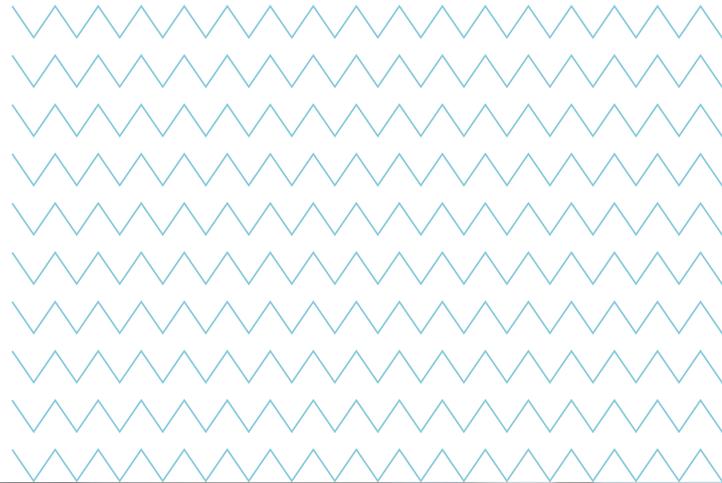




Ultimaker white paper

Getting started with 3D printing in the classroom



Ultimaker

Academic Representative



Technology Education Concepts

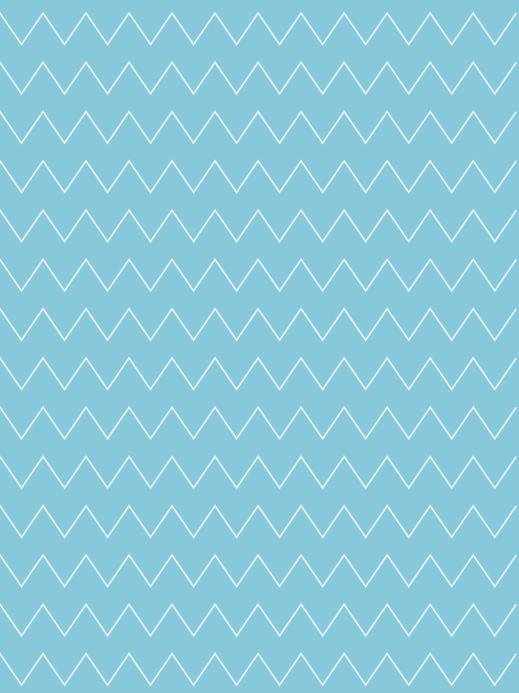
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Getting started with 3D printing in the classroom



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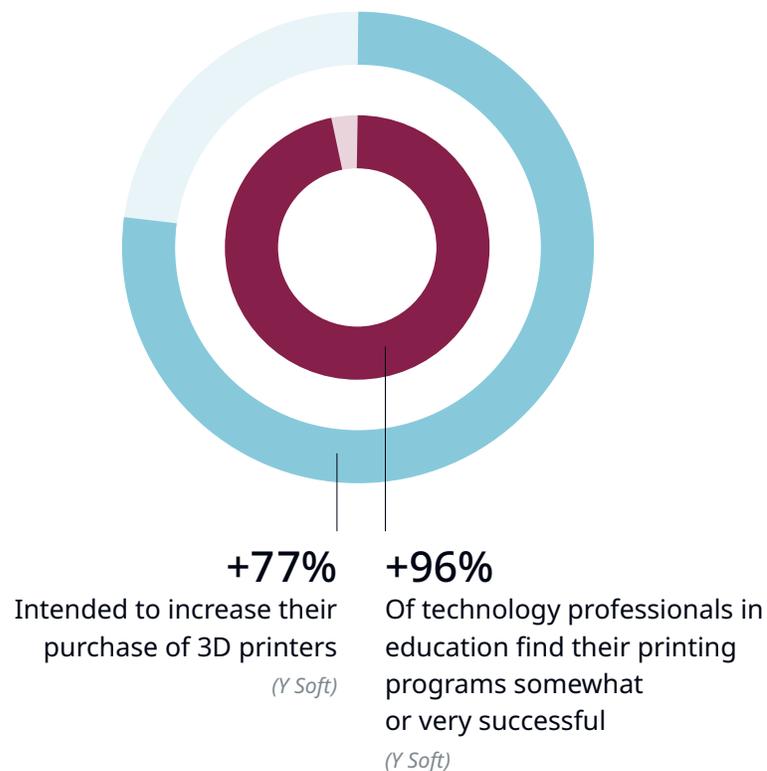
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Introduction

3D printing has become a powerful tool for educators looking for innovative technologies to incorporate into their curricula. Not only does 3D printing provide greater opportunities for learning in science, technology, engineering, art, and mathematics (STEAM) by sparking engagement and encouraging creative thinking, but also it serves as a way for teachers to prepare their students for the future.

It's a trend on the rise: [Y Soft](#), a software company which offers 3D printing management solutions in academia, found that more than 77% of educators plan to increase their purchase of 3D printers in order to meet the needs of additive manufacturing in STEAM, while 96% of technology professionals in education are finding success in their established 3D printing programs.

Developments and trends in 3D printing



Source: [Developments and trends in 3D printing](#)

The ability to incorporate 3D printing early in their academic careers will provide learners with the skills they need to master design, prototyping, testing, and product development in disciplines that are quickly adopting additive manufacturing.

In addition to career preparedness, the immediate benefits of 3D printing in the classroom include:

- Enhanced engagement through hands-on activities
- Critical and creative thinking skills through solving design challenges
- Collaborative problem solving through participating in team-based projects

Additive manufacturing in the classroom incorporates more than just the ins and outs of how 3D printers work; it invites students to explore every aspect of designing on paper, designing or modeling with 3D software, and preparing their files for 3D printing. From working through design concepts to product development and engineering, the critical-thinking skills students develop by working with 3D printing early on will remain with them throughout their education and beyond.

Once you've decided to take the next steps and purchase a 3D printer for your classroom, where do you start?



