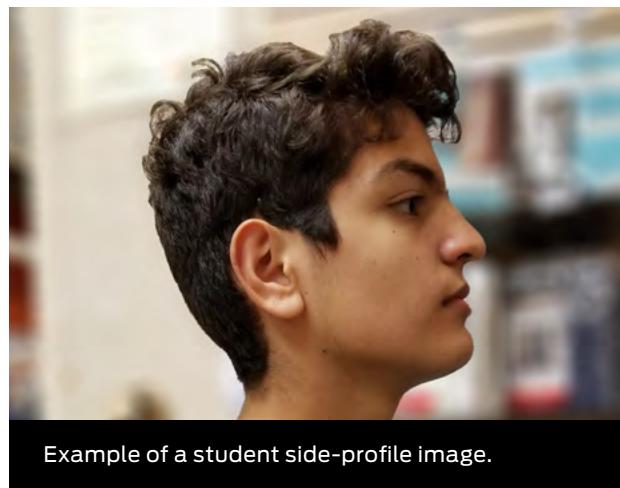
Design Difficulty



LEARNING OBJECTIVES

- Develop an understanding of how objects can be interpreted differently depending on the object's surroundings.
- Explore how Rubin's Vase works as an optical illusion and makes it possible to see both a vase and a face
- Create a "Rubin's Vase" using advanced 3D modeling software

Students will learn to identify both shape and design by creating vases with the negative impressions of their own facial profile and develop an understanding of how negative and positive space can be used to create optical illusions.

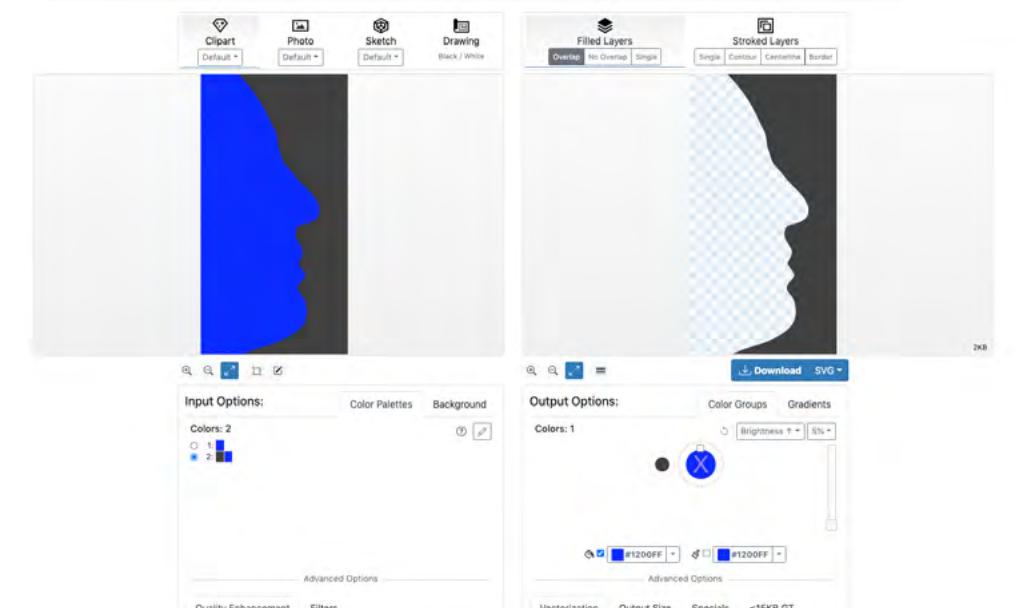


Example of a student side-profile image.

01

Students can work with partners or teams to take side-profile photographs of each other's face; crop the photo so that it is centered on the student's face.

03

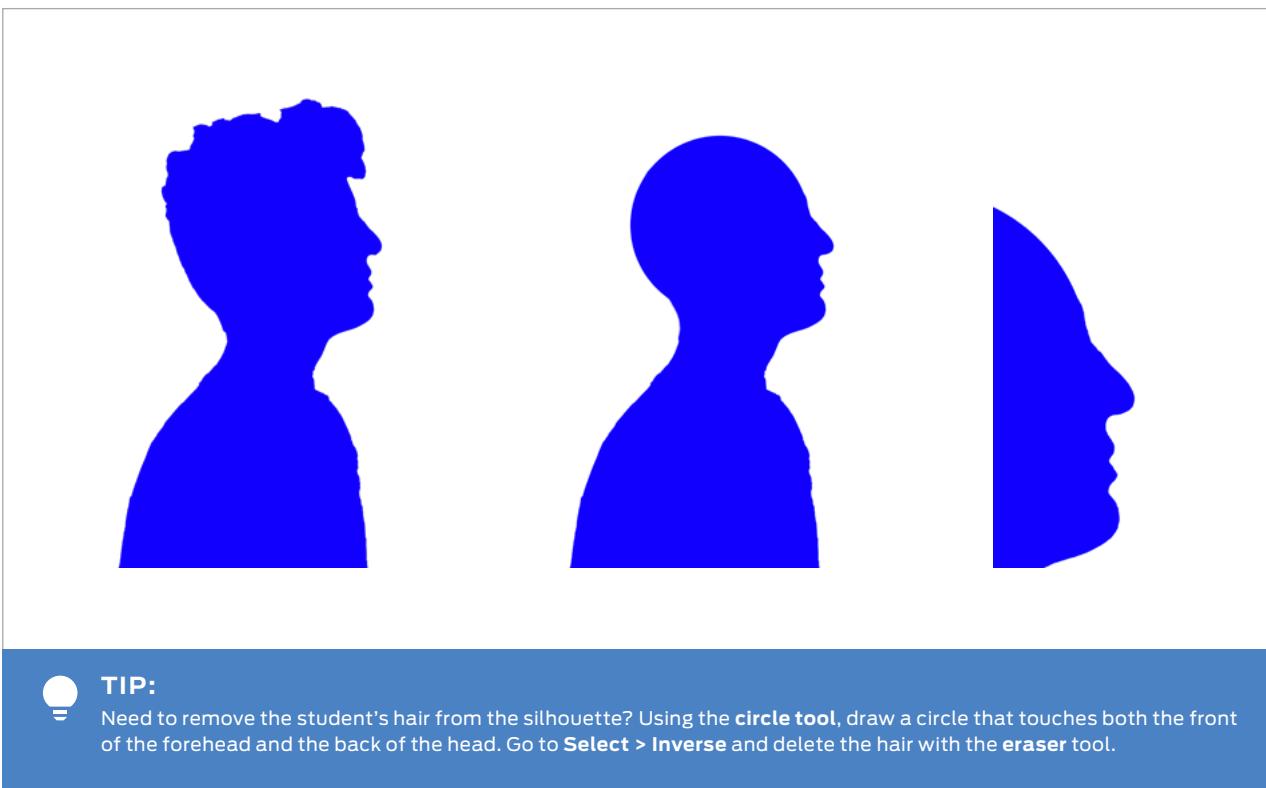


Save the file as a **JPG** or **PNG** file and go to [vectorizer.io](#) to convert the image to an **SVG vector image**.

02

Using Adobe Photoshop, or a preferred image editing software, students can import their photograph and remove the background by **duplicating** the image layer. Next, go to **Select > Subject**, then paint the background a dark color and the foreground (the silhouette) a lighter color. **Crop** the image so that it is centered on the shape that creates the silhouette.

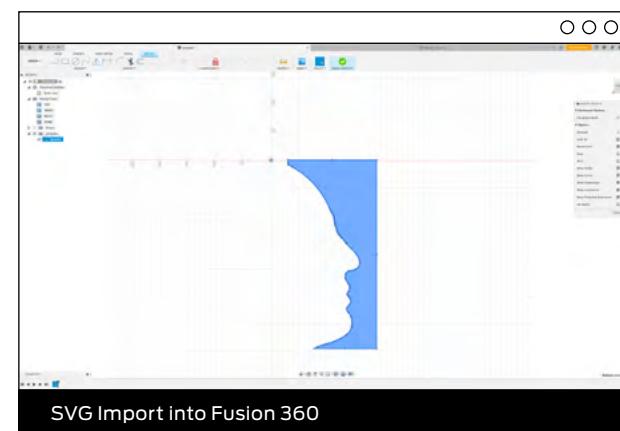
The process should look something like this:



TIP:
Need to remove the student's hair from the silhouette? Using the **circle tool**, draw a circle that touches both the front of the forehead and the back of the head. Go to **Select > Inverse** and delete the hair with the **eraser tool**.



TIP:
Go to page 117 to learn how to convert an image into an SVG image and why this step in the process is needed.



Clean Silhouette Line

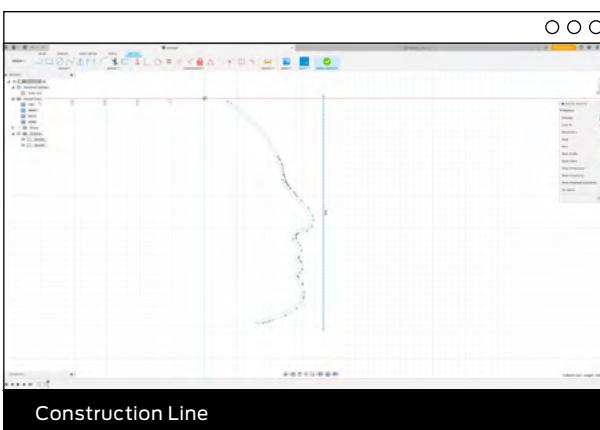
04

Using Fusion 360, OnShape or student's preferred advanced CAD program, create a sketch and import the **SVG** file. **Trim (T)** away any line that is not part of the silhouette. Select the entire silhouette and go to **Modify > Offset > 5mm**, then draw **Lines (L)** to connect the silhouette and offset line together. This will create one shape we can further manipulate.

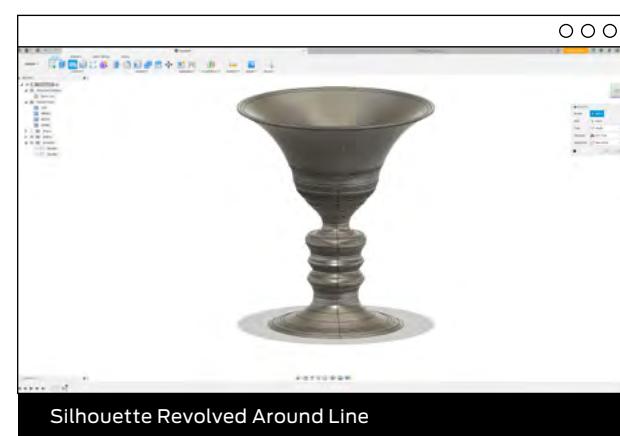


Silhouette Line Offset

O O O

**05**

Draw a **Construction Line (L)** to the right of the silhouette, this will serve as the axis with which the silhouette will revolve around. Next, click **Create > Revolve**. On the **Revolve** menu, select the silhouette as the **Profile** and select the construction line as the **Axis**. Click OK. Export as an **STL**.



Prepare the file to print. We recommend orienting the model upside down to reduce print time and the need for printed supports.

EXPLORING MORE PROJECTS



ROMAN SCULPTURE - LAOCOÖN AND HIS SONS

Thing #: 2720417
@icefox1983

Students can select and print statues and structures inspired by the art of Ancient Greece & Rome. These prints can be used in a variety of ways - from studying art forms and architectural marvels, imagining how these statues looked painted and how they represented, making inferences about the time's politics and environment, to observing how these statues and structures reflected the eras in which they were created.

Licensed Under: CC BY 4.0

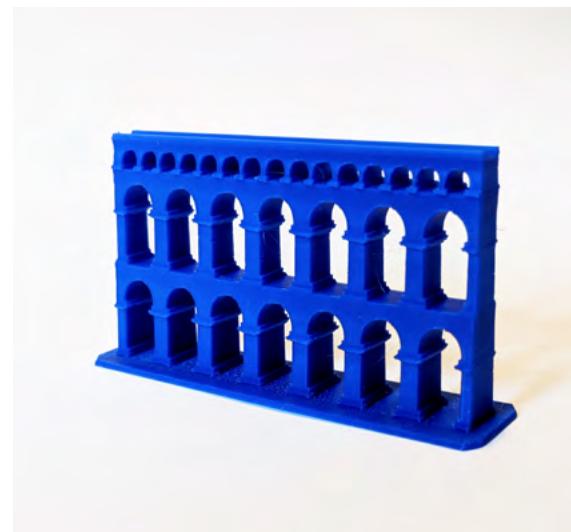


GREAT PYRAMID OF GIZA

Thing #: 296260
@MakerBot

Give students the opportunity to hold the Great Pyramid in their hands and see how each block of stone makes up this famous structure - students can also look inside the pyramid to get a better idea of how the pyramid was used.

