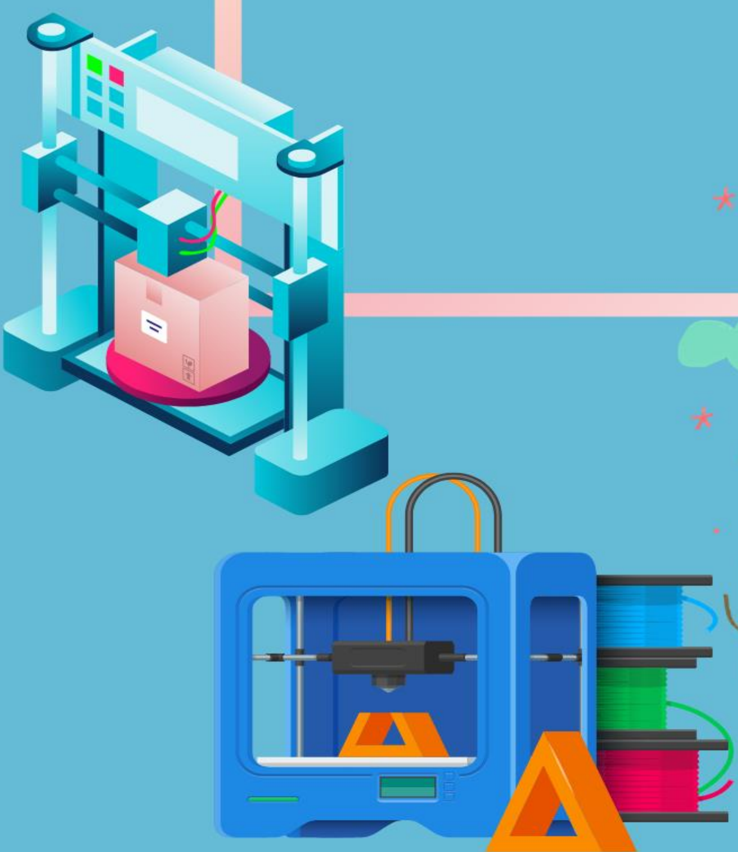
The recreaMATHS 3D Printing Module

20-hour 3D Printing Module for Kindergarten Educators



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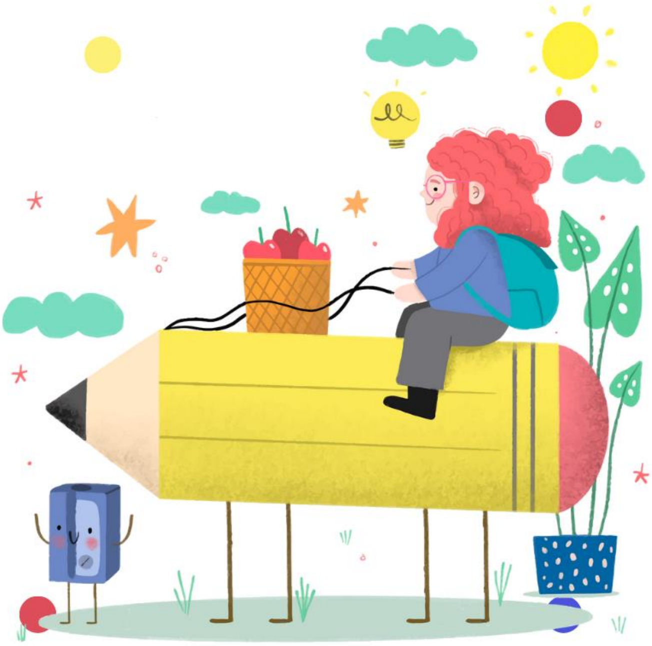
Introduction

3D Printers open a new world of possibilities in the classroom. This multi-disciplinary approach combines core curricula with art and technology to showcase teachers' academic skills. The 20-hour Module on 3D modelling and printing will endow kindergarten educators with the appropriate know-how to utilize computer-aided software to ideate, design, illustrate and print out their math manipulatives and three-dimensional exhibits. Starting from some initial concepts and historical facts, the module outlines the stages of 3D printing, from idea to software model to a printable file that slices the planned object into printable layers to the finished object itself. Readers are given hands-on, concrete projects to practice on, making their first steps into the world of 3D printing!

Unit 1

What is 3D Printing?

Initial Concepts & use in Education



Chapter 1:

What is 3D Printing?

When using the word printer, most people think of the conventional printer they might use at home or in the office to print out text and images on paper. However, the gadgets print in a flat two-dimensional (2D) space using length and width dimensions. A three-dimensional (3D) printer uses length and width, but also adds depth to the print. This transforms a flat print into a tangible, workable object you can hold and use.

Imagine you are printing a flat square on a piece of paper lying on a table, and then you pull that printed shape "up" from the flat surface, creating a physical cube that illustrates how the sides rise from the flat surface during the 3D printing process.

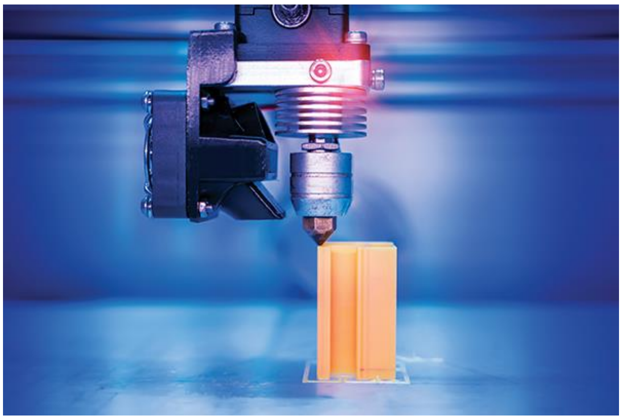
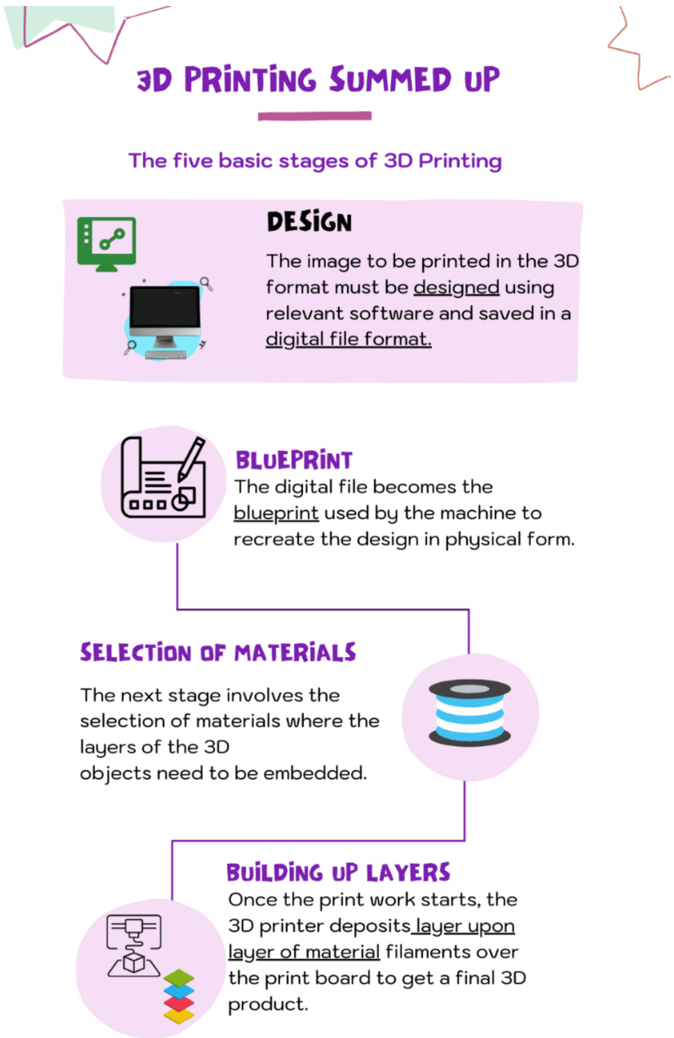