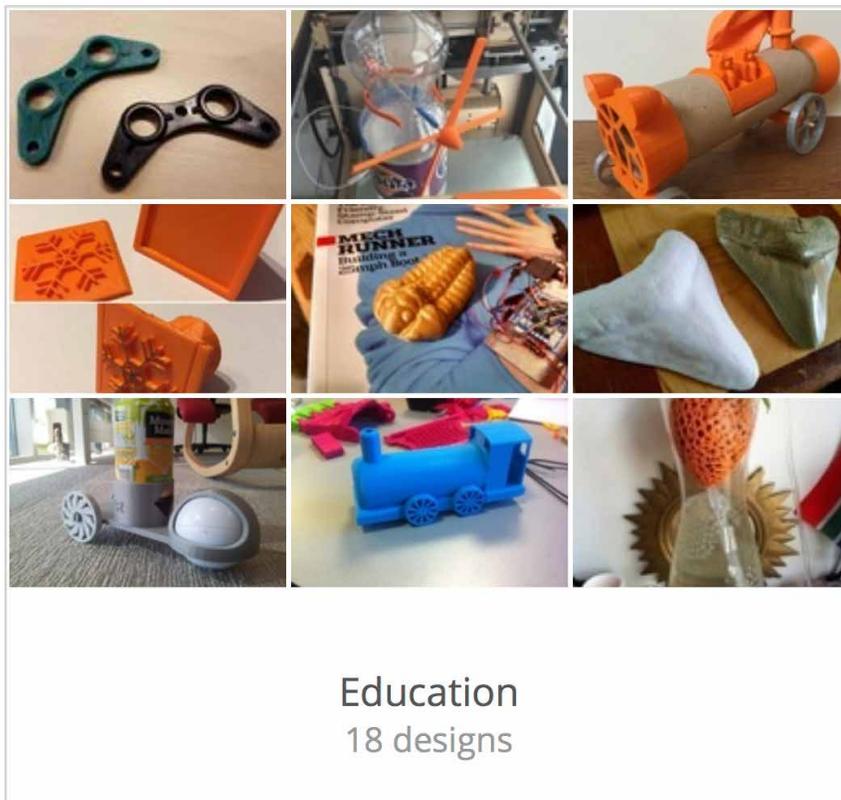
Downloading files for classroom projects

There is an abundance of online resources for files that will work with 3D printers.

[Ultimaker 3D printers](#), for example, support the following file types:

- STL
- OBJ
- 3MF
- X3D

Once you've determined the file type you need, a quick internet search will bring up options you can download for free, and others you can purchase. Websites like [YouMagine](#) offer thousands of open-source designs for download, many of which are grouped into [Collections](#) that make it easier to find similar 3D prints for each project.



Source: [YouMagine](#)

As with any new technology, practice makes perfect. Begin experimenting with tools you can use to keep your 3D printer properly calibrated, or try printing a basic puzzle you can use to introduce your students to the concept of 3D printing - while also challenging their problem-solving abilities. For younger learners, consider starting off with a series of fun games and exercises you can easily create with your 3D printer:

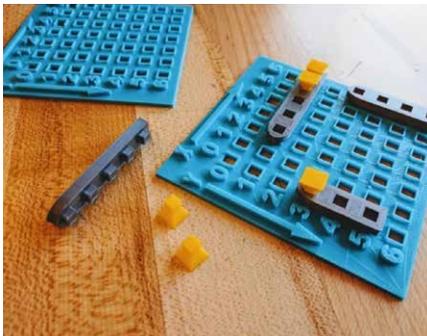
Challenge older students with 3D printing projects by asking them to design tools, jigs, and fixtures to teach them about engineering and manufacturing. Or delve into complex models like rockets, historical buildings, and math art to pique curiosity in various subjects:



[123 Counting Fun for Kids](#)
by Richard Horne



[Sphero Can Holder Vehicle](#)
by Tim van der Vaart



[Computer Coordinates Battleship](#)
by Rob Morrill



[Model Rocket](#)
by Inholland University



[Solar System](#)
by Ultimaker



[Loobius](#)
by James Wood

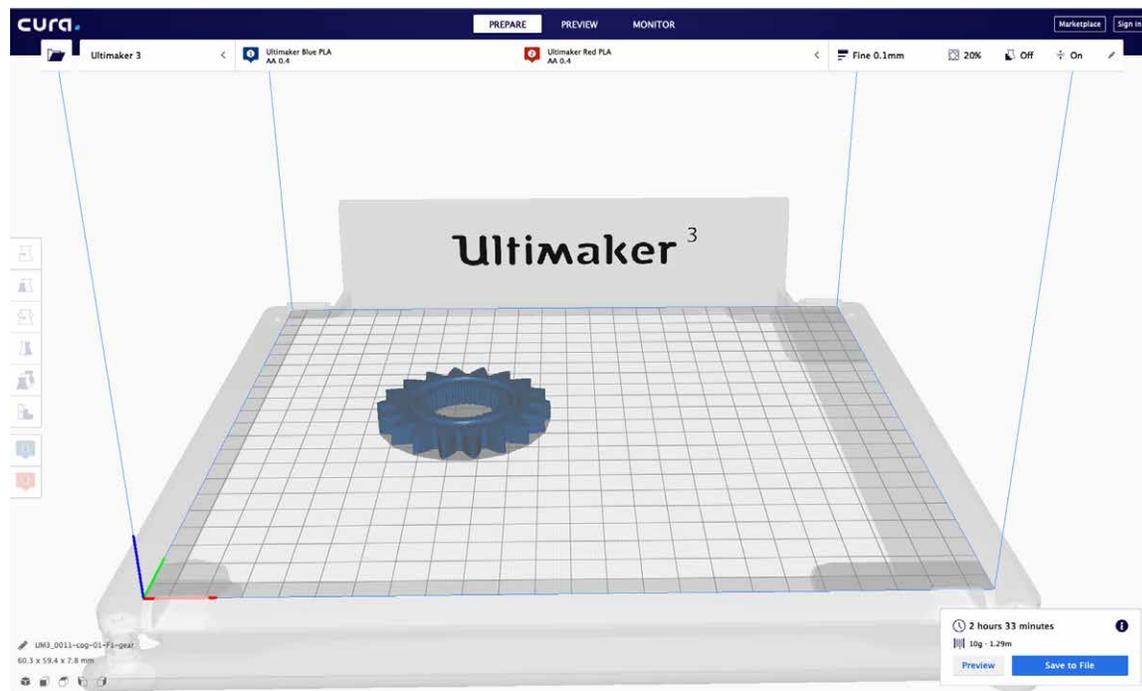
Deciding on material needs

Before you can begin printing, you will need to load filament into your 3D printer. Ultimaker printers either have single or dual extrusion capabilities; the [Ultimaker 3](#) family and the [Ultimaker S5](#) both offer dual extrusion, so you have the option to load two materials into the these printers.