Licensed Under: CC BY 4.0



ROMAN AQUEDUCT

Thing #: 3552200
@Juest1147

Using one of the many aqueduct prints found on Thingiverse, have students hypothesize what the structure was used for. Next, discuss methods of moving freshwater from a source to different locations in a city. With 3D printing, allow students to design and print their own aqueducts that can move water from one location to another.

Licensed Under: CC BY-NC-SA 4.0

**MAYAN MATH HIEROGLYPHICS**

Thing #: 1699941
Username: @Dimorgoniv

Learn more about the Maya math vigesimal system and how their system allowed scholars, astronomers, architects as well as traders and farmers to make complex calculations.

Licensed Under: CC BY 4.0

**TECHNO MUSIC**

Thing #: 2936868
@CreativeFilament

Students can get a basic understanding of the basic "ta-ta-tee-tee-ta" beats and rests through 3D printed musical notes.

Licensed Under: CC BY 4.0

3D PRINTED RECORDER

Many students are introduced to music through learning to play the recorder. Allow students to create their own recorder while experimenting with print orientation and infill - see if/how it changes the sound.

BUILD YOUR OWN MUSICAL INSTRUMENTS

Have you ever wanted to build your own musical instrument? Now is your chance! 3D print fully-functioning instruments, enough instruments to form your own band!

A PORTRAIT IN TIME

Information to cultures all around the world is more accessible now than ever before. In this project, students can choose a region of the world at random and imagine themselves as a member of a civilization that made up the region at a specific point in time. Using a digital sculpting software, students will create a self-portrait that is representative of both the time and style of their selected region.



There are endless ways to use 3D printing in the classroom and the projects in this book are only a hint of what's possible with 3D printing. We encourage you to actively search through Thingiverse.com and find inspiration in all the ways that 3D printing is leveraged across subjects, curriculum and student ideas. In the next chapter we'll get a crash course in what tips and tricks teachers are using today to push 3D printing even further in the classroom.

TEACHERS' TRICKS OF THE TRADE

As you progress through the 3D printing journey you may find yourself learning 3D printing tips and tricks you wished you had known about earlier. This is what this section is about. We've collected the top 5 tricks educators use to push the way 3D printing can help in the classroom just a little bit further.



SECTION 5.1

Turning a Sketch into a 3D Print

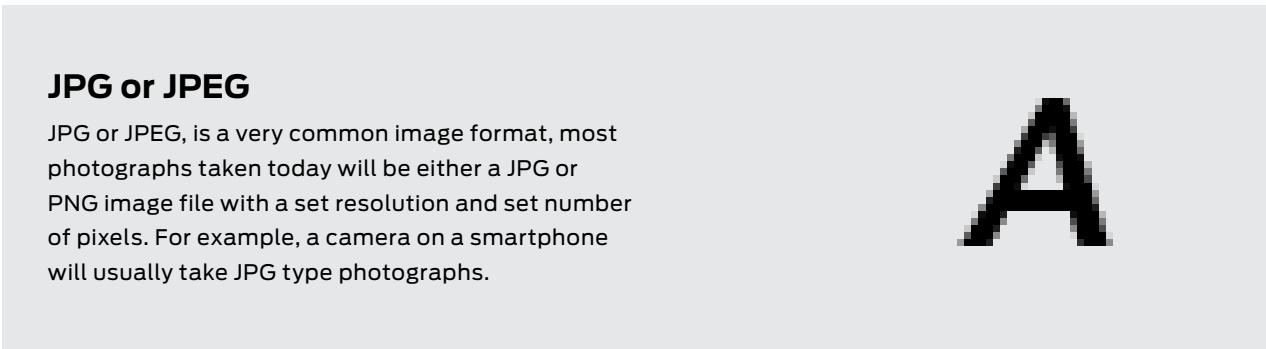
One of the easiest ways to connect the relationship between 2D images and 3D shapes is by converting students 2D drawings in paper into an actual tangible object they can hold in their hands. When students first learn 3D printing it can be difficult for younger students to understand the idea that a three-dimensional object can be created by a machine using models in a computer.



With this method, students can see something that they draw in the physical world, see it become digitized and finally see how their creation comes back into the physical world but as an actual three-dimensional object - giving them a solid understanding of what it means to go from a digital model to a physical print.

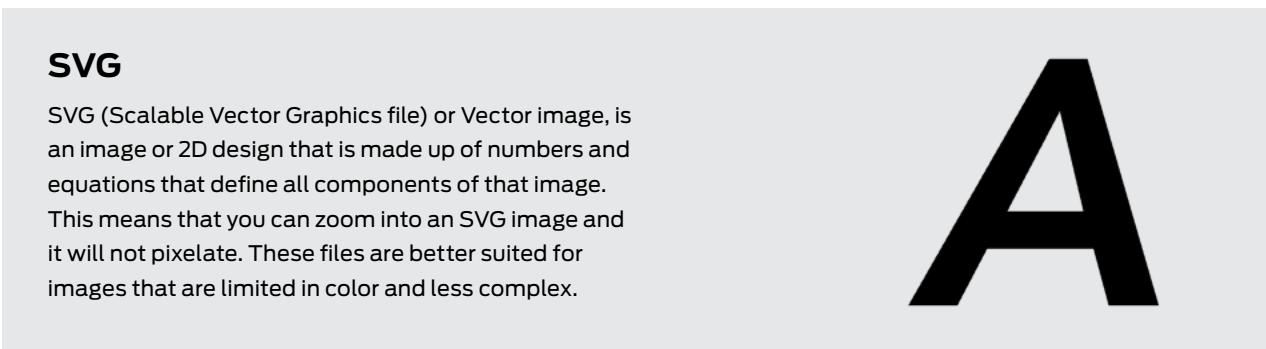
HOW DOES IT WORK?

It's pretty easy to go from a hand drawing to a 3D printed part. Before getting started we recommend familiarizing yourself with the following terminology:



JPG or JPEG

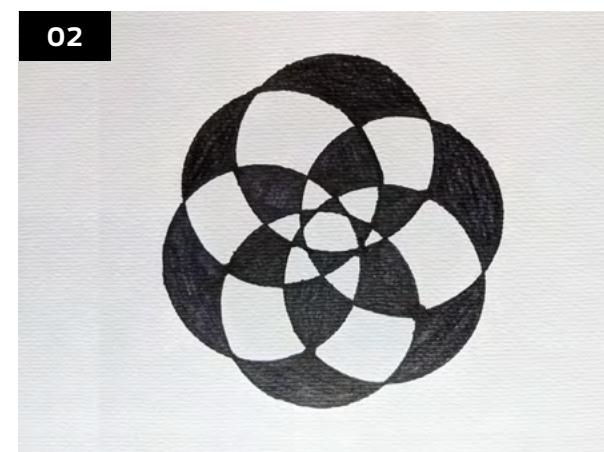
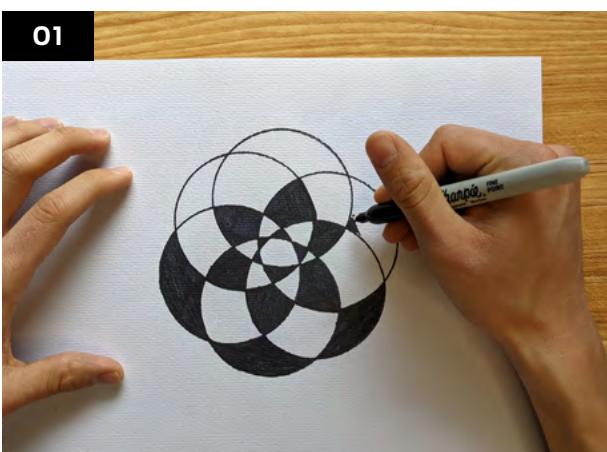
JPG or JPEG, is a very common image format, most photographs taken today will be either a JPG or PNG image file with a set resolution and set number of pixels. For example, a camera on a smartphone will usually take JPG type photographs.



SVG

SVG (Scalable Vector Graphics file) or Vector image, is an image or 2D design that is made up of numbers and equations that define all components of that image. This means that you can zoom into an SVG image and it will not pixelate. These files are better suited for images that are limited in color and less complex.

STEPS:

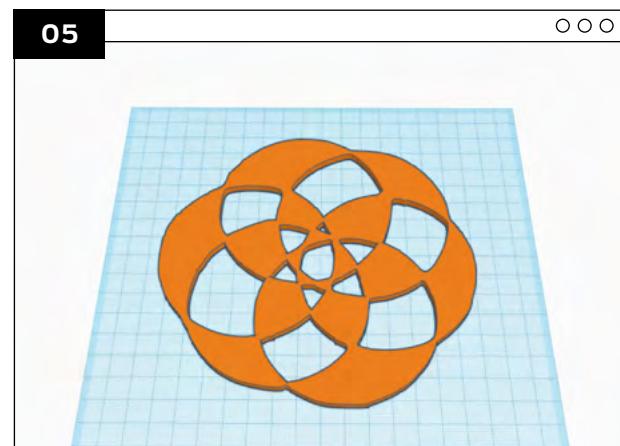
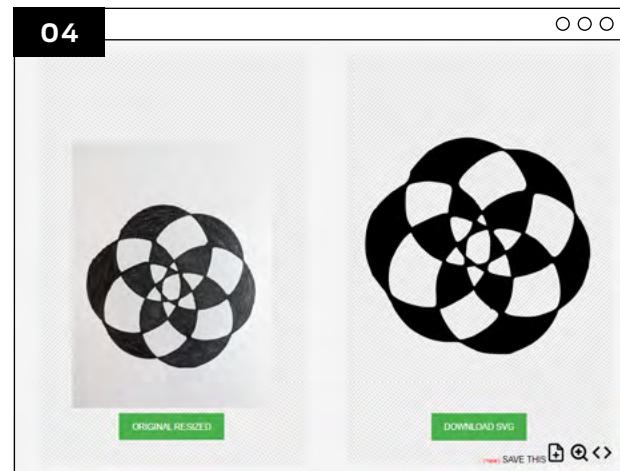


DRAW AND COLOR

Using a piece of white paper and a black or dark marker, students can draw a design on the paper as shown below. Be sure that the designs in the drawing are bold and filled in well.

PHOTOGRAPH THE DRAWING

Take clear, well-lit photos of the drawings and avoid any shadows or harsh lighting when photographing the drawings as the shadows may show up later in the design. Then crop the photograph so that only the drawing is present.



TAKEAWAY

Students can quickly see what it means to take something that is created in a 2D space and how it can be made 3D using some quick tools and a 3D printer. You can use this technique to help students create their own designs while they're still getting comfortable with 3D design software - from printing school logos, name tags, storybook characters to anything else. Sky's the limit!

FROM JPG TO SVG

Use a vector graphics editing software or a website that converts images to SVGs (scalable vector graphics file). For this example we used vectorizer.io to convert the photographs into SVGs.



TIP:

- Establishing a method to transfer files back and forth between teacher and students will save you a lot of time.
- We recommend choosing the Drawing Black / White option on vectorizer.io to get a cleaner SVG of your image.

DOWNLOAD THE SVG

Depending on the software or website you use to convert your image into an SVG, you may see an option to convert your file immediately into an STL. We recommend bringing your SVG into Tinkercad software to further customize and clean up the SVG image if needed.

CUSTOMIZE AND PRINT!

Now that your SVG has been imported onto Tinkercad, you can customize the sketch and connect parts of the design if they're not already attached. Export to MakerBot CloudPrint and get ready to print!



TIP:

- At this point, make any adjustments that are needed. You can add text, numbers, or a background shape to make sure no parts of the design will print separately.

SECTION 5.2**Z-Pause - Adding More to the 3D Print**

If you're looking to add another element to your 3D prints you can use your MakerBot printer's Pause feature to pause your print at a given Z-height or vertical length of the print. This method of Manual Z-Pause is commonly used by educators when looking to change or add colors to make features of a student's model pop.