Figure 1 / A 3D model being printed
Source: satellitleprome.com

3D printing is a manufacturing process where a **digital model (3D design blueprint) is created using computer-aided design software (CAD) and is turned into a physical three-dimensional object by adding material a layer at a time.** There are many methods of melting or softening the material to produce the layers. The technology has been around since 1990, but it was only in the last decade that people realized the game-changing potential in all industries. It is also known as additive manufacturing and is changing how we manufacture and create, not just in the industry. Innovative designs are used to develop machine parts, prosthetic limbs, sustainable housing, and even 3D-printed medications.

Additive Manufacturing is a general term referring to various fabrication processes that use manufacturing tools to create 3D physical objects by adding material.
A 3D printer is one subset of this manufacturing process because it continuously adds layer upon layer of material to build a physical 3D object. This is different from subtractive manufacturing, where material is removed from existing resources to create an object or the consolidation process that combines smaller parts and fuses them to make the designed object. **At its core, 3D printing is a manufacturing method that takes a digital design and creates a physical 3D object by building up layers of a selected material.**



History – Initial Concepts

In 1983, Chuck Hull invented Stereolithography, or 3D Printing, creating the first-ever 3D printed part. **The machine was named the Stereolithographic Apparatus**, as it used stereolithography to printers.

Figure 2 / The first 3D printed part, produced by Chuck Hull in 1983

Source: [historyofinfromation.com]

Since the development of this machine, rapid progress has been made in the field of 3D printing.

Its contribution to the medicine field has played a catalytic role to its rapid development. The first lab-grown organ was successfully transplanted in young patients, using a 3D-printed synthetic scaffold that was coated with cells from their own bodies.

This proved that the raw materials used to create objects could range from plastic to metal, to even human cells. The possibilities were endless, and the future looked extremely bright for 3D Printing technology. That same year, a company called "Objet" introduced a 3D printer that was capable of printing objects using numerous types of raw materials.

The year 2008 saw the **first self-replicating printer which was capable of 'producing itself' by printing its own parts and components**. This enabled users who had access to such a type of printer to create more printers for other people, such as friends and family.

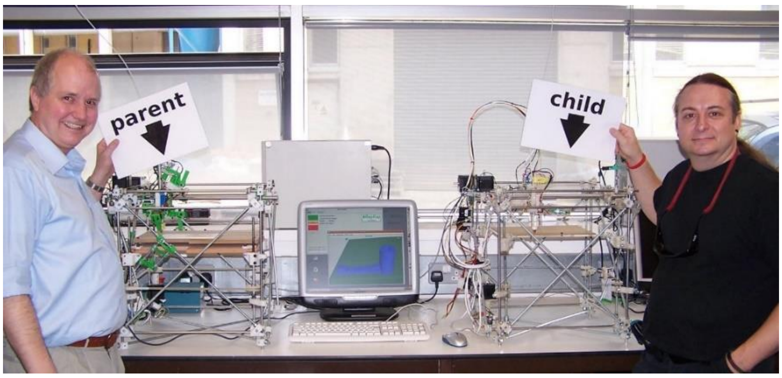


Figure 3 / The first self-replicating printer: All plastic parts on the right were produced by the 3D Printer on the Left

Source: [Wikipedia.com]

Later in the same year, major breakthroughs were achieved in prosthetics when a person successfully walked with a 3D printed prosthetic leg consisting of all parts including the knee, foot, and socket created as a part of the same structure without any assembly.

Figure 4 / First 3D Printed Prosthetic Leg

Source: all3dp.com

MakerBot Industries, an open-source company, started selling DIY kits in 2009 that allowed people to create their own desktop 3D printers. The following years, the use of 3D printing exploded when the first 3D printed airplane flew over the University of Southampton, UK.

The Development of 3D Printing

3D printing has gone through 3 primary phases:

- its creation (1981-1999)
- its development (1999-2010)
- its widespread use (2010-nowadays)

- **Beginnings of 3D printing (1981 – 1999)**

IBM's introduction of the first personal computer in 1981 paved the way for the widespread use of computer-aided design.
Then in the 1980s, there were multiple projects and research topics that focused on 3D Printing, originally called Stereolithography (SLA), in 1986.

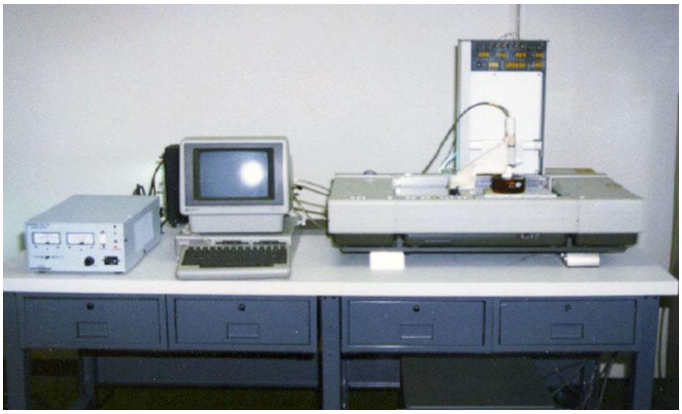


Figure 5/ The first 3D printer ever created was made in 1983 by Chuch Hull

Source: sculpteo.com

In less than ten years, three different methods were patented, marking the birth of 3D printing.
The 1990s saw the development of the first industrial prototyping system and the production of applications for 3D printing.

• Improvement of 3D Printing (1999 – 2010)

Since the 2000s, 3D printing has continued to develop in many sectors of activity, significantly increasing in terms of visibility and accessibility and gradually becoming widely available.

Here are a few examples:

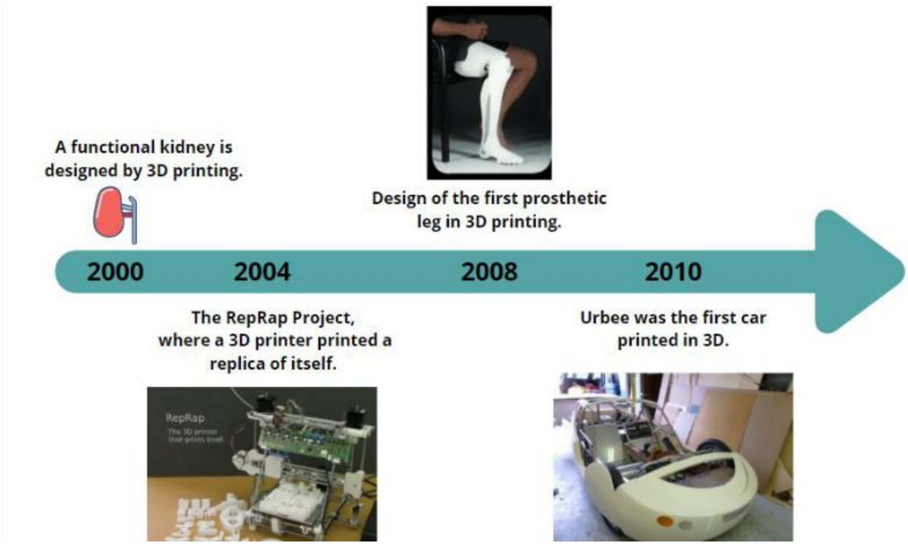


Figure 6 / Examples of the first successful 3D Printed applications

Towards the end of the 2000s (in 2006), 3D printing has been gaining more and more enthusiasm in the industrial sector with new processes, materials, and many new opportunities. At this time, the 3D printing market opened to the public as it became more accessible, more affordable, and more documented.