Most classroom projects work well with PLA – the most popular material for schools – as the material properties make it is less likely to warp if printed while proper cooling is applied. If you have a dual extrusion printer like the Ultimaker 3 or the Ultimaker S5, you can also utilize support materials like PVA or Breakaway. A single extrusion printer like the [Ultimaker 2+](#) has the ability to create PLA supports for complex models and overhangs.

Material needs per semester

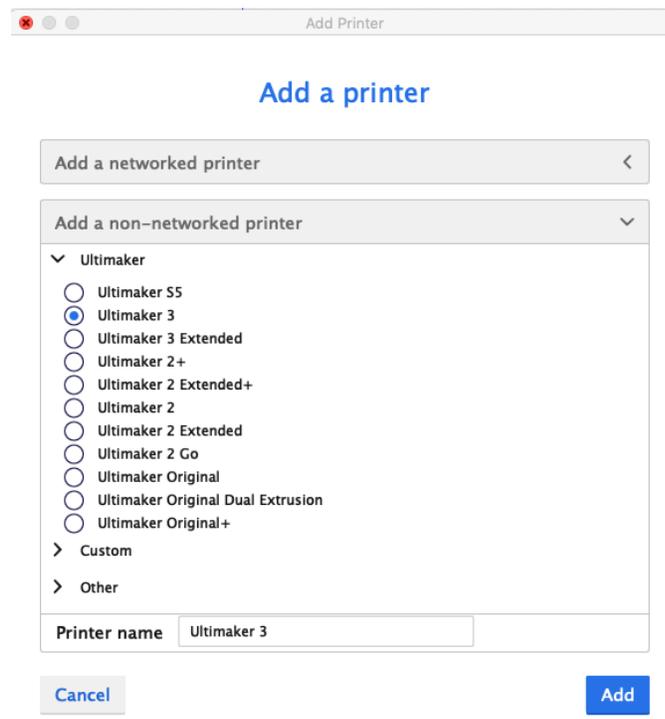
When purchasing filament for a semester, it is important to take into consideration the scope of your planned 3D printing projects. PLA is a great choice for primary and secondary schools, as it is safe to use and easy to print with – and a full spool lasts quite a while. Ultimaker PLA, for example, comes in 750-gram spools and will last through numerous small print jobs. If you plan on group projects with just one or two printers, then you may only need two or three spools of PLA per semester.



Some slicing softwares, like [Ultimaker Cura](#), have the ability to calculate how much filament you will need per printing project. Simply load the file into Ultimaker Cura, adjust the settings, and read the output on the bottom-right section of the window. For example, the [Loobius](#) model by James Wood scaled up 350% in size and using supports would only require about two grams of filament on the Ultimaker 2+ and the Ultimaker 3.

Preparing your prints in a slicing software

Once you've chosen your 3D prints, preparing it for printing is a breeze. You should first ensure that you have properly set up your printing profiles in the slicing software. If you choose to use [Ultimaker Cura](#), you can take advantage of the default profiles already in place to ensure a seamless process.



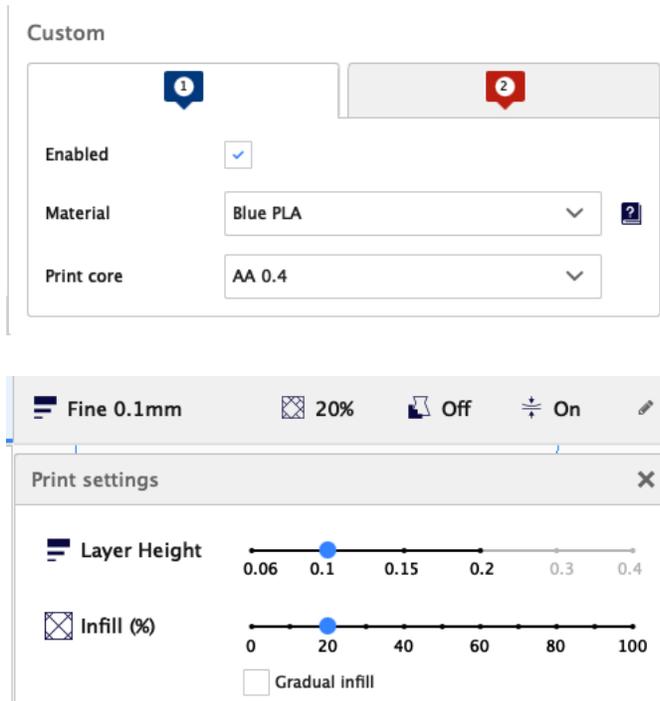
Once Ultimaker Cura is installed onto your computer, you will be asked to select the 3D printer that you have set up in your classroom. You can select from the list of Ultimaker printers, choose a Custom FFF printer, or add another manufacturer from the Other list.

For the Ultimaker Original+ and the Ultimaker Original, you will be guided through a configuration wizard to help you correctly calibrate your printer. During setup, you can give your printer a unique name, which is helpful if you have more than one in your classroom or workspace.

To load a model that you have downloaded from the Internet, simply click on the 'Open File' icon in the top-left corner of the screen, select the model you want to prepare, and open it. It is also possible to click, drag, and release a model onto the build platform in Ultimaker Cura.

Selecting a profile in Ultimaker Cura

Once your model is loaded, you can select the settings you would like to use for your 3D print. The Prepare tab on the top of the Ultimaker Cura interface has information about the Print Job configuration, where you can select your printer, nozzle size, and material. To the right of this, you will find the print settings panel, where you can choose either Recommended or Custom mode.



Available default profiles in Custom mode depend on the material and configuration, and may include:

- Normal quality (0.15 mm layer height): This prints quickly while retaining acceptable quality
- Fine quality (0.1 mm layer height): This creates a good quality print with an acceptable print time, and works for most models
- Extra-fine quality (0.06 mm layer height): This prints with a very smooth surface finish

Select your profile in Custom, or adjust the settings in Recommended. Recommended mode is ideal for beginners, but once you are comfortable with the slicing process you can use Custom mode to modify your settings. Doing so will allow you to change the infill to adjust the density of the print, enable support for complex structures and overhangs, and add a build plate adhesion strategy, such as a brim or skirt, to ensure that the print does not detach from the build plate.