Using Z-Pause, teachers and students can begin to incorporate the following:

**CHANGE OF COLORS**

- Name plates & School Logos
- Detailed Designs
- Diagrams with Text

**ADDITION OF OTHER MATERIALS**

- Magnets
- Beads
- Modeling Wire

**SECURING MATERIALS INTO PLACE**

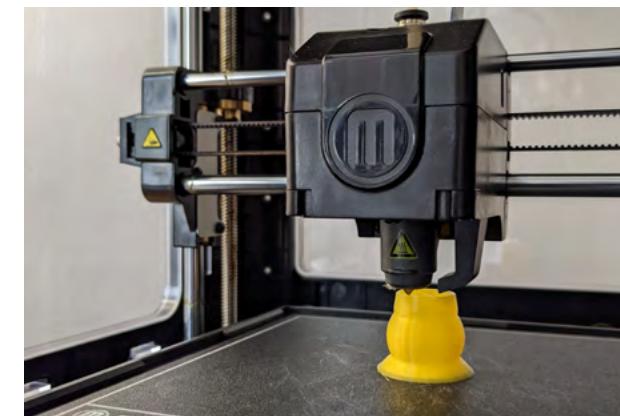
- Bearings
- Fabrics
- Jump Drives or USB Sticks

HOW IT'S DONE

This MakerBot logo print was first started using black filament to print the base and once it got to the actual logo design we paused the printer and changed the filament to a white filament to make the logo standout from the original color.

**TIP:**

To pause your printer mid-print simply click 'Pause' on your MakerBot printer's interface. The extruder will go back to its home position and give you enough access to manipulate your print.



Z-Pause can also be used to add material to the inside of an ongoing print. One reason we might do this is to add magnets or even enclosing a bearing on the print like we did above. This technique is great for making musical instruments (by adding beads), making magnets, securing items in place, and even as shock absorbers (by adding hot glue to the inside of the print).

**NOTE:**

This process can be difficult to control since you will need to keep a close eye on your ongoing print in order to catch the specific layer or section at which you will be pausing your print.

**TIP:**

Older students can use this method as well but if you're working with younger students we recommend teachers actually do this part as the printer will be paused and the extruder's nozzle will still remain hot!

TAKEAWAY

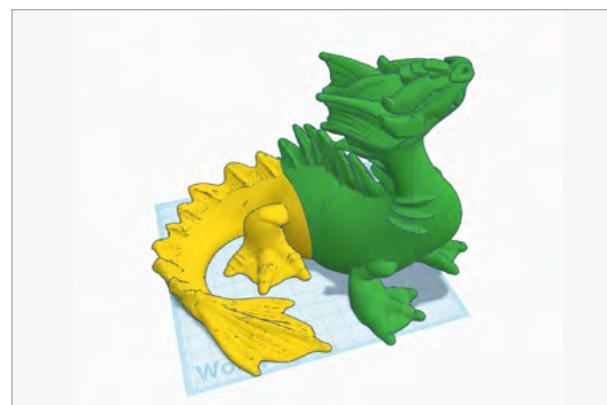
Z-Pause is a great way to bring in another element into the 3D printing process and opens up the ways that 3D printing can be used to bring a 3D print or prototype to another level. Using Z-Pause can also help students further familiarize themselves with the potential capabilities of the MakerBot 3D printer giving them an added level of confidence and a better understanding of how to leverage 3D printing.

SECTION 5.3**Printing Bigger than the Build Plate**

Students' imaginations know no bounds - even the bounds of a 3D printer. Sometimes 3D models, components of a design or whole assemblies can end up being bigger than the actual build volume (or print volume) of a given 3D printer. While we can scale down a design so that it fits within the bounds of a printer certain projects and designs require that their 3D models be printed at their designed size since scaling a model up or down can distort components of a design - such as unique design details, text or tolerances. This means we sometimes have to go beyond the print volume.

GOING BEYOND THE PRINT VOLUME

Two ways to allow students to design and print models that may exceed the physical bounds of a printer's actual print volume are to either cut a 3D model into parts to be printed separately or creating an assembly of parts to be fitted together after printing.

Scenario 1: Slicing a Model into Separate Parts

Design Difficulty ★ ★ ★ ★

Similar to the **Fractionate Your Creation Project** on page 82 this method requires either the student or teacher to take their model into the design software of their choice and cut up their design into separate parts that will fit within the printer's build volume.

Scenario 2: Creating Assemblies to Print

Design Difficulty ★ ★ ★ ★

Assemblies are groups of printed objects that can fit and work together for specific purposes. This method is used a lot in robotics for parts that will be used together once assembled.

HOW TO: Slicing a Model into Separate Parts

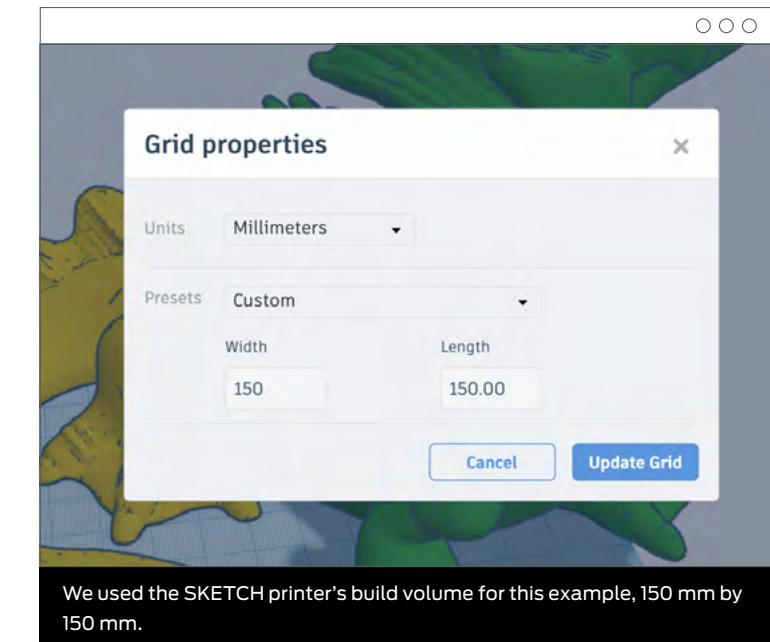
Two ways to allow students to design and print models that may exceed the physical bounds of a printer's actual print volume are to either cut a 3D model into parts to be printed separately or create an assembly of parts to be fitted together after printing.

STEP 1

Open **Tinkercad** software and import your model onto the XY grid.

STEP 2

Set the dimensions of the grid to the same length and width of your printer's build dimensions by clicking on **Edit Grid** on the bottom right of the Tinkercad screen.

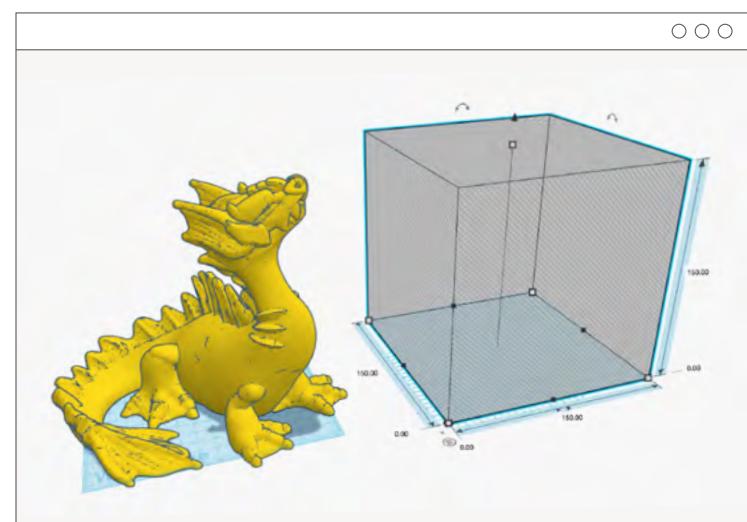
**STEP 3**

Click **Update Grid** to finalize changes. You'll now be able to see how much bigger the model is compared to your printer's length and width printing dimensions.

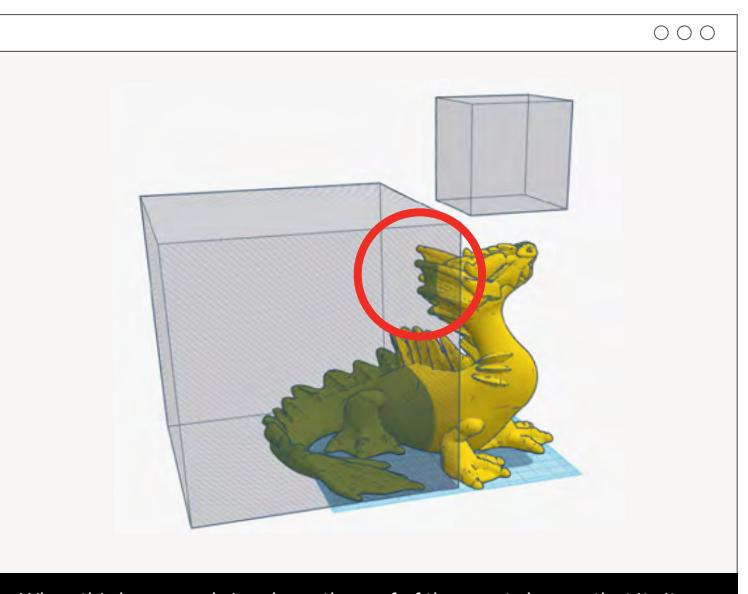


STEP 4

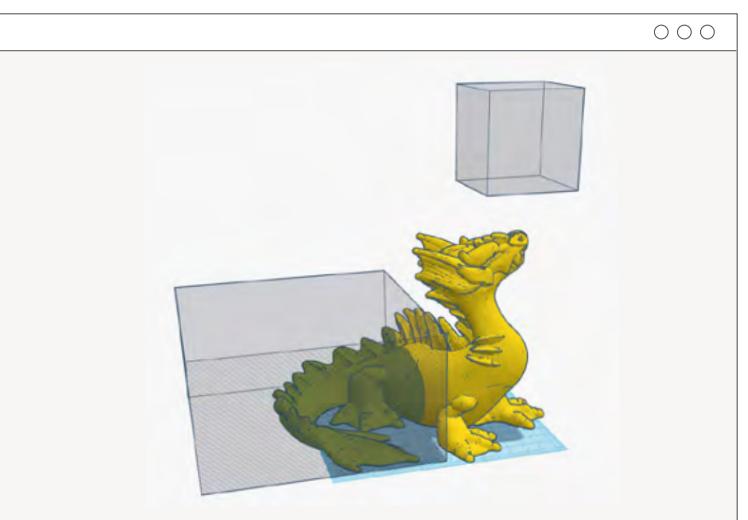
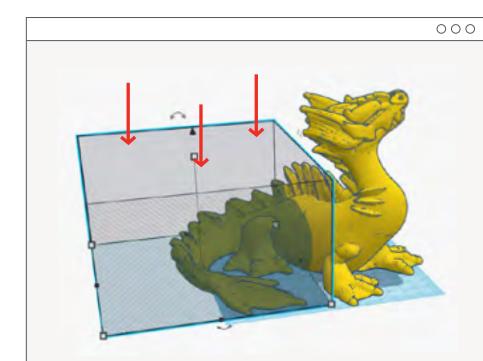
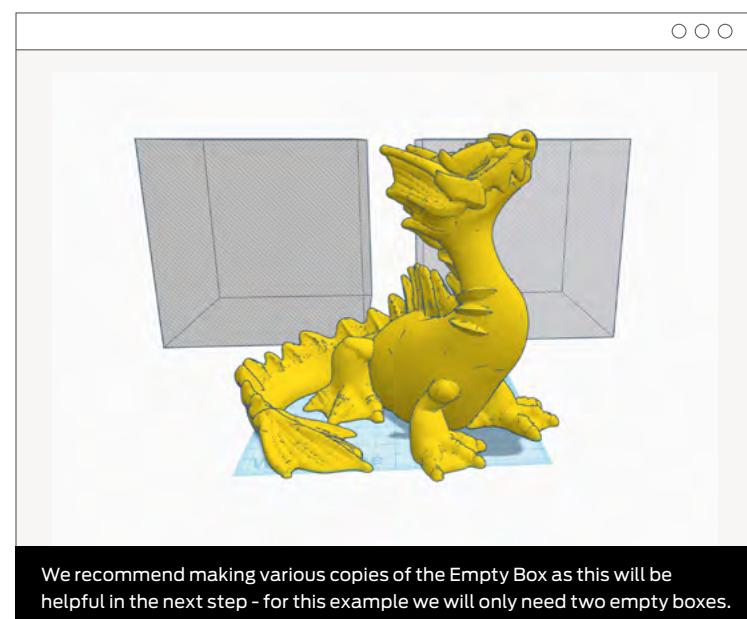
With your model on the grid, drag an Empty Box and resize the box so that it is the same dimensions as your printer's build volume. This will give you a better idea of how big your printer will be able to print and how to begin cutting up your model.