• 2011 to nowadays

3D Printing technology continues to develop, and more and more companies understand the benefits that additive manufacturing can offer them. Considering the decreasing cost and prototyping advantages that 3D printing offers, numerous industries have fully integrated it into their iterations, innovations, and production processes.

While 3D printing started to be used for prototyping, nowadays various areas, such as medicine and architecture, are benefiting from this technology. Moreover, the easy access and lower cost of this technology have allowed the public, in general, to use it for academic purposes, art, decoration, the creation of spare parts at home, and many other applications.

Importance of 3D Printing

Similar to the ways in which computing was considered to be the hotbed of innovation in the early 1970s, 3D printing is also experiencing an analogous renaissance. 3D printing technology in its early days was limited to industries that could afford the highly expensive 3D printers. However, as the costs began to lower because of the developments in the technology, desktop 3D printers have granted access to hobbyists and anyone willing to try out the new technology.

As previously discussed, 3D printing is being used for several applications across many fields and is also being used extensively for educational purposes. What is it that makes this emerging technology important?

Fundamental Change to Manufacturing Processes

Today's commercial manufacturing process uses assembly lines to gather various parts together until the final product takes shape. 3D Printing will have huge implications for the current manufacturing processes.

For example, the use of a 3D printer for manufacturing products at a factory will only require a computer design to be sent to the printer, thus eliminating the need of assembly lines, as the printer will be able to churn out complete products.

As previously mentioned, 3D printing technology falls within the boundaries of additive manufacturing, which is the opposite of subtractive manufacturing processes where objects are 'carved out' using numerous tools. The former, on the other hand, builds the object layer-by-layer without the use of any tools. This enables designers to devise even the most complex of designs without having to worry about how they will be created; 3D printers can generally print out complex designs with no problems at all.

3D printing can produce objects with complex internal structures, which would otherwise be almost impossible with traditional methods of construction. Take the example of an adjustable wrench; using traditional manufacturing processes, several actions including forging, grinding, milling, and assembly are required just to create an adjustable wrench. On the other hand, 3D printing can create this wrench in a single process.

3D printing has the potential to be greener than traditional methods of manufacturing. 3D printers can be used is for fixing old items, such as cars that have become obsolete (and the manufacturer no longer supplies or creates the spare parts). Due to the unavailability of spare parts for old cars, they are usually recycled or left to be dumped into landfills, thus harming the environment.

Some people have been using 3D printers to create obsolete parts in order to keep their cars running. The same idea can apply on almost any other product out there that can be revived using parts from a 3D printer. The possibilities are truly endless. Even something as simple as a battery cover for remote control can be created, reducing the need to throw the old remote away.

Localizing Production of Items

3D printing can also be used to localize production of items, resulting in a massive change to supply chains and logistics. Rather than supplying from a single factory outlet, a company will be able to establish much smaller production units all over the areas which they serve, thus minimizing transportation costs. This will be a great advantage to multinational companies that serve at a global level. Smaller batches could be created at strategically placed locations to effectively cover all the countries while reducing the logistical expenses significantly.

The increased efficiency offered by 3D printing will also pave way for greater customization for consumers. Before the 3D printing technology can bring about significant changes to the manufacturing industry, it first must establish itself as being ready for mass, mainstream manufacturing; with the rates at which the technology is improving, the day may not be far when instead of buying products, people buy design blueprints and print the products using their desktop 3D printers! However, while 3D printing ideas are limitless, they are slow when it comes to producing many objects. Depending on printer size and quality, it can take several hours to days to print. In the upcoming year, 3D printing will continue to evolve, with the machines becoming gradually faster, and jobs that currently take days or weeks will instead be completed in hours or even minutes.

Approaching Mathematic Concepts with 3D Printing

The rapid development of technologies has complicated their adoption and integration into kindergarten teachers' professional development.

Whereas various studies have examined the digital technology development provided to kindergarten educators worldwide, relatively little is known about 3D modeling and 3D printing as a tool for developing educational material for early childhood.

As emerging technologies are creating avenues for teachers to go beyond traditional teaching methods, inspiring them to seek new ways of interacting with math problems is a topic of great interest. 3D printing technology is a powerful educational tool can promote integrative STEM education by connecting engineering, technology, and applications of science concepts.

Figure 7 / 3D Printed Math Art: Sierpiński Pyramid

Source: [all3DP.com](all3DP.com)

Figure 8 / Students engaging with 3D Printed Objects in Schools

Source: Simon Biggs via LinkedIn

Research has shown that low levels of participation and performance in mathematics are not due primarily to a lack of ability or potential but to educational practices that deny access to meaningful, high-quality learning experiences.

Mathematical modelling in teaching practices has become a prominent topic worldwide because of the importance of mathematical literacy in everyday life. However, kindergarten teachers often face difficulties in STEM engagement, lacking innovative, modern, and hands-on material for approaching mathematical concepts.

This is where 3D printing offers a wide array of options for student learning, allowing them to connect with the problems not only **theoretically and by incorporating visual and tactile learning in their classes.** Many such issues involve authentic situations that must be interpreted and described mathematically. From kindergarten to graduate school, **3D printers are helping students represent numbers and symbols with objects in the physical world.**

Furthermore, students learn how to apply mathematics with 3D printed objects, creating various fun shapes or toys that integrate mathematical learning. Any object represented by mathematical meaning can be printed and integrated into the curriculum. **When combined with 3D printing, several opportunities exist to address mathematical modeling's needs while helping students explore mathematics in authentic settings.**

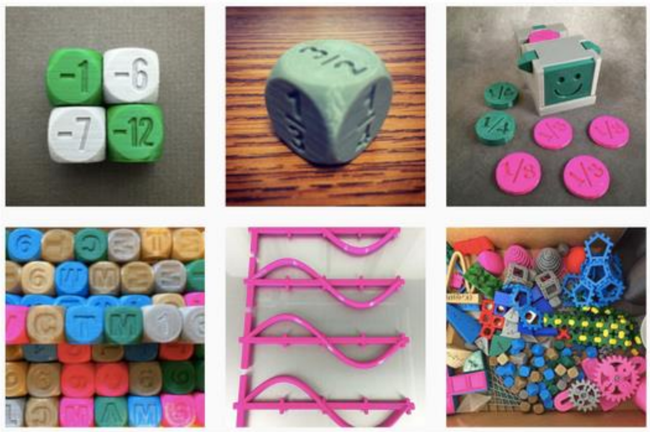


Figure 9 / 3D Printed Objects in the Math Classroom

Source: designermaketeach.com

This evolving technology makes the realization of mathematical expressions much more accessible by creating tangible representations that were not possible using traditional educational methods. 3D printing has made the realization of mathematical models more accessible than ever, helping intangible mathematical expressions come to life. These 3D printed mathematical models are essential for hands-on learning and can be used as functional prototypes. Additionally, 3D modeling software allows educators to design things they could not create without the program. While mathematical modeling may not be the intentional focus of many kindergarten schools and institutions, there are many examples where it was incorporated in classroom contexts with great potential for introducing mathematical concepts.