Once Ultimaker Cura has sliced your model, you can Save to File on a USB stick or SD card depending on your printer's capabilities, or send the file directly to your printer over a network connection.

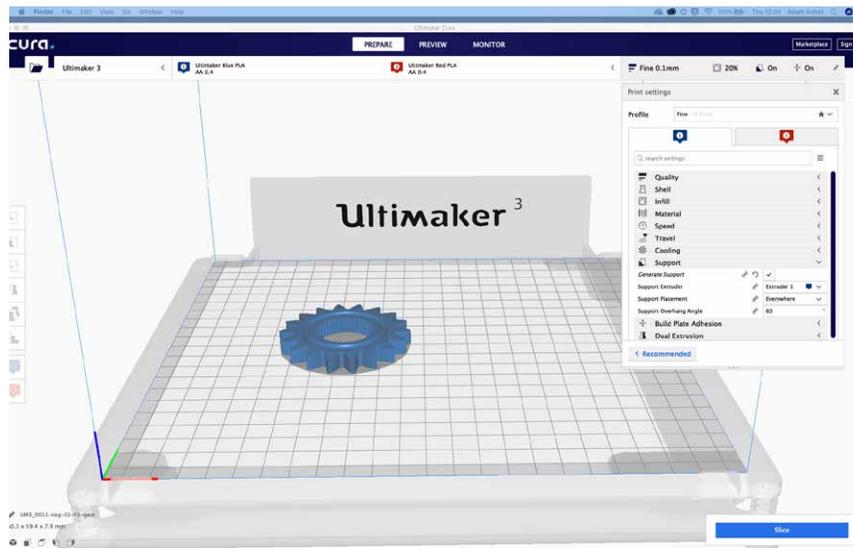
Working with custom profiles in Ultimaker Cura

Some slicing softwares, like Ultimaker Cura, allow you to select custom profiles that offer more settings. When you're comfortable with your slicing software, you can delve into these tools with your students to explore the many available options for creating a customized slicing profile.

Keep in mind that based on the selected printer, nozzle size, and material, Ultimaker Cura will automatically update each profile with the recommended settings. Not all profiles are visible for each nozzle size, and certain nozzles will not work with certain settings.

When you are ready to adjust the settings in Ultimaker Cura, you will find the Custom mode of Print Settings is divided into categories to make navigation easier. The available categories include:

- **Quality:** Settings that define the (visual) quality of the print
- **Shell:** Settings related to the outside of the print
- **Infill:** All settings that have to do with the inside of the print
- **Material:** Material-related settings
- **Speed:** Speeds at which the print head moves while printing
- **Travel:** How the print head behaves during travel
- **Cooling:** Settings that define how the plastic is cooled
- **Support:** Options for printing with support structures
- **Build plate adhesion:** Defines the adhesion of your model to the build plate



- **Dual extrusion:** Options for printing with two print heads
- **Mesh fixes:** Options for fixing faults in models
- **Special modes:** Features that influence printing methods
- **Experimental:** Experimental new features

Hover your mouse over each setting and click the gear icon to view further options related to each setting's functionality so you can better understand how to use them, or browse the comprehensive [online manual](#). If you'd like to jump to or search for a specific field, simply find it the filter search area, adjust your setting, then X out to go back to the unfiltered view.

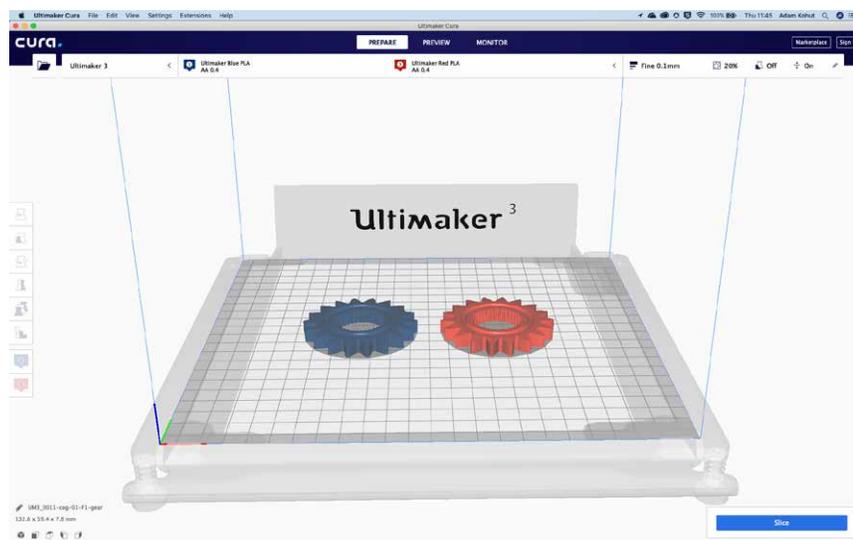
In Ultimaker Cura, you have the ability to easily move, scale, rotate, and mirror models. You can bring multiple models into Ultimaker Cura at the same time, adjusting each model by applying custom settings to enhance quality and speed of each part. Often, you will find these custom settings listed within instructions on the website where you downloaded the files.

Using two different materials

If your 3D printer has multi-extrusion capability, Ultimaker Cura allows you to assign an extruder to specific models on the build plate. Some Ultimaker 3D printers allow you to [print with two colors](#), or with two different materials.

Follow these simple steps to assign extruders:

- Select the desired model on the build plate
- Select the extruder you want to print the model with
- Select the appropriate icon to change colors and indicate which material the model will be printed with; these colors correspond to the loaded materials in the printer settings and the model on the build plate



Using two different filaments is ideal for multicolored prints, and for prints with complex structures and overhangs that require a support material. Note that in order to print a model with two colors, you will need two separate STL files – one for each color.

Support material options

Support material enables you to more easily print models with overhangs and cavities, providing greater design freedom. You can choose water-soluble [Ultimaker PVA](#) or easy-to-remove [Ultimaker Breakaway](#) material. You can also use PLA to create supports when slicing your models to prepare for printing. Allowing your students to decide which support material will work best for their model is a great way to encourage problem solving in the design process.