**STEP 6**

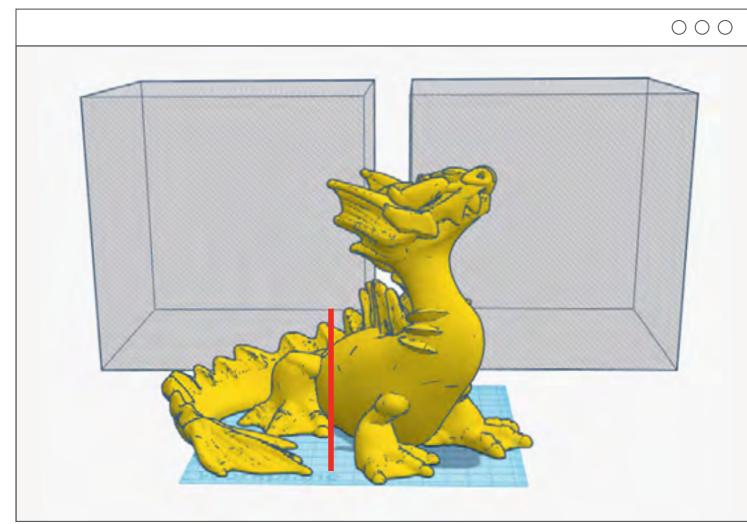
Place the first empty box in what you determine to be the best location - keep in mind that you're cutting an object into pieces and the way you cut may leave some details hanging in mid-air like so:



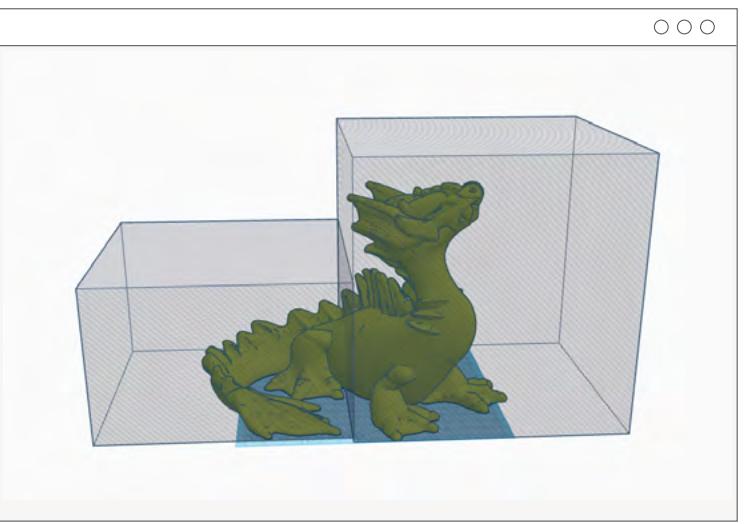
When this happens, bring down the roof of the empty box so that it sits below any details that would otherwise be floating if cut off.

**STEP 5**

Before we begin cutting the model up into printable parts, study the figure and see if there are any easy cutoff points for your model. For example, the dragon model could potentially be cut up into 2 pieces - the head and torso, and the tail.

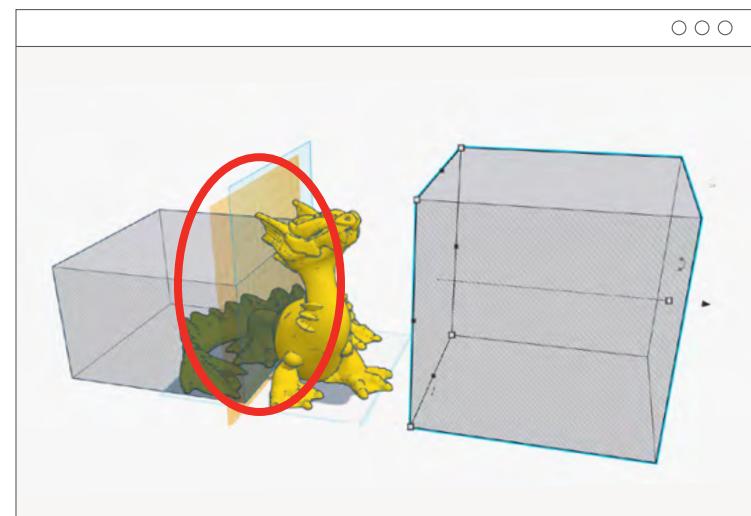
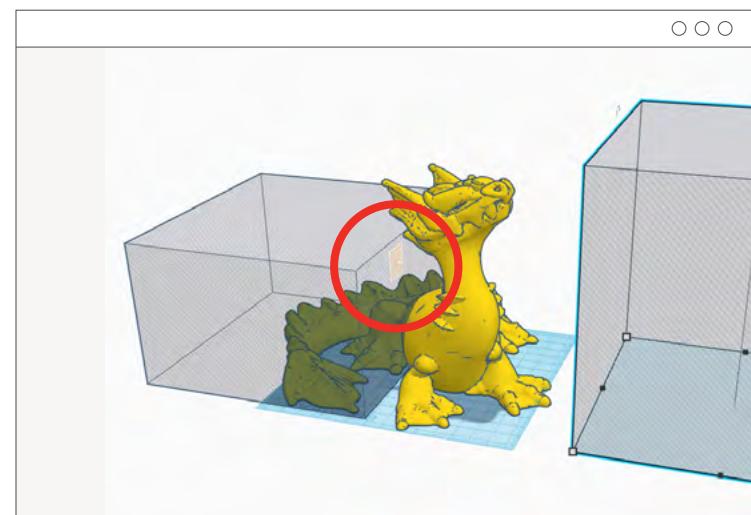
**STEP 7**

Next, bring the other square so that it covers the rest of the dragon's details. We recommend using the workplane tool in order to stack the second empty box exactly next to the first empty box like so:

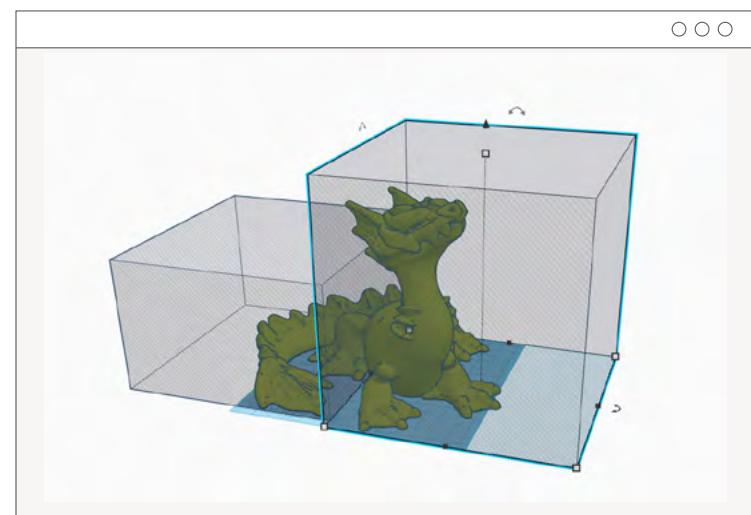


A. USING THE WORKPLANE TOOL:

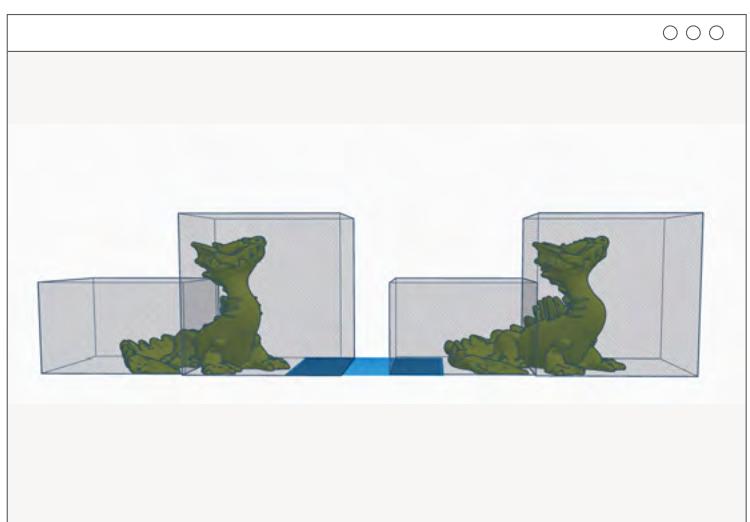
Located on the top right of the Tinkercad screen, the Workplane Tool allows you to “shift gravity” or adjust where Tinkercad’s workplane is temporarily located. First, drag the Workplane Tool and hover the tool over the right side of the first empty box and release, like so:

**B. DROP ONTO THE NEW WORKPLANE:**

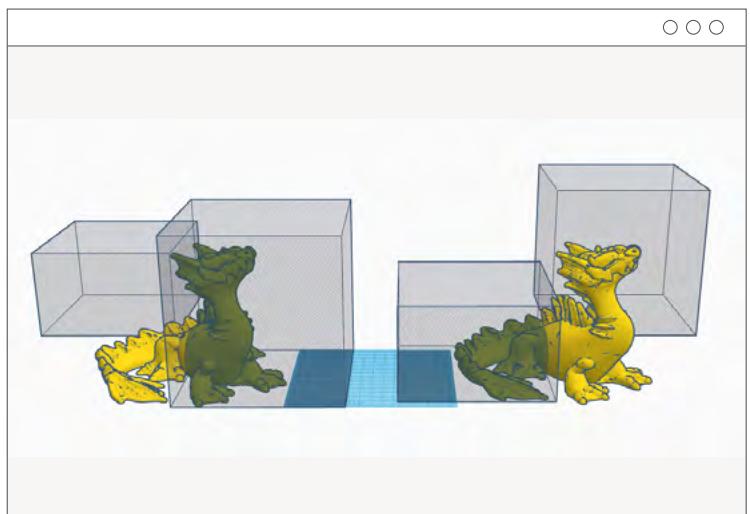
Next, position the second empty box so that it is inline with both the model and first empty box. Then with the second empty box selected, click the ‘D’ key to have that empty box drop onto the new workplane. (Once that’s done you can remove the new workplane by dragging a new workplane onto the screen)

**STEP 8**

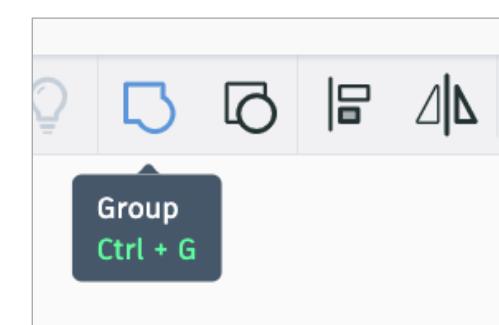
Now, select ALL the objects on your workplane - for this example, this includes both the dragon model and the two empty boxes. A rule of thumb here is to duplicate the entire selection and create the same number of copies as there are empty boxes - in this case there are two empty boxes so we will make two duplicates like so:

**STEP 9**

Now, we can cut up the model so that there are two pieces we can fit back together. We’ll remove one empty box from each duplicate, as shown:

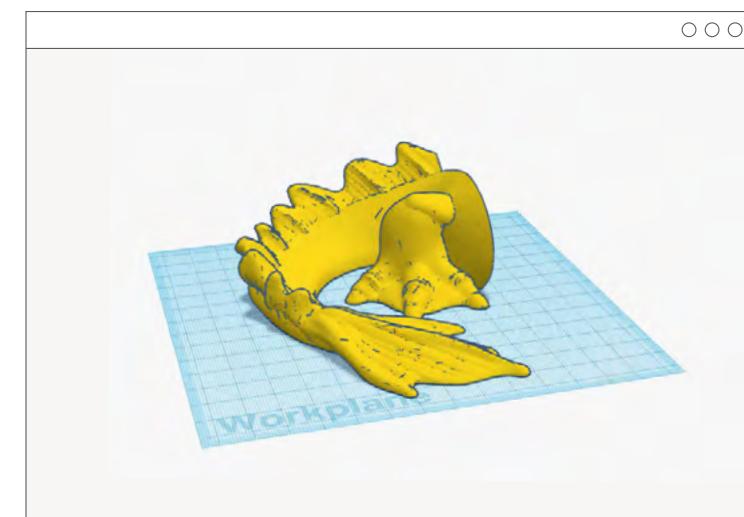
**STEP 10**

Next, we’ll use the Group function to group each duplicate separately like so:



STEP 10

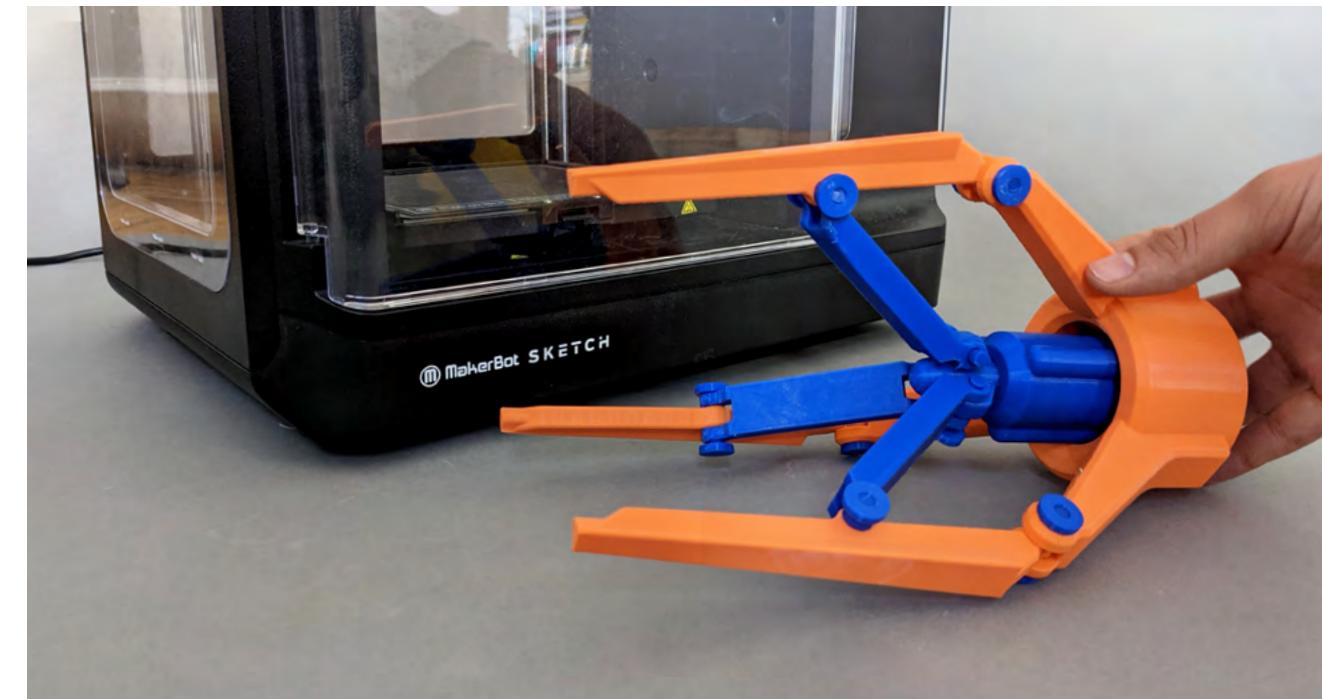
We've now cut the 3D model into two pieces that can be exported as separate STL files to be printed separately and assembled together afterwards.

**FINAL RESULT**

To connect these two pieces together you can use superglue or if students are more advanced with CAD design they can then use different methods to create a friction fit (such as a dowel and corresponding hole) to allow the parts to firmly fit together.

**HOW TO: Creating Assemblies to Print**

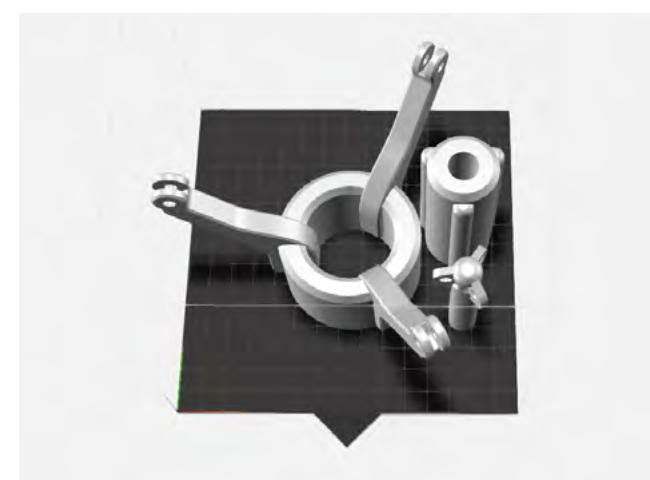
Assemblies are groups of printed objects that can fit and work together to serve a specific purpose. For this example we'll use the Mechanical Gripper example as shown below:



This print comes in 27 unique pieces that all work together to give this mechanical gripper its gripping capability - when assembled together this gripper is bigger than the actual build dimension of the printer it was printed on.

HOW DO WE DO THIS?

We design parts that are smaller than the build plate that are designed to later fit together when being assembled. When preparing the build plate, group items closely together and rotate models around to find the best way to fit everything together like below:



ONCE PRINTED, IT'S TIME TO ASSEMBLE.



SECTION 5.4

Reduce 3D Printing Time

Facilitating a 3D printing project is exciting, but printing students' projects can be daunting if you have a lot of students and only one or two printers available to use. Properly managing and planning for print time will help your projects run smoother. Take a look at these tips for ideas on how to manage and streamline your print time.

1. CHANGE PRINT SETTINGS

Altering a few print settings can help to save a lot of time, especially on longer prints:

1. Reduce infill density: 5% is plenty strong for most parts, and uses less filament.

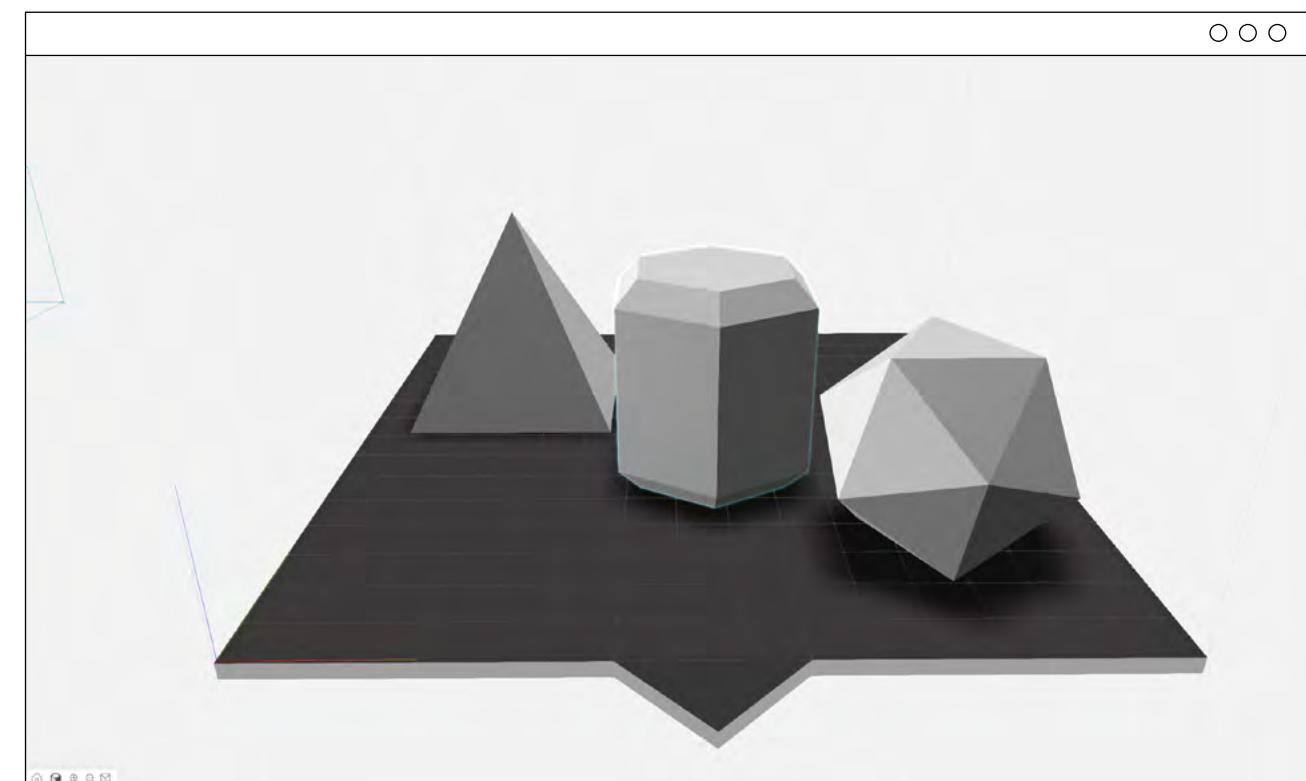
2. Number of shells: 2 shells is usually enough, adding more will add print time.

3. Layer Height: Switch to 0.3 mm layer height, though surface detail will be rougher.

SETTINGS	PRINT TIME
10% infill 0.2 mm layer height 2 shells	5 hr 7 min
5% infill 0.2 mm layer height 2 shells	4 hr 45 min
5% infill 0.3 mm layer height 2 shells	3 hr 43 min

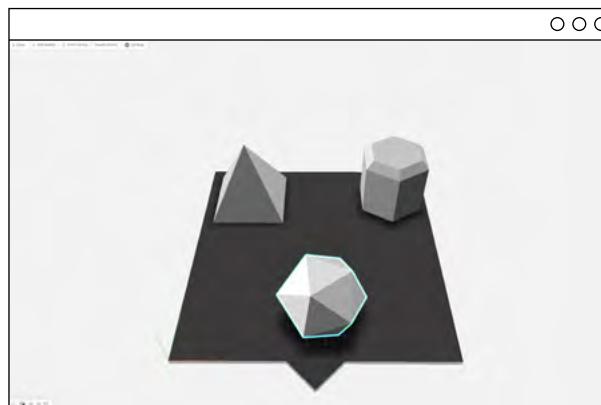
TAKEAWAY

Going beyond the bounds of a printer's print volume is a great way for students to start thinking about how 3D printed parts can fit together. This brings up questions on more complex strategies with 3D printing such as designing for specific tolerances, material properties and mechanical performance for each designed component.



2. MOVE OBJECTS CLOSE TOGETHER

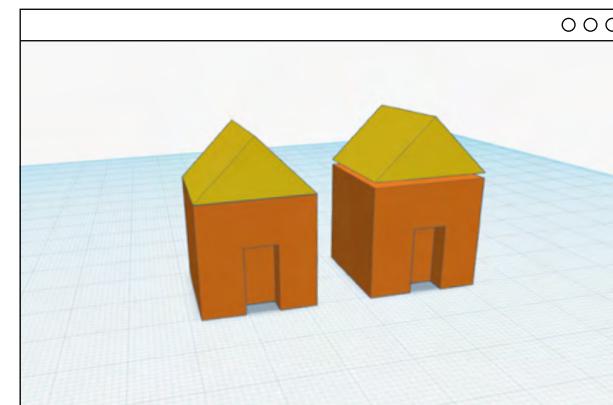
Make sure parts are close together (but not touching) on the build plate. If parts are far away from one another, the extruder will have to travel a further distance and the print will take longer. This won't save a ton of time, but will shave off a few minutes.



POSITION	PRINT TIME
Spread apart	22 hrs 42 min
Close together	9 hrs 28 min

4. REVIEW MODELS BEFORE EXPORTING

Look at your model before exporting from the design program. Is there any unnecessary material that can be removed from the design? Are there any gaps in the model that might cause a print failure?

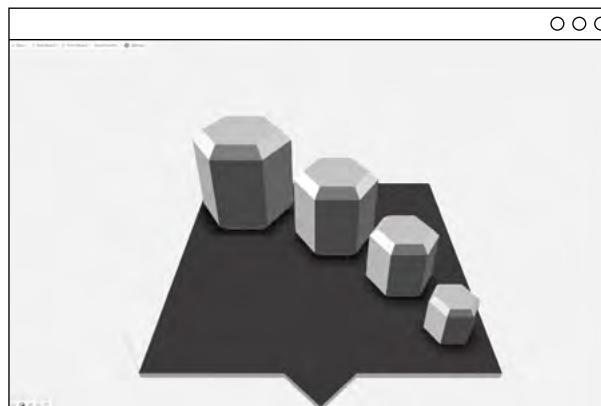


MODEL	PRINT TIME
Name Tag with excess material (right)	52 min
Name Tag with material removed (left)	39 min

MODEL	PRINT TIME
House with gap (right)	Print failure
House with no gap (left)	39 min

3. REDUCE SCALE

Is the size of the model important for this project? If not, even reducing the size to 90% can save a lot of time and material.