Using interactive exhibits in kindergartens, math museums, and math organizations

One of the central challenges facing early childhood teachers is how to meet academic standards while creating learning environments that honour young children's mathematical ideas, curiosity, and playfulness. Kindergarten students often consider mathematical topics challenging, as the traditional learning approach is different from the hands-on and creative activities, they usually experience in their everyday class routines.

Incorporating mathematical exhibits from international museums can support teachers' resources regarding experimental tools and play-based pedagogies in mathematical concepts.
However, finding ready-to-use materials can be demanding. This is where 3D printing has the solution!

3D printing allows educators to design personalized learning experiences adapted to each teacher's objectives and needs. 3D printing technologies enable educators to provide students with accurate physical prototypes and practical, hands-on knowledge, helpful in visualizing and approaching scientific concepts in a gamified way. Teachers can develop "3D printed manipulatives" – hands-on learning tools that can be utilized to show different results. The key here is that students can interact with these printed toys and tools, improving their learning via a hands-on approach.

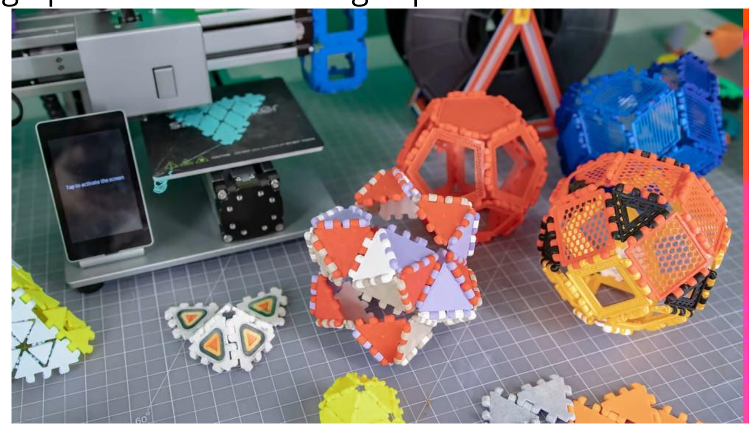


Figure 10 / 3D Printed Polypanels with various shapes and sizes but the edge connectors are always the same, allowing you to run wild with ideas

Source: [All3DP.com](All3DP.com)

With advancements in technology constantly picking up, the place of 3D printing technology in education evolves significantly faster. 3D printing technologies facilitate improved learning and skills development and increase teachers' engagement with the subject matter in kindergarten education.

Furthermore, 3D printing in a didactic way familiarizes kindergarten educators with digital tools and technological innovation, providing them with resources and material for constructing modern math manipulatives that serve their particular educational needs and objectives.

3D printing in education highlights how 3D-printed artefacts provide learning benefits that are not achievable with screen- or paper-based learning. Improved understanding comes through the children's experimentation with touching and physically observing 3D-printed objects. 3D printed puzzles and games promote learning through exploration instead of outdated methods that only focus on learning from textbooks. When students participate in projects such as a math museum, they see mathematics as more familiar than they realized, helping them see math as a beautiful arrangement of patterns and logical steps.

Regarding the technical aspects, it is crucial to get a 3D printer suitable for how you want to use this technology to educate students. Schools need robust printers built for the demands of daily classroom use while also being affordable and user-friendly.

Choosing a 3D Printer for Schools and STEM Education

Schools around the world are increasingly turning to more creative ways of teaching students, introducing more gamified and hands-on lesson plans. The world is changing, and education must adapt accordingly. For this reason, various 3D printers have been developed specifically for classrooms.

However, choosing a 3D printer for your school can be a difficult decision.

From countless conversations with teachers, their most important considerations when choosing a 3D printer had to do with **ease of use, affordability, durability, and safety.**

Ideally, a 3D printer for schools should come with lesson plans, class projects or interactive exercises. 3D printer companies such as Makerbot, Tinkerine and Dremel 3D printers have focused on **developing 3D printers as educational tools, offering complete plans, tailored by age group.**

Starting with the most affordable choice, **Toybox 3D Printer** is greater for younger kids to learn 3D printing.

Figure 11 / Toybox 3D Printer

Source: https://www.3dsourced.com/3d-printers/3d-printer-for-schools-education-children/

A gentle, inexpensive entry point into the world of 3D printing (*costs around 300 euros)*, the Toybox's accessible, user-friendly design is tailored for students experimenting with a 3D Printer for the first time. Touch screen functionality, Wi-Fi connectivity, a small footprint, compatibility with non-toxic, biodegradable '3D printer food' PLA, and support for iOS/Android devices and web browsers all work to empower young learners with the tools to experience 3D printing simply (3D Sourced Team, 2020).

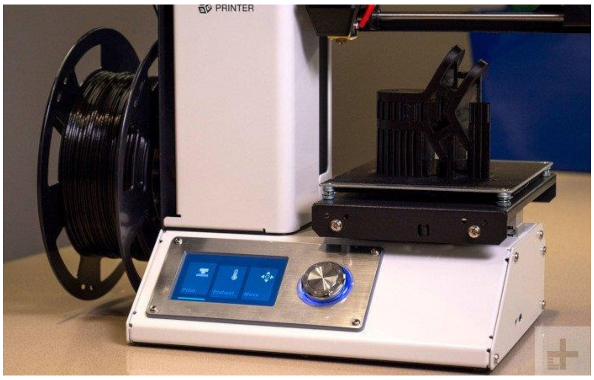


Figure 12 / Select Mini V2 3D Printer

Source: https://www.3dsourced.com/3d-printers/3d-printer-for-schools-education-children/

Though not positioned as a 3D printer for education, the **Select Mini V2** is a cheap 3D printer and simple enough to use that every student could have their own, for the same price as one or two more expensive printers. Moreover, it's open plan design lets students see the printing done up close, which isn't always the case with more closed off printers. It doesn't come with any lesson plans or education guides, but the Monoprice Select Mini V2 has applications for teaching 3D printing in schools.

Though on the pricier side (with its price ranging around 3,800 euros), the **Ultimaker 3's** ease of use and print monitoring (clever auto levelling features, remote printing via phone) make it a fantastic option for 3D printing in schools. Simply because things rarely go wrong since the printer is so reliable, the Ultimaker 3 is ideal for use in teaching children about 3D printing.

Figure 13 / Ultimaker 3 Printer

Source: https://www.3dsourced.com/3d-printers/3d-printer-for-schools-education-children/

Due to the lack of experience and great curiosity associated with educational institutions, we recommend a 3D printer that takes extra steps to streamline and simplify the process. Features like automatic bed leveling (see Chapter 2 – Print Bed) , Wi-Fi connectivity, and touchscreen controls take the more technical and tinkering aspects out of the equation.

Features like these should make the printer accessible not only to young learners, but also to less experienced teachers introducing 3D printing to their classes for the first time.

You can find details on the technical characteristics and features of 3D printers online, with a variety of resources thoroughly comparing and reviewing different models and designs.