Designing your own 3D print files

When you're ready to help your students design their own files, there are a variety of free or commercially available software tools you can choose from. What software you choose should depend on the theme of their project, their skill level, the time needed to learn the tools and techniques, and the budget you have in place. Here are some of the many options you can start with:

Name	Description	Difficulty	Cost
Tinkercad	3D design and 3d printing tool	Beginner	Free
Sculptris	A sculpting software that allows users to pinch, push, pull, and twist virtual clay	Beginner	Free
Morphi	An application to make 3D modeling, designing, and printing more accessible and affordable to all ages, skill levels, and educational backgrounds	Beginner	Free
SketchUp	3D modeling computer program for a wide range of drawing applications such as architectural, interior design, civil and mechanical engineering, film, and video game design	Beginner	Free
FreeCAD	FreeCAD is an open-source parametric 3D modeler made primarily to design real-life objects of any size	Beginner	Free
Autodesk Inventor	Inventor® 3D CAD software offers professional-grade 3D mechanical design, documentation, and product simulation tools	Intermediate	Free for education
PTC Creo	Creo offers a range of 3D CAD product development packages and tools that help engineers imagine, design, and create products	Intermediate	\$
Onshape	Primarily focused on mechanical CAD (MCAD), Onshape is a collaborate software that facilitates product design across a variety of industries	Intermediate	Free for education
Autodesk Fusion 360	Autodesk® Fusion 360™ allows you to create toolpaths, perform simulations, and iterate design ideas with sculpting tools	Intermediate	Free for education
Blender	Blender supports an array of 3D features, from modeling to rigging, animation, simulation, rendering, and compositing	Intermediate to Professional	Free
Solidworks	Solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program	Professional	\$
Rhino	3D modeler used to create, edit, and model designs ready for manufacturing	Professional	\$

For even more options, you can [browse a list](#) of software applications used by [Ultimaker Pioneers](#) and their students. You can also use [mesh fixes](#) in Ultimaker Cura to fix errors in models that are not correctly designed for 3D printing.

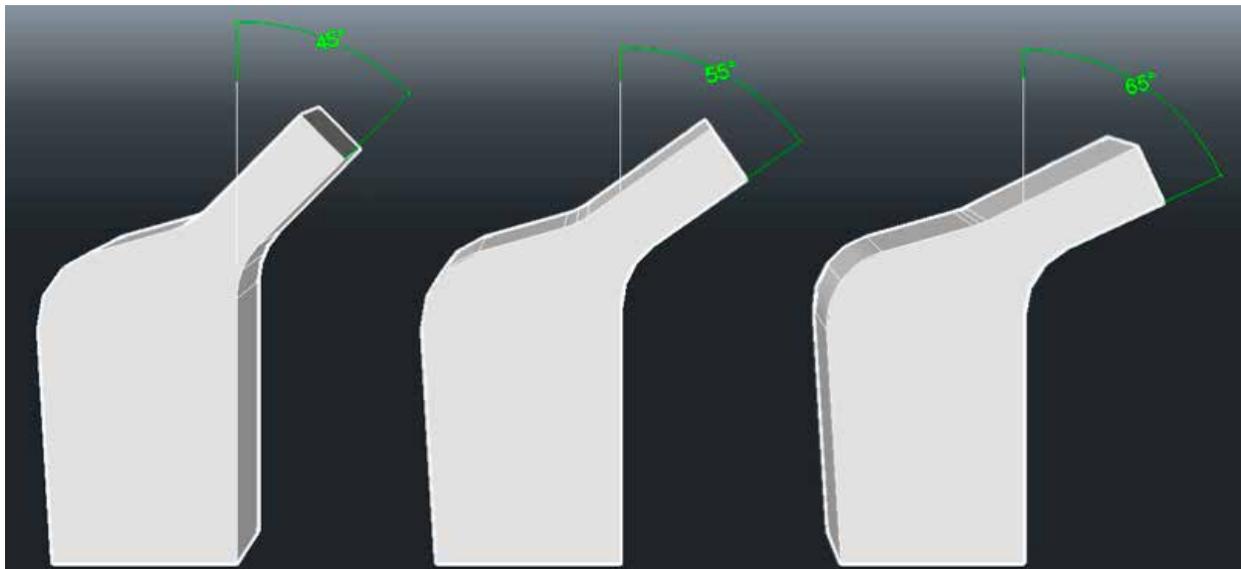
Tips for printability

When you and your students begin the design process, there are a few key factors to keep in mind for printability. Consider model orientation to ensure models lay flat on the build plate or that they are supported by material. You also want to check the following:

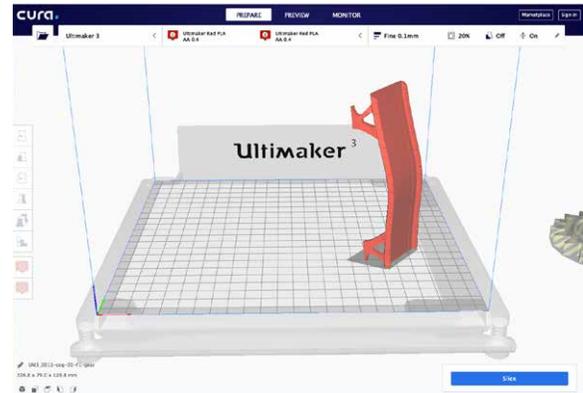
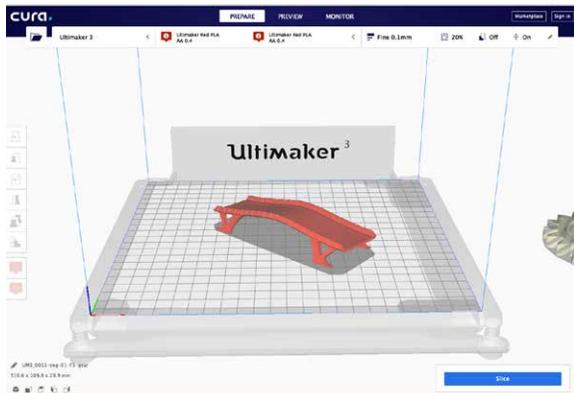
Build volume: Your model must fit within your printer's build volume, so you may need to scale it down before printing. Ultimaker Cura will not allow you to slice a model if it exceeds the build volume size, but you can easily resize the model before proceeding.

Wall thickness: There is a constraint to how thin walls can be in a model to ensure a successful print. The Line Width is set in your slicing software and is determined by the size of your nozzle. Single pass printing with a .4 nozzle produces a lightweight print with walls that might buckle, so design your models with .8 mm to 1.2 mm walls if you are using a .4 mm nozzle. To enhance strength and quality in your design, double the minimum wall thickness under the Shell settings in Ultimaker Cura.