SCALE	PRINT TIME
100%	3 hr 57 min
90%	2 hr 51 min
75%	1 hr 54 min
50%	49 min

5. ESTABLISH DESIGN CONSTRAINTS

Provide design constraints to students before they begin designing their parts. If you're running a large class project, this will allow you to better predict the total print time. For example:

- › Maximum part size (i.e. no more than 2 in.³)
- › Maximum print time (i.e. parts must print in 90 minutes or less)
- › Designs must be printable with no support material

SECTION 5.5**Advanced Design for 3D Printing**

Through this chapter, we've seen how educators have used their experience with 3D printing to apply it further within projects. In this component we're going to learn about how we can better design and prepare our files for 3D printing.

Designing for 3D printing can help us keep in mind best practices to create prototypes that are stronger, will print successfully and help us get closer to a problem's solution.

SMALL FEATURES AND DESIGNS

We mentioned earlier on page 122 how scaling models up and down can distort features once a model is 3D printed - but how do we account for that? We can use the example below as a guideline:

We've printed the MakerBot logo three times in different sizes to see the loss of detail as the scale is decreased.

**25 millimeters or about an inch**

This first print measures in at 25 millimeters or about an inch in the Y axis, no distortion or loss of detail is present.

12 millimeters or about half an inch

This second print measures in at 12 millimeters or about half an inch in the Y axis. You can see in some areas that we're beginning to see a loss of detail.

6 millimeters or about a quarter inch

This third print has been scaled down to 6 mm or about a quarter inch - you can see an obvious increase in loss of detail.

**RULE OF THUMB:**

It's good to consider that since our printers' nozzles typically have a diameter of 0.40 millimeters, details smaller than half a millimeter may be lost or distorted since the nozzle will not be able to extrude material thin enough to capture all the details in your model. If you want to increase how small you can print we recommend looking at the custom settings on MakerBot CloudPrint.

BRIDGES, OVERHANGS & TOLERANCES

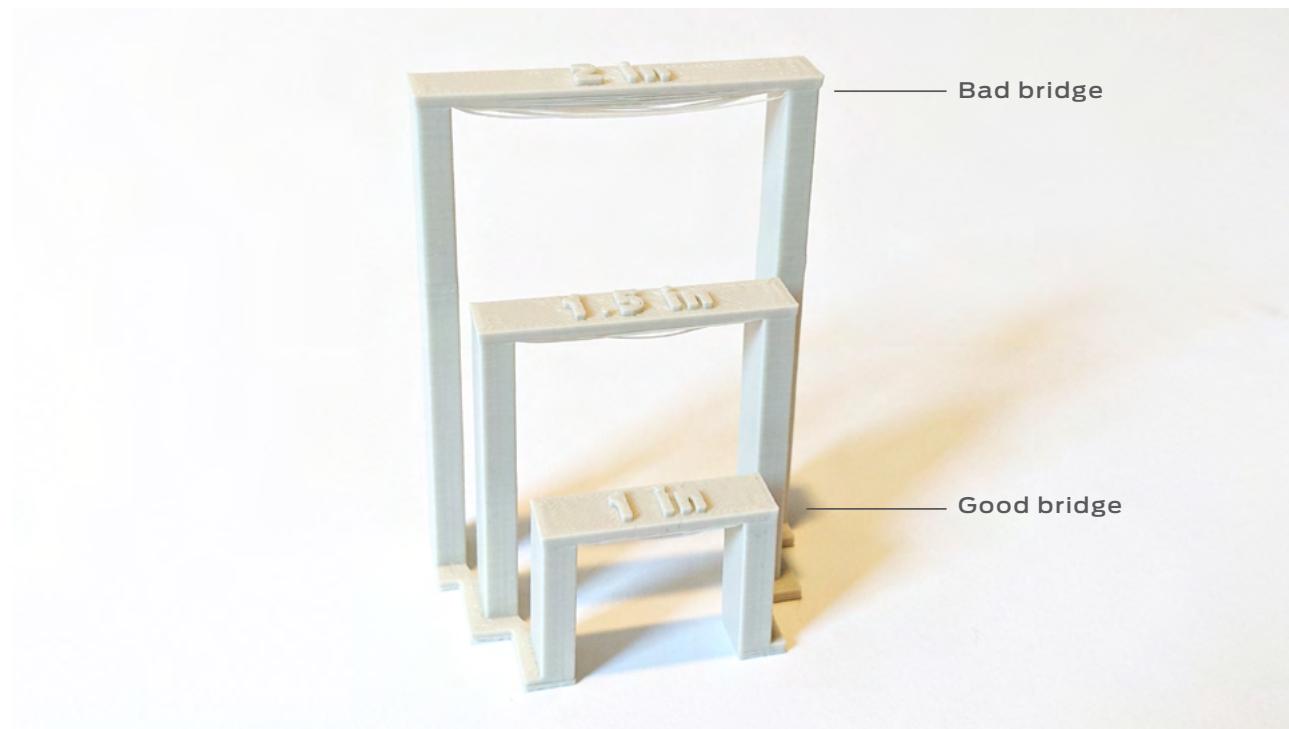
Knowing how to design with bridges and overhangs can enable students to both print without supports and allow for print-in-place assemblies. Print-in-place assemblies are models, like the gear below, that can be printed in a single print without needed supports in hard to reach areas - these assemblies make it possible to create moving parts within a print without having to assemble parts together after being printed.

**How do we achieve this?**

We can start learning how to make print-in-place assemblies by familiarizing ourselves with the capabilities and limitations of a given 3D printer - and that starts with bridges, overhangs and tolerance.

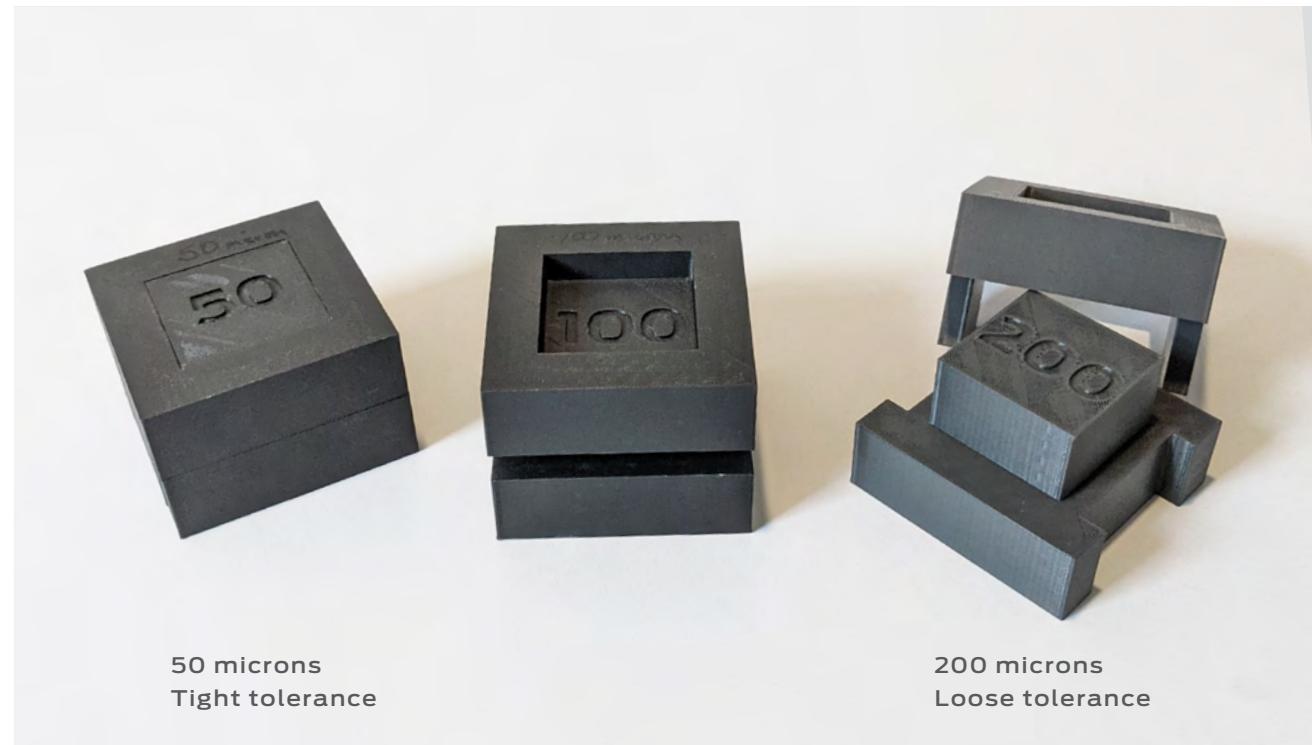
Bridge

A bridge is the underside of a print that is supported at both ends but not in the middle. If a bridge is longer than 50mm, supports will be automatically printed underneath to avoid strings of filament drooping from the print.

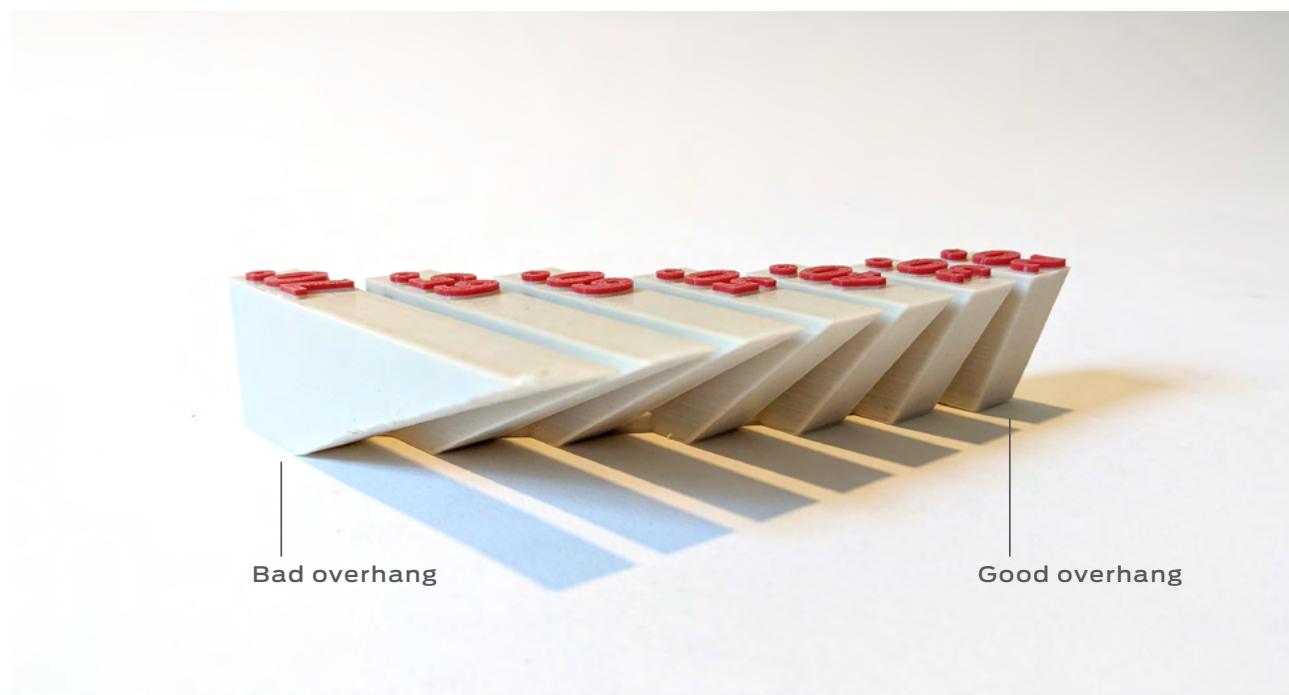
**Tolerance**

Tolerance in 3D printing is the planned amount of clearance between two 3D printed components.

Tolerance can vary depending on the printer, the printing material and the intended purpose for a printed assembly
- a loose tolerance will allow for a certain amount of movement or wiggle room, a tight tolerance will keep an object secured in place.

**Overhang**

An Overhang is a part of a print made up of layers that have little contact with the previous layer. We can typically print overhangs that deviate up to 68 degrees from the Z-axis with no support. Overhangs that exceed a 68 degree angle will require printing with supports to maintain good print quality.



The fidget gear below was intentionally designed to allow this two-part gear to have movement:

- Both gears' teeth do not have any overhangs that exceed 68 degrees.
- The printed housing around both gears does not have any bridges that exceed 50 mm.
- There is enough tolerance between both the gears and the housing to allow for easy movement between both gears.



Takeaway

With this knowledge, students can then start creating designs and print-in-place assemblies that do not require printed supports and can allow for movement and interacting parts all within one print.