Best Practices – The example of MIND Institute California

A group of teachers in California took a "hands-on" approach, utilizing 3D printed manipulatives and toys to help kids learn by doing.

Ki Karou, a game-based learning designer at MIND, says in the past, it has been challenging to get students the tools they need because of cost and purchasing issues.

"We've seen this 3D printing as a new technological tool that not just us, but other people, can use to get into kids' hands," Karou says.

"Kids especially learn best through hands-on experiences," Karou confirmed. "Manipulatives as a class of objects are a way of taking these abstract symbols and bringing them to life so that kids can get a concrete understanding of how the math works."

According to MIND, one benefit of 3D printing is that if a teaching tool should happen to be broken or lost, teachers can print out a replacement and get back to work.

But using 3D printers to teach math concepts does present a new set of challenges. Karou supports that a school district may need to provide some new resources to make the notion operate effectively.

"You'll need someone who's a dedicated staff," Karou says.

"Someone who understands how to use the technology and can explore that and find how to bring it into the curriculum." This underlines the importance of teachers' self-motivation and personal interest.

The MIND Research Institute has content development team that works on developing teaching tools to provide students with the conceptual help they need to understand math concepts.

Figure 14 / The co-founder and CEO of the MIND Research Institute, Matthew Peterson, says learning math will be more attractive to students once they make the transition from word-based learning to visual learning techniques.

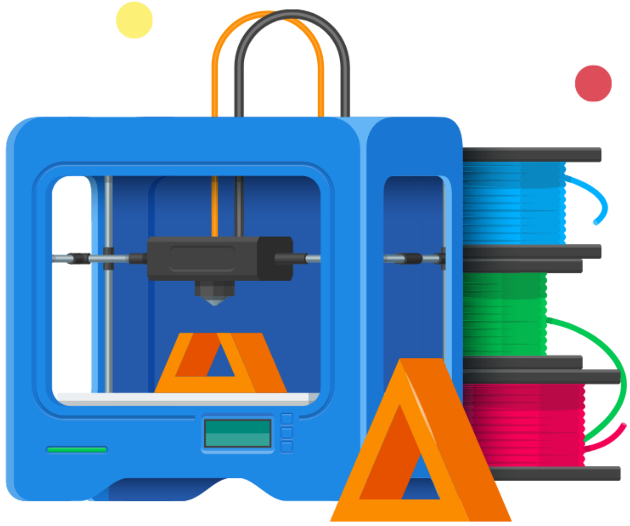
Source: 3dprint.com

Matthew Peterson, co-founder, and CEO of the MIND Research Institute believes that arithmetic will be more appealing to them once students transfer from word-based learning to visual learning strategies.

According to MIND researchers, a 3D printer can help pupils understand fundamental and sophisticated mathematics in numerous ways. More specifically, they state that a final printed product can demonstrate that it's made up of a network of coordinates used to create the structure of an object and that the technology can be used to show students concepts like axial symmetry and how to interact with geometric shapes.

Unit 2

3D Printing Processes & Components of a 3D Printer



Chapter 2:

Different 3D Printing Processes

Technically, the term “3D printing” refers to the development of any three-dimensional object layer-by-layer using a computer created design. Different procedures are used in this offset of additive manufacturing, varying in the way and materials used during the product development. However, regardless of the process used, the idea behind the creation of objects using 3D printing technology remains the same, starting from the production of a 3D model using computer-aided design (CAD) software to the setting up of the machine. Even so, as it will further be discussed, the actual technical process used to create the physical object varies.

There are four different types of 3D printing processes that you are likely to encounter:

- ✓ Fused Deposition Modeling (FDM)
- ✓ Stereolithography (SLA)
- ✓ Selective Laser Sintering (SLS)

Fused Deposition Modeling (FDM)

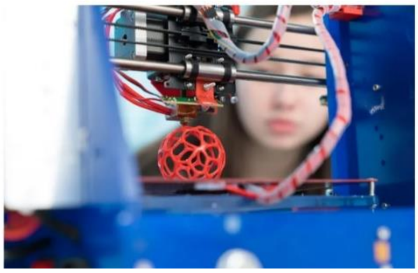


Figure 15 / FDM 3D Printer in Process

Source: sinterit.com

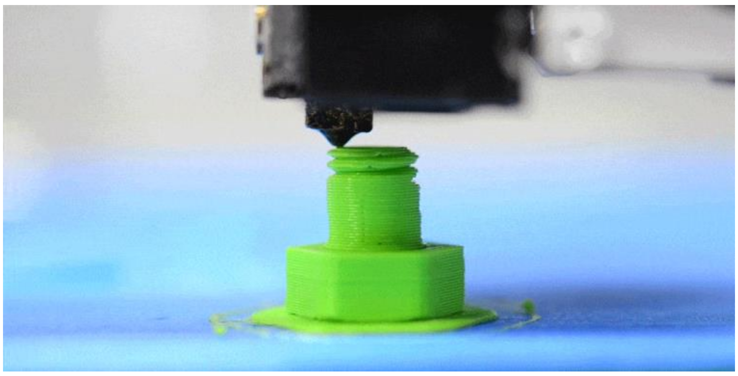
Fused Deposition Modeling (FDM) is the most known 3D Printing process. It is a bottom-up technique based on melting of the filament and depositing it on a table layer-by-layer according to the sliced model. FDM utilizes mostly **plastic-based materials** such as polylactide (PLA) or acrylonitrile butadiene styrene copolymer (ABS). The Fused Deposition Modeling printing process is an additive manufacturing technology that is used for the purposes of modeling, prototyping and production applications. This method also works by creating an object layer-by-layer. However, there are some differences in the way the materials are used by this technology.

How it Works

3D printers that utilize the FDM technology construct an object layer by layer; they heat a thermoplastic material to a semi-liquid state. Two materials are used by FDM to complete the printing: a modeling material and a support material. The former constitutes the final product, while the latter acts as scaffolding.

The raw materials are supplied from the printer's bays and the printer head is designed to move based on X and Y coordinates, controlled by the computer. It only moves vertically (Z-axis) when a layer has been completed.

The benefits offered by FDM make it suitable for use in offices, as it is a clean and easy-to-use method.



Stereolithography (SLA)

SLA holds the historical distinction of being the world's first 3D printing technology. Stereolithography was invented by Chuck Hull in 1986, who filed a patent on the technology and founded the company 3D Systems to commercialize it.

Figure 16 / SLA 3D Printer working its magic

How it Works

An SLA 3D printer starts off with an excess of liquid plastic. Some of this plastic is cured (or hardened) to form a 3D object.

There are four main parts in an SLA printer:

- A printer filled with liquid plastic
- A perforated platform
- A UV laser
- A computer which controls both the laser and the platform

To begin with, a thin layer of the plastic (anywhere between 0.05-0.15 mm) is exposed above the platform. The laser 'draws' the pattern of the object over the platform as depicted in the design files. As soon as the laser touches the material, it hardens. This process continues until the whole object has been constructed.

Objects that are created using SLA are generally smooth, while the quality of the object is dependent on the complexity of the SLA machine.

Selective Laser Sintering (SLS)

SLS is one of the most used 3D printing technologies. During the SLS printing process, tiny particles of ceramic, glass or plastic are fused together by a high-power laser. The heat from the laser fuses together these particles to form 3D objects.

Carl Deckard, an undergraduate student at the University of Texas, along with his Professor, Joe Beaman, developed and patented this process in the 1980s.