Overhang: When designing a model with an unsupported 90° overhang, the maximum overhang length that you can print without support is 1-2 mm. You can print models that lack support with overhang angles up to 55° using PLA and cooling fans. To maintain quality, keep unsupported overhang angles under 45° when designing.



Bridging: Using lower temperatures, better cooling, and increasing retraction settings will prevent stringy 3D prints that could make bridges look messy. Generally, the shorter a bridge's length, the greater the chance it will succeed structurally. You can increase the odds of a bridge's success by slightly altering its shape and creating arches. You can also make difficult bridging situations print more successfully by slightly altering the shape of the bridge to create arches.



Bridges are shorter and easier to print on a rotated model

Embossing and engraving: When adding embossed details, 0.5 mm is universally readable from a distance, while 0.2 mm is visible when closely examined. Engraved details are similar, although they are more likely to cause fluctuations in the model wall when the print speed is too high. Additionally, embossed and engraved text is clearer when printed on the Z axis.

Minimum allowance: If you want to join parts together, you can do so through press, force, or interference fit. Generally, you'll want to allow for a 0.2 mm offset from the interior structure when using friction. If you would like the parts to slide together or fit freely, the minimum allowance for a moving or rotating part is 0.4 mm on each side when using a standard 0.4 mm nozzle.



Press fit with chamfered edges



Press fit



Sliding fit

Minimum hole diameter: Although dependent on your material and settings, it is safe to assume that the diameters of the holes in your 3D models should be at least the value of your Line Width setting.

Test your printer and the settings to determine tolerances for your prints, as each 3D printer is slightly different.

Helpful tools for printing

When you begin 3D printing in the classroom, make sure that you have all of the tools you might need to start and post-process your prints. Some of the extras include:



Spatula: Spatulas, like those from BuildTak, are designed specifically for 3D printing with durable non-slip handles and rigid stainless steel blades. A sturdy spatula will help you separate your 3D prints from the build platform.



Glue sticks: Apply glue sticks onto the build plate before printing to help with bed adhesion, or use a Magigoo Pen.



Superglue: Use superglue to repair models, fill gaps, or combine parts.



Desiccant: Silica is helpful when storing material to prevent absorption of water, so consider keeping your filament in a sealed plastic bag with a pack of silica gel.



Deburring tool: This tool can be used to clean out modeled holes and remove small amounts of plastic from your 3D printed parts.



Digital caliper: This precision measuring tool is necessary for accurate measuring and modeling of 3D prints.



Hot-air heat gun: Hot-air heat guns are helpful for thermoforming models, and when troubleshooting a flooded hot end.



Needle-nose pliers: Pliers and other precision tools are ideal for removing supports, especially long and thin needle-nose pliers that allow you to reach into small areas. Wire-cutters are also helpful when removing supports.

Ready to print? Use this checklist

- Did you start with default settings? If not, why?
- Does your model have a flat surface to place on the platform?
- Did you place your model flat on the platform?
- Does your model need support material?
- If using support, did you select Touching Build Plate or Everywhere in Custom mode?
- Are you slicing for the right machine?
- Did you slice for the right nozzle diameter?
- Did you specify the layer height appropriately?
- Did you specify the wall thickness and line count?
- Did you specify an appropriate infill density?
- Did you name your file to associate your model with the right project?
- Is the build plate free of debris and material from previous prints?
- Do you have enough filament?
- Is the type of filament you want loaded on the printer?
- Do you have enough time to complete the print?
- Once you start the print, are the first few layers printing as they should?

Find a comprehensive checklist [here on the Ultimaker website](#).



Lesson plans to get you started

Whether you teach primary or secondary education, or work in an informal learning environment, integrating 3D printing into your teaching practice will help you:

- Support personal student exploration in the pursuit of a learning objective
- Incorporate design-thinking techniques
- Build cooperative learning opportunities
- Build resiliency by taking advantage of rapid prototyping and testing techniques
- Develop communication skills through continuous documentation and sharing

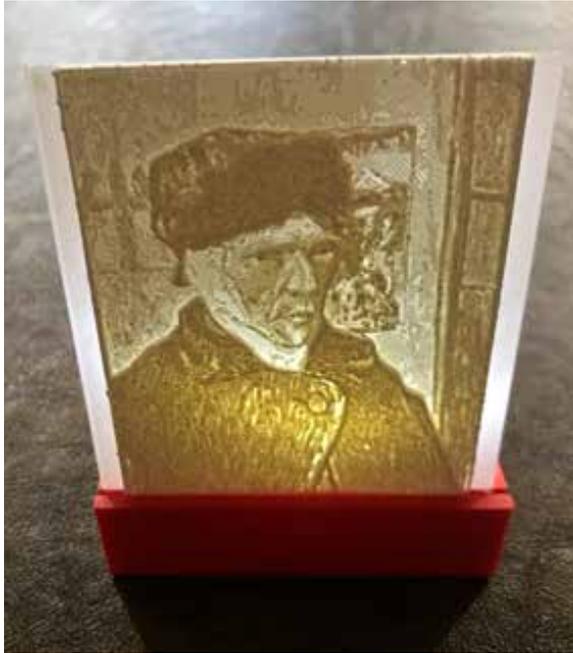


The Ultimaker Met Set

The Metropolitan Museum of Art in New York City has been a source of inspiration for artists since 1870. Now, you can incorporate that creativity into your own 3D printing program to meet the above objectives. Within the Ultimaker Met Set is a series of sample lesson plans that will help you leverage this transformative technology in your classroom. Following are three projects to get you started.

Lesson 1: Art history lithophane night light

Explore 3D printing technology as a means for illuminating aspects of art history, referencing a number of works from the Met's collection and guiding your students to create art history lithophane night lights.



Project objectives:

- Research topic: artist, movement, work of art
- Produce a digital model
- Prepare a model for 3D printing
- Create presentation

Recommended age range: 12+

Difficulty: Beginner

Software: Ultimaker Cura, Photoshop, and Fusion 360

Lesson Duration: Time for research, file preparation, printing, and presenting

A traditional lithophane is an etched or molded artwork in very thin, translucent porcelain that can only be seen clearly when backlit with a light source.