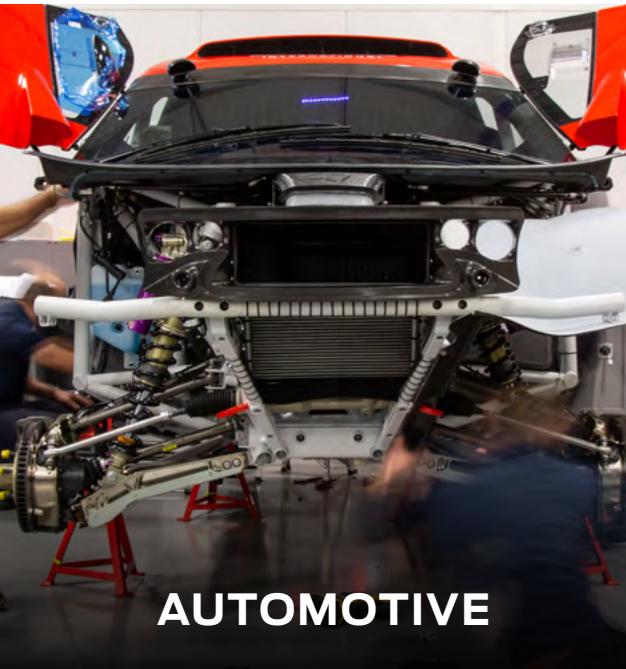
TIP:

There will always be some trial-and-error when it comes to this and students will find that there will be other variables that can affect their printed model's intended purpose - beginning to account for overhangs, bridges and tolerances will start them on a fast path towards reaching their prototyping and design goals.

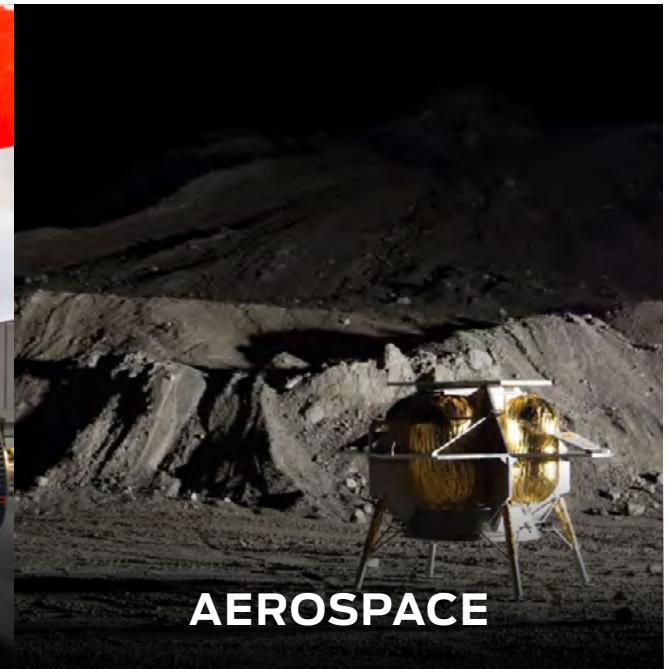
CHAPTER SIX

3D PRINTING BEYOND THE CLASSROOM

At a glance, we know 3D printing is playing an increasingly important role in robotics, automation, supply chain management, automotive production, product design and development, prototyping and so much more. The ability to design, test, iterate and produce parts on demand and earlier in the production cycle have enabled businesses to become more agile and innovative. See how 3D printing is impacting industries today and learn how their applications can be applied in the classroom.



AUTOMOTIVE



AEROSPACE



ROBOTICS

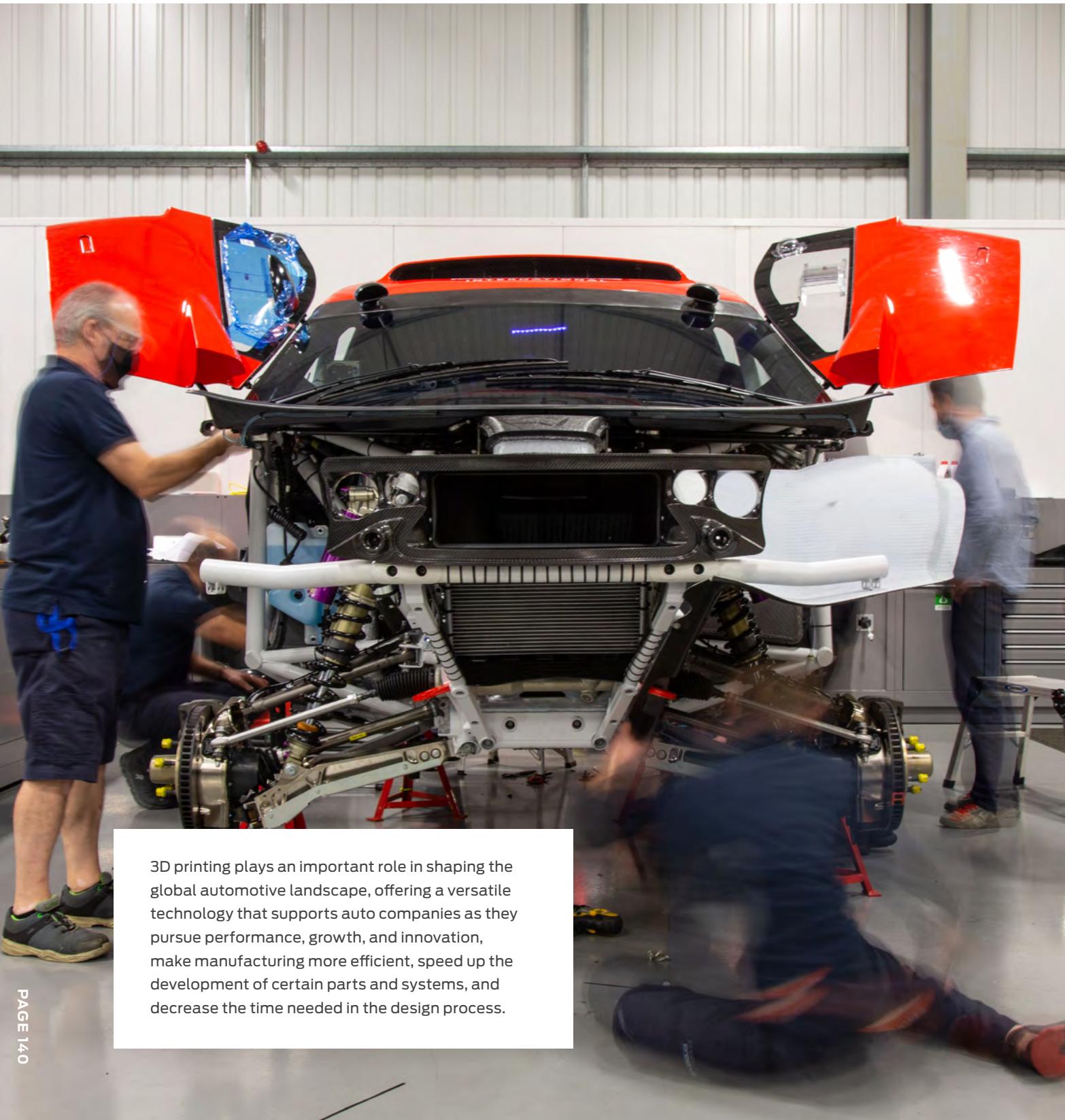


PRODUCT DESIGN

SECTION 6.1

AUTOMOTIVE

Driving Evolution Forward in Automotive Design and Engineering



3D printing plays an important role in shaping the global automotive landscape, offering a versatile technology that supports auto companies as they pursue performance, growth, and innovation, make manufacturing more efficient, speed up the development of certain parts and systems, and decrease the time needed in the design process.

PAGE 140

CASE STUDY

Dakar Rally 2021

3D Printing from the Workshop Floor to the Open Desert



Bahrain Raid Xtreme (BRX), a new rally racing team, took on the famous 2021 Dakar Rally - a grueling 12-day, 4,751 mile-long race in the deserts of Saudi Arabia.

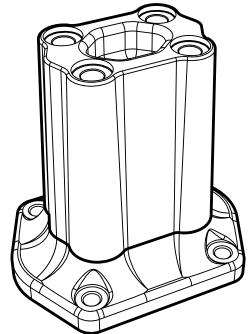
With the help of two MakerBot METHOD X® 3D printers in their production facility and aboard their desert support truck, the veteran team of drivers and engineers printed over 30+ carbon fiber car parts on the brand new Hunter T1, helping them achieve the highest finish ever by a newcomer!



BENEFITS FROM 3D PRINTING:

With METHOD X at their fingertips, the BRX team:

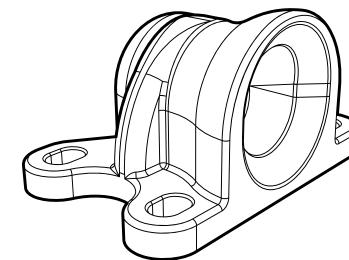
- Prototyped and printed much-needed end-use parts on-site, quickly and conveniently
- Experimented with different applications, on and off the course
- Streamlined prototyping and part production while saving on production time and costs

WHAT THEY PRINTED**Sprinkler System**

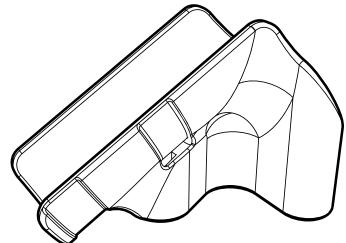
With an extremely hot turbo engine, 500 liter fuel tank, and other highly flammable materials, fire suppression is critical. Using MakerBot® Nylon 12 Carbon Fiber, the BRX team printed a lightweight nozzle mount for the car's fire suppression system.



Materials NYLON 12 Carbon Fiber
Supports SR-30
Print Time 11h 19m

Tailgate Socket

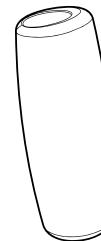
Materials NYLON 12 Carbon Fiber
Print Time 5h 41m

**Suspension Bracket**

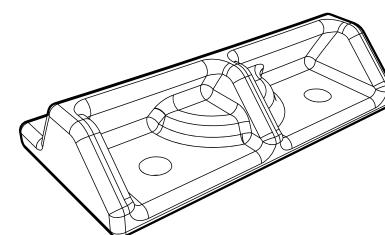
The suspension bracket for the position sensor allowed engineers to look at damper performance, vehicle dynamics, wheel alignment, drive shaft, and more. The sensor generates data and relays information back to the team for better analysis, which can then be used to improve vehicle performance.



Materials NYLON 12 Carbon Fiber
Print Time 3h 40m

Handbrake Lever

Materials NYLON 12 Carbon Fiber
Print Time 3h 40m

**Windstop Bracket**

Materials NYLON 12 Carbon Fiber
Print Time 2h 27m



SECTION 6.2

AEROSPACE

Advancing Innovation in the Aerospace Industry



3D printing has helped to transform the aerospace industry and advance innovation across various segments, from commercial and military aircrafts to innumerable research, space and infrastructure applications. From small scale, low volume production to fabricating tooling and manufacturing aids, 3D printing is enabling aerospace companies to become more agile, efficient, and inventive.

CASE STUDY

Triton Space Technologies

Landing on the Moon with the help of 3D Printed Rocket Engines



Triton Space Technologies, a engineering design and manufacturing company that specializes in producing rocket propulsion systems, contract engineering and bespoke manufacturing services, was commissioned to build rocket ship valves for a customer, who was scheduled for a mission to the moon in 2021.