Figure 17 / SLS 3D Printing; laser is used to solidify and bond grains of plastic, ceramic, glass, metal or other materials into layers to produce a 3D object.

Source: Mindware Redefining Technology and Human Touch

How it Works

Like all other 3D printing processes, the process of creating an object with an SLS machine begins with designing of a 3D model using CAD software. These files are then converted into. STL format, which is recognizable by 3D printers.

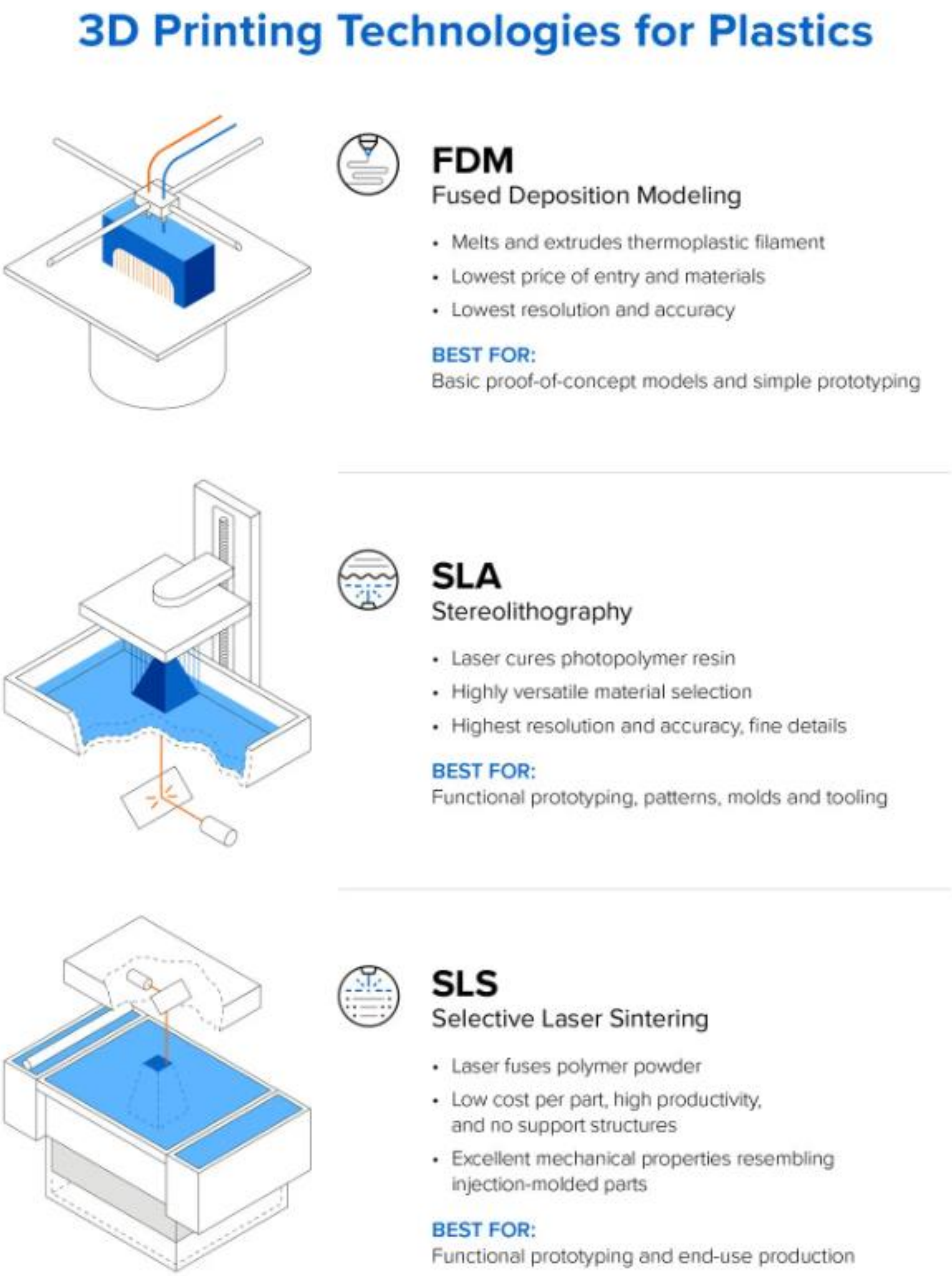


Figure 18 / 3D Printing Processes

Source: https://formlabs.com/

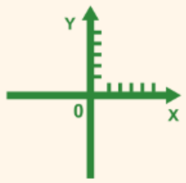
All types of 3D printing processes have a few things in common; **they all require a 3D model in .STL format** in order for the printer to be able to understand the blueprints it must develop.

All types of 3D printers **build objects layer by layer**; the major difference lies in the technique they use to solidify the raw materials, as well as the nature of the raw materials themselves.

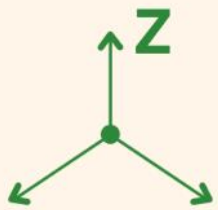
Parts of a 3D Printer

If you are a beginner looking **to start 3D printing, your first 3D printer will most likely be an FDM printer.** The easiest way to understand how FDM works is to first learn its parts. Before we talk about specific components, though, it's worth mentioning that most 3D printers use **three axes: X, Y, and Z.**

The X- and Y-axes are responsible for left and right, forward, and backward horizontal movements respectively, while the Z-axis handles vertical movement.

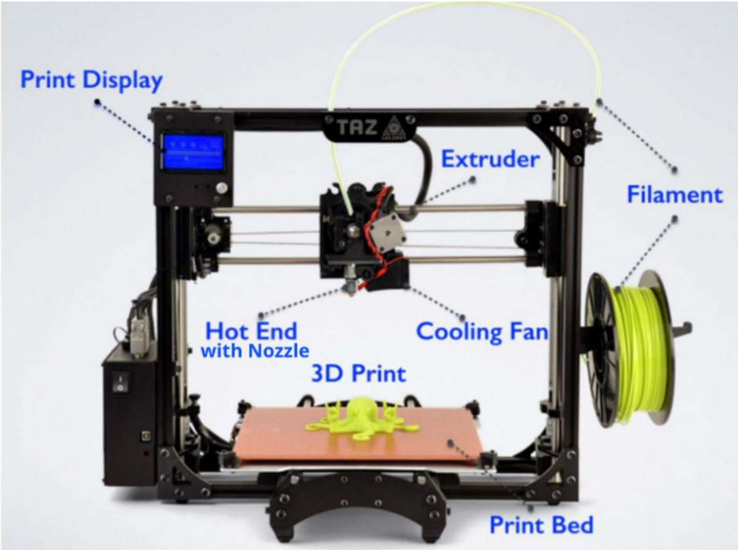


- **x axis is responsible for the left / right movements**
- **y axis is responsible for the forward / backward movements**



- **z axis is responsible for the up / down movements**

Let's take a look on the **main components of a 3D Printer**:



Source: http://my3dconcepts.com/explore/main-components-of-desktop-3d-printers/

Nozzle (attached to the extruder)

Nozzle diameters have an impact on several aspects of your print, including accuracy and speed. When choosing a nozzle, **the goal is to balance speed and precision.**

Larger Nozzles (>0.4 mm)	Smaller Nozzles (<0.4mm)
✓ Faster print time	✓ High Precision
✓ Fewer maintenance / nozzle-related errors	✓ More maintenance - clogging

QUICK TIPS

Commonly, most people use 0.4mm nozzles as it has a good balance between speed and precision. **As such, it is commonly recommended to go for 0.4mm nozzles.**

Extruder

Figure 20 / Extruder of a 3D Printer

Source: https://3dprinterly.com/wp-content/uploads/2021/08/What-Are-the-Parts-of-a-Filament-3D-Printer-Extruder-3D-Printerly.jpg

The extruder is one of the most important parts of the printer. Also known as the cold end, **it is responsible for guiding and conducting the filament from the reel to the hotend for melting.**

The extruder is the upper portion of the extruder assembly. Its job is to transport and push the filament into the lower parts of the assembly, the hot end.