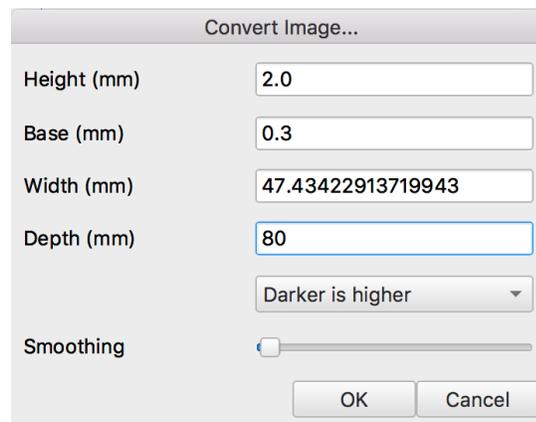
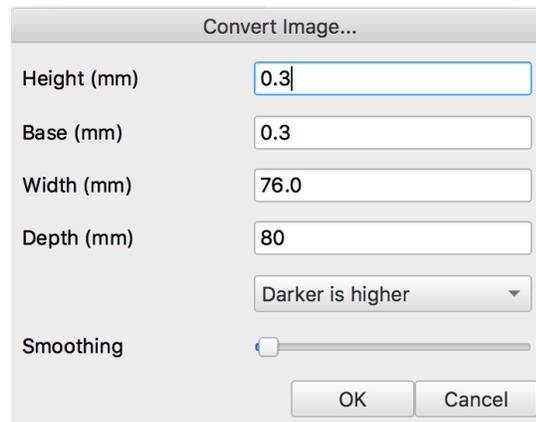
By converting an image to heightmap, in which your whites are transparent and your blacks are opaque, you can obtain a similar effect using a 3D printer. There are several ways to create these heightmaps, but you can easily do so by dragging an image (JPG or PNG) onto the build platform in Ultimaker Cura. The software will ask you for parameters, but will essentially convert your darkest areas to more layers.

Creating the Lithophane

1. Find an image to work with. If using the Met's online collection, you should use an image in the [Public Domain](#).
2. You need to establish a base depth for your panel. We recommend a minimum of 80 mm.
3. Open your image in Photoshop and change the height to 80 pixels. Make a note of the width. Cancel the operation.
4. Create a new blank Photoshop document. Add a white background. Add 9 mm to your width. Set the height of your Photoshop document to 80. Save as a PNG or a JPG.
5. Open Ultimaker Cura and drop your white PNG on the build platform.

Set the following:

- a. Height to 0.3 mm
 - b. Base to 0.3 mm
 - c. Depth to 80 mm
 - d. Change pull down to "Darker is higher"
 - e. Click OK
6. Now open (add the image to the build plate) your image that pairs with this blank image. Set:
 - a. Height to 2.0 mm
 - b. Base to 0.3 mm
 - c. Depth to 80 mm
 - d. Change pull down to "Darker is higher"
 - e. Click OK
 7. Right click on the lithophane and in the Move panel set the X, Y, and Z to 0
 8. Use white or a light-colored PLA
 9. Set the Profile to Normal
 10. Set Infill Density to 99
 11. Set Build Adhesion Type to Skirt
 12. Print



Creating your box

You can use this [Fusion 360 file](#) to create your box. Simply download the file and upload it, and update your parameters to match your own dimensions. Under Modify, select Change Parameters.

Lesson 2: Design Engine Met challenge

The [Design Engine](#) is a card game that provokes, inspires, and entertains students, educators, 3D designers, artists, and engineers of all experience levels. The cards are used to generate new ideas and projects that fuel a deeper exploration into the use of desktop 3D printing.

The game can be a handy icebreaker or a challenging activity that sparks creativity over a period of time. You can purchase the cards on thegamecrafter.com, download from the [Ultimaker site](#), or [play online](#).



Project objectives:

- Design a new object or system
- Present idea

Recommended age range: 10+

Difficulty: Beginner

Software: User's choice

Lesson Duration: One 45-minute class for developing idea. If prototyping, provide additional time to design and print

With the Design Engine game, students use cards to develop problem-solving skills by facing challenges that change with parameters and modifiers. You can choose to:

- Have students work individually or in teams
- Encourage students to compete head-to-head with others
- Have your students use the set solo to help them come up with projects they can focus on while they learn to use and master software

The three-minute Starter Round is Ultimaker's recommended way to introduce new players to the game. For the starter round, new players focus on delivering design sketches and a description of their idea. In longer rounds, there is time to go through the entire design process (discovery, interpretation, ideation, experimentation, iteration). Students can move beyond the initial inspiration sketches and create digital designs in a CAD program if you choose, then create physical models with the 3D printer.



The Design Engine set contains:

- Over 50 black challenge cards
- Over 60 blue parameter cards
- 20 yellow modifier cards
- 20 red gameplay cards
- 10 green warm-up activities

When playing an unmodified or basic starter round of the game, as soon as the timer starts, players turn over one black card and two parameter cards. They then take into consideration the phrases that are right-side up on their parameter cards to come up with a quick idea for how to solve the challenge. When the timer runs out, players should have:

- A name for their idea
- A one-to-two sentence description
- A rough sketch of their design

Using the Design Engine for the Met challenge

Students can work individually or in pairs.

1. Do your own research to select pieces (just remember to stay with those works that are in the public domain), or use [these pieces](#) that were pre-selected by Ultimaker
2. Ask students to identify one piece that speaks to them
3. Set a timer to 10 minutes and have students create a sketch of their chosen artwork
4. Set a timer to one minute and have students redraw their piece, including only essential details and lines
5. Give each student or pair of students a challenge card and a parameter card from the [Design Engine](#), with the artwork serving as the second parameter
6. Set a timer for three minutes. Have students come up with and share their solutions. You may want to add two minutes to the timer if students are working in pairs
7. Use 3D Design software to create prototypes

Lesson 3: Create a mask

Challenging students to research historical masks and create their own is not only educational, it's also a great way to practice design skills in the software of their choice. Encourage students to think about the style of masks they choose as inspiration and how they relate to history. Are they ceremonial, decorative, or made to be worn?

Note that while there are many masks in collection from the Met, not all of their images are in the Public Domain. Watch for the Open Access icon to choose ones you can use directly in new work, and focus on drawing inspiration only from those that are not Open Access.