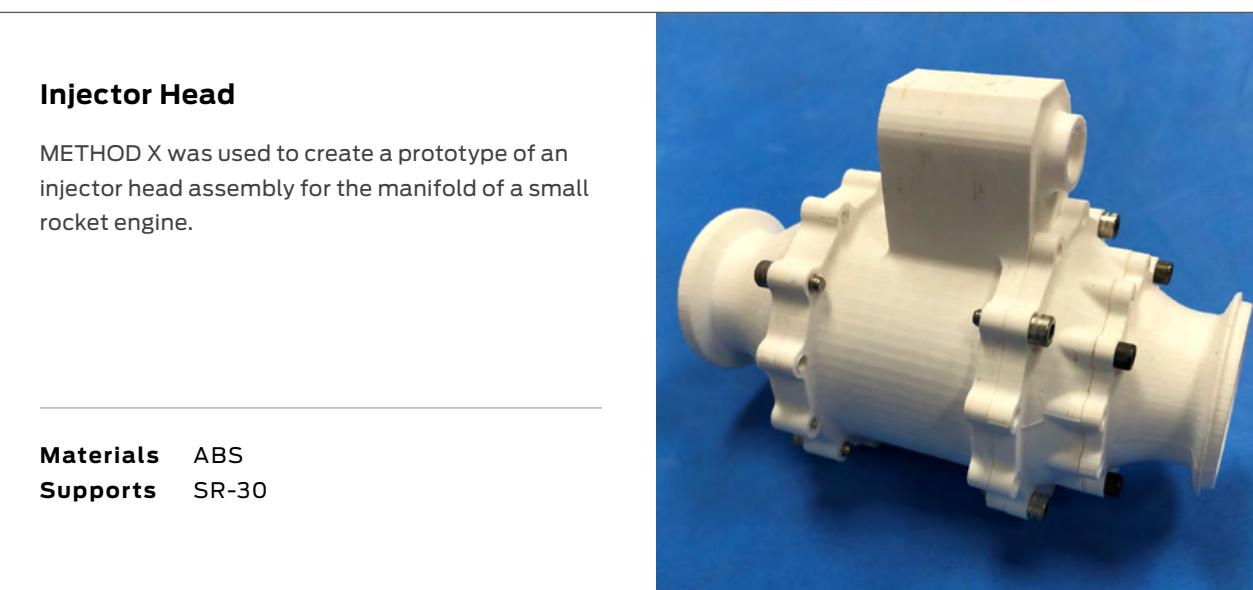
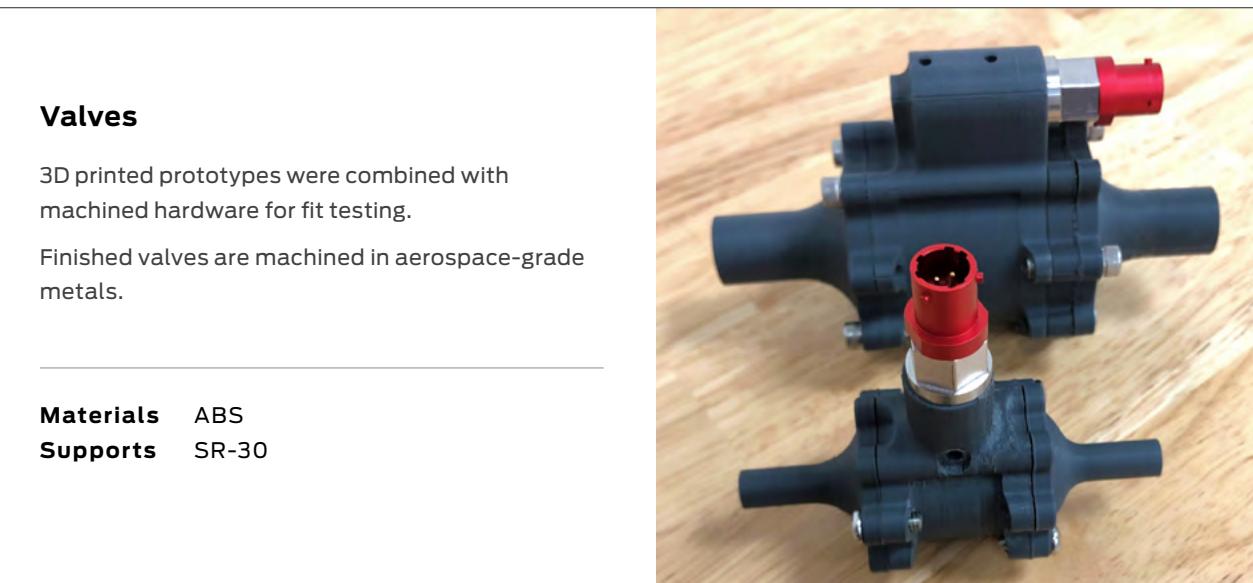
Using the METHOD X 3D printer, the company produced functional prototypes of the valves, taking advantage of the printer's industrial features to achieve dimensionally-accurate parts and ensure that the parts fitted correctly and moved as they were meant to.

BENEFITS FROM 3D PRINTING:



Using METHOD X, the team at Triton Space Technologies:

- Created sophisticated parts capable of meeting the diverse needs of customers
- Improved print quality and expedited design process, which enabled faster fulfillment
- Significantly reduced costs, materials waste, and turnaround time from days to hours
- Leveraged soluble supports to produce functional prototypes with intricate geometries and tight tolerances required for the demanding aerospace industry

WHAT THEY PRINTED:

SECTION 6.3

ROBOTICS

Powering the Future of Manufacturing



CASE STUDY

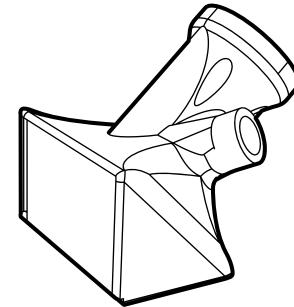
All Axis Robotics

Automating the Future of
Manufacturing through Robotics

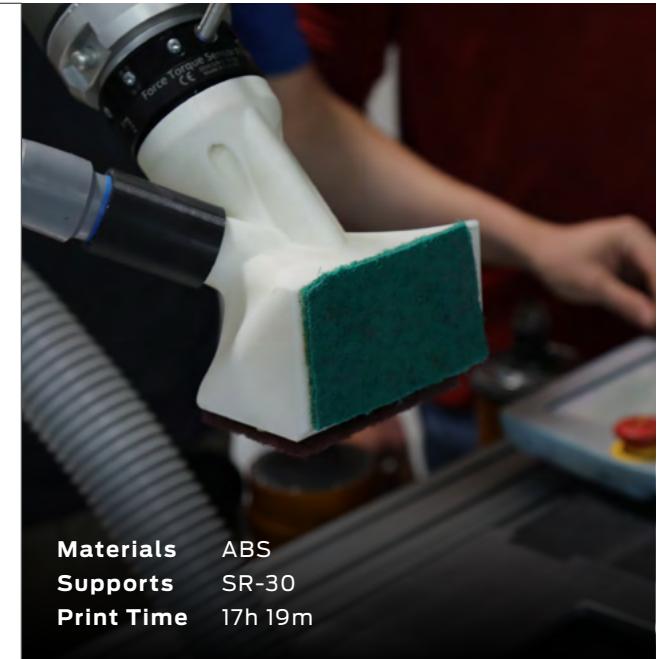


WHAT THEY PRINTED

Sander



The robot sander automates the time-consuming manual aluminum sanding operation, helping a machine shop to run more efficiently by freeing up personnel for other tasks. The robot sander features two angled sides with specific grit sand pads as well as a connection for a vacuum to remove debris.



Materials ABS
Supports SR-30
Print Time 17h 19m

All Axis Robotics, a machine shop and provider of turnkey custom robot solutions, helps other machine shops and manufacturing facilities eliminate pain points typical in traditional manufacturing processes. One of those pain points is the automated process of loading and unloading raw materials or parts in a machine through the use of robotics.

The engineering team at All Axis used the METHOD X 3D printer to produce custom tooling parts for their robots' end-effector designs, reducing lead times and costs for custom parts. This ability to create bespoke solutions for customers - combined with rapid turnaround times - has helped All Axis gain a competitive advantage and enabled them to meet the increasing demands of industry 4.0 and the modern global marketplace.



BENEFITS FROM 3D PRINTING:

- By printing much-needed production-grade parts in-house with METHOD, the All Axis engineers were able to:
- 3D model parts quickly without having to account for complex assembly considerations
 - Eliminate inefficiencies typical with traditional manufacturing
 - Reduce costs on expensive materials and improve turnaround time
 - Generate a new revenue stream by creating a whole new product line of 3D-printed parts for customers

SECTION 6.4

PRODUCT DESIGN

Streamlining Product Design and Development



Product development has never been easier. 3D printing allows teams to be uninhibited in their design, testing and iteration processes. With rapid prototyping, teams can get instant feedback with every new design and make changes immediately - shortening production cycles, accelerating time to market, and increasing innovation.

CASE STUDY

Pensa

Accelerating Product Design and Innovation

PENSA!



PENSA, an industrial design and invention consulting firm based, used METHOD to streamline its product design and development processes while reducing overall production time and costs.

Since integrating 3D printing into their daily design process, the product development teams at PENSA were able to test ideas early and often to accelerate design iteration cycles and make quicker decisions. At the same time, they utilized 3D printing for a wide range of applications, including fixtures, end-use parts, form studies, volume studies, and functional testing.

BENEFITS FROM 3D PRINTING:

PENSA designers utilized METHOD to:

- Accelerate the design, testing, and iteration cycles to check for functionality, ergonomics, and mechanics of their products
- Showcase fine and detailed features and produce accurate geometries required for precision fits
- Meet PENSA's high standards for product development and deliver top notch products

WHAT THEY PRINTED

One Blade Razor

Tasked with creating and designing a luxury razor, PENSA used 3D printing to meet its design needs and accelerate the design process. To create the One Blade Razor, the team needed to better understand different aspects of the razor, from form to function. The team asked exploratory questions, such as, 'How will the razor be held?', 'Does the razor feel balanced in one's hand?', 'Does the angle at which the razor is placed have the desired effect?'. As a result, the team was able to iterate on its design through rapid prototyping in order to achieve the final product.



Materials Tough PLA
Supports PVA

THANK YOU

Thank you for letting us be a part of your 3D printing journey - this would not have been possible without Educators like you lighting up the path for innovation. We hope this book has served as a proper guide to bringing 3D printing into the classroom and that you've come away with ideas and techniques that can be implemented in your classroom.

You can find more of our resources on makerbot.com/resources. We look forward to growing with you and seeing how you and your students continue to redefine the possibilities with 3D printing in the classroom.

Happy Printing!

CONTACT US

SUPPORT

If you have any questions or issues with your printer or the quality of your prints, please visit support.makerbot.com to learn more about troubleshooting or to open a case with our support experts.

MAKERBOT EDUCATION

If you want to share your 3D printing journey with us or highlight how your students are using 3D printing, reach out to us as education@makerbot.com

SALES

Have a question about purchasing? Contact sales@makerbot.com

ACKNOWLEDGEMENTS

AUTHORS

Andrea Zermeño
Beverly Owens

DESIGNERS

Yanz Zeng
Felipe Castañeda

SPECIAL THANKS

Bennie Sham	Ojembo Tafawa
Pooja Hoffman	Jon Benskin
Ramon Cruz	

LEGAL

MakerBot Educators Guidebook is an official product of MakerBot Industries, LLC and is not authorized, sponsored, associated with, or otherwise associated with any of the other parties listed in this Legal section or otherwise mentioned in this book.

TRADEMARKS

The MakerBot "M" logo, MakerBot, MakerBot Certification, MakerBot CloudPrint, MakerBot Education, MakerBot METHOD, MakerBot METHOD X, MakerBot SKETCH, MakerBot SKETCH Classroom, MakerBot Replicator, Thingiverse, and Tough are trademarks or registered trademarks of MakerBot Industries, LLC. All rights reserved.

Apple and App Store are trademarks of Apple Inc., registered in the U.S. and other countries and regions.

Autodesk, the Autodesk logo, Fusion 360, the Fusion 360 logo, Maya, the Maya logo, Meshmixer, the Meshmixer logo, Mudbox, the Mudbox logo, Tinkercad, the Tinkercad logo, 3ds Max, and the 3ds Max logo are trademarks or registered trademarks of Autodesk, Inc., and/or its subsidiaries and/or affiliates in the USA and/or other countries.

Blender and the Blender logo are trademarks or registered trademarks of the Blender Foundation.

Solidworks and the Solidworks logo are trademarks or registered trademarks of Dassault Systèmes SolidWorks Corporation.

Qlone is a registered trademark of EyeCue Vision Technologies LTD.

Google Classroom and Google Play are trademarks or registered trademarks of Google Inc.

Onshape and the Onshape logo are trademarks or registered trademarks of Onshape Inc.

Sculptris, ZBrush, the ZBrush logo, ZBrushCoreMini, and the ZBrushCoreMini logo are trademarks or registered trademarks of Pixologic, Inc.

SculptGL and the SculptGL logo are trademarks or registered trademarks of Stéphane GINIER

Wings 3D and the Wings 3D logo are trademark or registered trademarks of Wings 3D.

All other brand names, product names or trademarks belong to their respective holders. All rights reserved.

SCREENSHOTS

Tinkercad™ and Fusion 360™ software screenshots reprinted courtesy of Autodesk, Inc.

vectorizer.io software screenshots reprinted courtesy of Andre Massow.

All other screenshots belong to their respective holders.