Hotend

Figure 21 / Hotend

Source: https://8059blank.github.io/individual/3D-printers-102/

The hotend is also another essential part of the 3D printer. It is the part that melts, extrudes, and deposits the filament on the printer's bed for printing.

After the extruder feeds the filament into the hotend, the filament goes through a heated path called the melt zone. Here, the filament melts from the heat. Due to the pressure from the extruder, it is forced out of the small nozzle opening.

Cooling (Part cooling fans)

Part cooling fans **cools the hot freshly extruded plastic as soon as it exits the nozzle**. This eliminates various forms of print problems. However, there are several materials such as ABS that will create more problems with a part cooling fan on. As such, it is recommended to always check if a part cooling fan is needed for different materials. **For most filaments such as PLA, a part cooling fan is recommended.**

Figure 22/ Cooling fans

Source: https://8059blank.github.io/individual/3D-

Build Surface / Print Bed

The build surface of the 3D printer refers to the platform on which the filament is deposited to form the print. Depending on the printer's model, the build surface can be stationary or move in a specified direction.

In 3D printing, the print's quality is influenced heavily by the first layer and the build plate adhesion. So, the build surface plays a big role in the printing process.

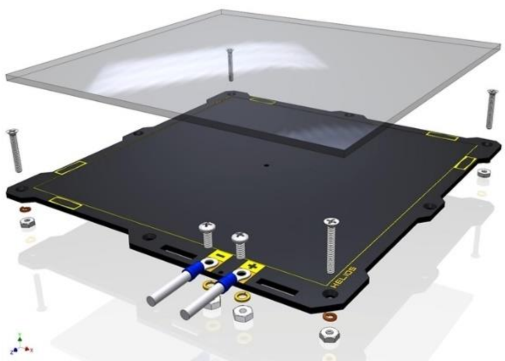


Figure 23 / Build Platform - Print Bed

Source: https://8059blank.github.io/individual/3D-printers-102/

Depending on the filament's material, there are different things to consider when using a print bed. These things include:

- ✓ **Heating:** Some print beds come with a heating pad attached to raise the temperature of the build surface. The increased temperature helps with first layer adhesion and warping.

- ✓ **Material:** The build plate's material also determines its performance. It determines how well the build plate holds up under heat, and how well the filament will stick to it.

Print Display

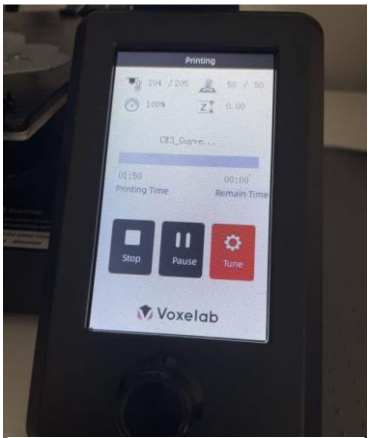


Figure 24 / Print Display

Source: https://3dprinterly.com/wp-content/uploads/2021/08/What-Are-the-Parts-of-a-Filament-3D-Printer-Control-Screen-3D-Printerly.jpg

The print display (or control box) is the Human Machine Interface of the 3D printer. It is how the printer's operator communicates with the 3D printer directly without using a PC or any device.

Using the control box, the operator **can start, pause, or stop printing.** They can also load the print files from external media like a USB stick or an SD card. It all depends on the sort of firmware loaded on the printer.

The control box interface can be a touchscreen or a plain LCD with physical buttons or a control knob.

The control box can also contain other sensitive electronics required for the proper functioning of the 3D printer. These electronics include the power supply unit, motherboard, USB ports, Wi-Fi antennae.

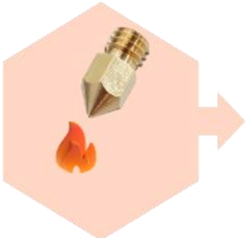
Preparing your 3D Printer

The process starts when you send a 3D model file to the printer. The file contains a set of instructions for everything, including **what temperatures to keep the nozzle and build platform at as well as how to move the nozzle and how much filament to extrude.**

When the print job starts, the nozzle heats up. When the nozzle reaches the required temperature to melt the filament, the extruder pushes the filament into the hot end. At this point, the printer is ready to start 3D printing the part. The printhead lowers and starts depositing molten filament, squeezing out the first layer between the nozzle and the build surface. The material cools and begins to harden shortly after exiting the nozzle, thanks to the part cooling fan (or fans). After the layer is complete, the printhead moves up along the Z-axis by a tiny amount, and the process repeats until the part is complete.

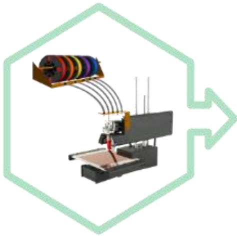
1. Heating Up

In order to print, the **nozzle** heats up and reaches the required temperature to melt the filament



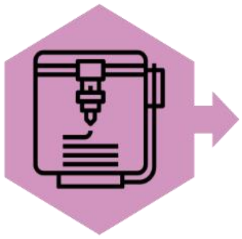
2. Pulling the filament

The filament is fed to the extruder via a motor that ensures the correct volume of plastic is laid down as it moves.



3. Actual 3D Printing

The extruder lowers and starts depositing molten filament, squeezing out the first layer between the nozzle and the build surface.

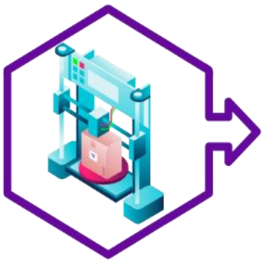


4. Cooling

The material cools and begins to harden shortly after exiting the nozzle, thanks to the automated cooling part (or fans). .

5. Final Product

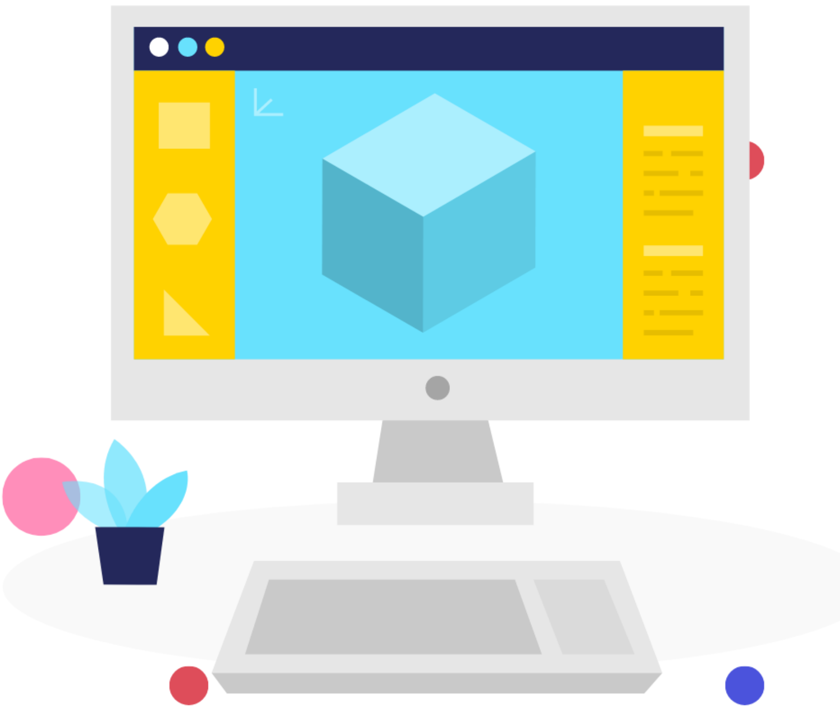
The material cools and begins to harden shortly after exiting the nozzle, thanks to the part cooling fan (or fans). .