Project objectives:

- Research topic
- Design and produce a digital model
- Prepare a model for 3D printing
- Create presentation

Recommended age range: 8+

Difficulty: Intermediate

Software: User's choice

Lesson Duration: Time for research, file preparation, printing, and presenting

Creating the masks

1. Use the Met collection as inspiration
2. Focus on a particular gallery or culture, or create a mashup
3. Work in design software to create your mask
4. Use a 3D printer to produce a tangible model of your design
5. Be prepared to explain where the influence came from and why you selected it

Other lesson ideas and starters

Sharing [lesson ideas](#) and 3D printing starter projects with other educators is a great way to find inspiration. If you're looking for more projects you can use to inspire your students, here are some ideas:

Art and design

- Design a puzzle comprised of three separate interlocking objects
- Make a model with a software application you have never used before
- Design a model that incorporates hardware

Interdisciplinary

- Design real or imagined mythological figures
- Find examples of 3D printing in art, fashion, medicine, etc
- Travel the world: Around the World in 80 Models

Math

- Explore Conic sections
- Explore Platonic solids
- Explore Tetrahedrons

Science and Engineering

- Design a fossil or skeleton of an invented species and determine its scientific classification
- Create pieces for a Rube Goldberg Contraption
- Print out copies of bones, jaws, etc. and have students determine their scientific classification
- Design the tallest structure with modular parts



Conclusion

When incorporating a 3D printing program into the classroom, the possibilities are seemingly limitless. Whether it's in math, science, history, or art, the process of designing a model and bringing it to life can teach students about collaborating to solve problems, innovation in design and product development, and the what the future holds for engineering.

The lessons they learn from 3D printing projects will only help to prepare them for the ever-changing workforce, as they learn to adapt to new technologies they may face in the future.

Interested in exploring the possibility of integrating Ultimaker 3D printers into your classroom or expanding your existing suite of printers? [Request a quote](#) to speak with a local reseller.

Explore more 3D printing knowledge

Learn more from industry leaders and experts, and compare the specs of our 3D printers, on the Ultimaker website.





About Ultimaker

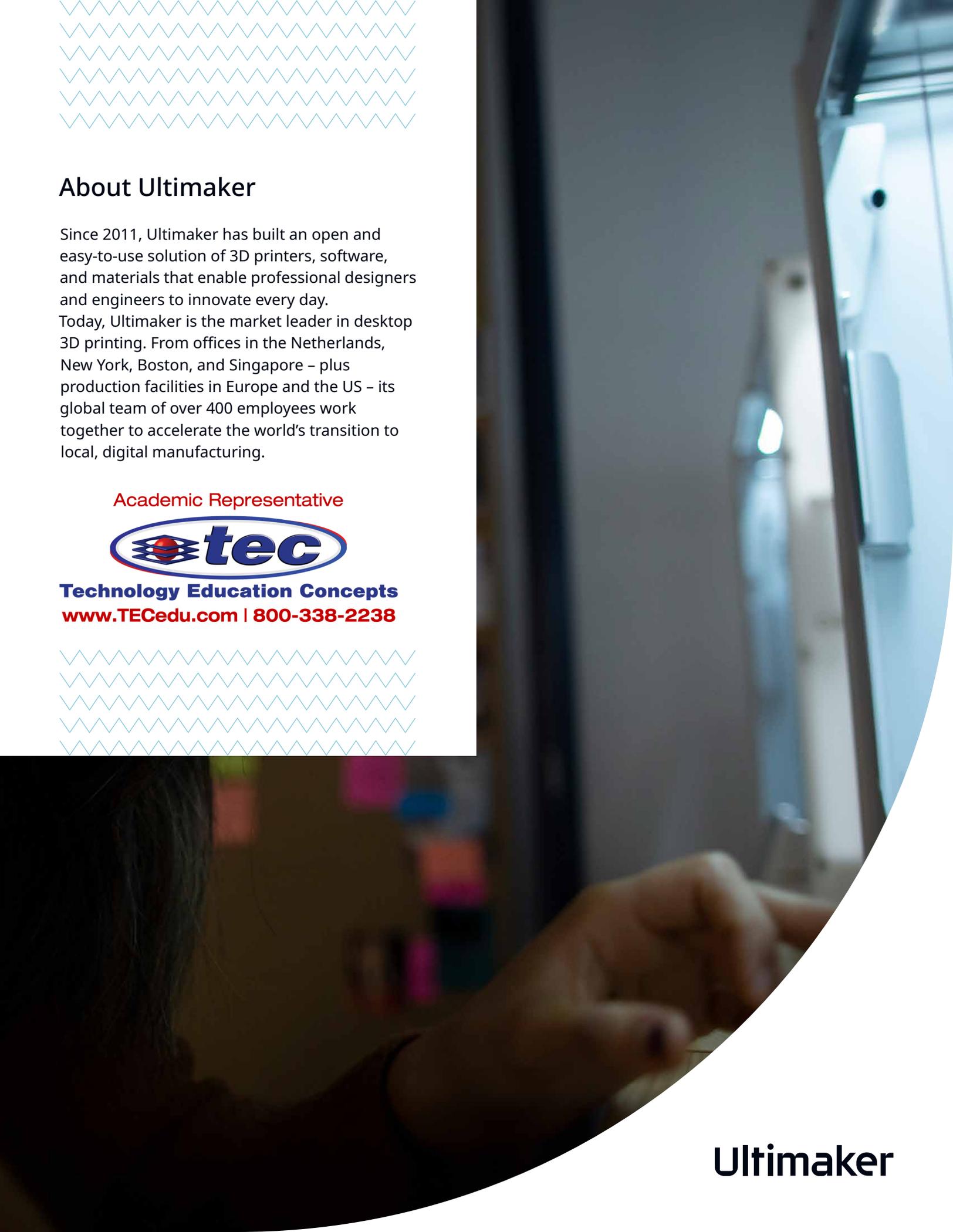
Since 2011, Ultimaker has built an open and easy-to-use solution of 3D printers, software, and materials that enable professional designers and engineers to innovate every day. Today, Ultimaker is the market leader in desktop 3D printing. From offices in the Netherlands, New York, Boston, and Singapore – plus production facilities in Europe and the US – its global team of over 400 employees work together to accelerate the world's transition to local, digital manufacturing.

Academic Representative



Technology Education Concepts

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The background of the entire page is a circular image. The upper right portion shows a close-up of a 3D printer's nozzle and print bed. The lower left portion shows a person's hands working on a project, possibly a 3D printed part, in a workshop or classroom setting with colorful sticky notes on a wall in the background.

Ultimaker