Unit 3

Getting started with 3D Modelling

Tinkercad Introduction & Exercises



Chapter 3:

Getting started with 3D Modelling

Before moving further into the discussion of 3D printing software, it is a wise idea to briefly cover the actual 3D modelling-printing process from scratch, highlighting the key stages and points.

- Step 1: The Idea

First and foremost: choose an object you would like to create. It can be anything, from a simple screw to a complex toy. We advise you to begin with basic projects until you feel more confident developing complex ones.

- Step 2: Design the Model

The main step is designing the actual model. After you have decided what you want to make, you should use CAD software that can help you create a first draft of your model.

- Step 3: Convert it into STL

It is necessary that you convert your model into STL format after it has been completed. Most of the CAD softwares you'll ever encounter come with built-in features that allow you to export the model as STL.

After you've converted your model into an .STL format, you're halfway across getting a 3D printable file.

- Step 4: Slicing it

The fourth step requires you to 'slice up' the model into layers. In this stage, the 3D model is converted into a set of instructions that the printer can understand. This is the last step involving the use of computer software, after which you will get the final **G-code file that the printer can recognize.**

Technical Drawing & Basic Views

Technical Drawing Definition

Technical drawing, drafting, or drawing, is the act and discipline of composing drawings that visually communicate how something functions or is constructed.

Definition from Wikipedia

The technical drawing is an essential and codified element to ensure that the plans and drawings developed are understood and communicated without error in the world of industry and engineering. Indeed, how to render on paper the reality of an object. Let's take a pencil as an example.

Depending on how it will be drawn and represented, it can be complicated to understand that we are dealing with the same pencil. It is always a matter of **perspective**.

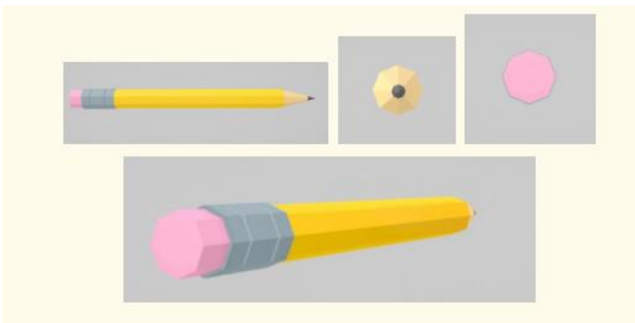


Figure 25 / 3 - Point Perspective

Perspective Projections

Perspective projections are drawings that seek to reproduce what the human eye really sees when looking at a specific object. There are three types of perspective projections: **one-point, two-point, and three-point projections**. The perspective points are called vanishing points.

When you're looking at a 3D object head-on and it's centred in your view, that is an example of **one-point perspective**.

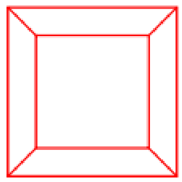


Figure 26 / 1 - Point Perspective

Now the cube is at eye level, and you're near one of its edges. To illustrate the cube with a good illusion of depth, you need two-point perspective.

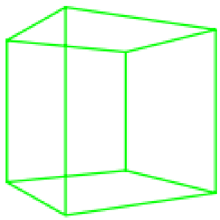


Figure 27 / 2 - Point Perspective

Now imagine you're above the cube near one of its corners. To draw it, you'd need three vanishing points, one for each set of parallel edges.

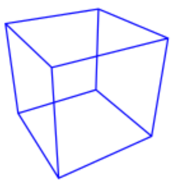


Figure 28 / Several Views of the same pencil in a 3D view

Perspective is challenging to draw by hand, but 3D Modelling software provide you with different scenes and tells where to view the scene from.

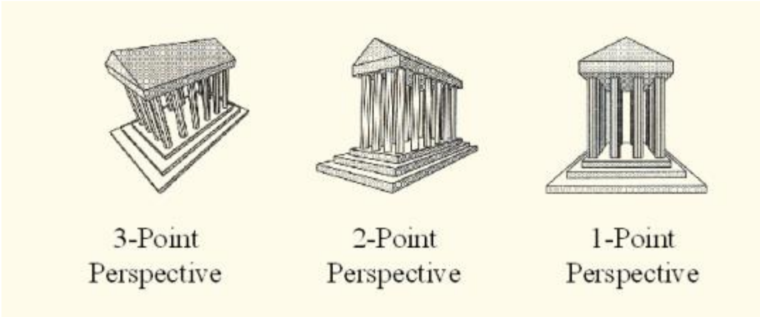


Figure 29 / The three types of projections

Without the right software, 3D printing remains a distant dream. While it is true that you need a specialized printer that can create 3D objects, you also need a variety of essential software that allows you to design the actual model and convert it into a format that the printer can recognize.

This chapter covers the types of computer software you need, as you begin your journey to becoming a 3D printing master.

Taking the above pencil as an example, we can see that several types of views are used for different purposes in the manufacturing drawing.

Technical drawings include dimensions, geometry, tolerances, material type, finish, hardware. In addition, technical drawings always have an information block that contains essential information about the assembly and are most often located in the lower right-hand corner.

TIPS One important tip with views: use/give only the necessary views that will contribute to a better understanding of the drawing.

3D Printing Software

Unless you're planning to download ready-made blueprints of models from the Internet and use them to print objects, you will need to understand what kind of 3D printing software you need.

Where Can You Get 3D Model Blueprints?

Regarding the actual design blueprints of the objects, you can either get ready-to-use models online or create your own.

You can find all kinds of models on Thingiverse. Even though famous the manufacturers of the Replicator printer, MakerBot, own the website, it contains an archive of designs created by ordinary users.

How Can You Make Your Own Models?

There was a time when Computer Aided Design (CAD) software was designed by engineers, for engineers. CAD software used to be exceedingly complicated (it still is, to some extent, but it is now more manageable) and only those with the right training could use it properly.

CAD software has a steep learning curve times have changed, and the latest in CAD software is aimed at general users. The best thing about modern CAD software is that it is not as difficult to learn and use as it was previously.

Computer-Aided Design Software (CAD)

Computer-aided design (CAD) software has been around for decades. Initially, it was only intended for engineering applications; however, since the inception of 3D printing technology, CAD software has been widely used to create 3D models of objects. One of the main reasons of using CAD software as compared to non-CAD alternative, such as Photoshop, is that it enables the designers to export the model as an STL file. **Just so you remember: An STL file is a format that contains information that is required to produce a 3D model on stereolithography printers.**

Thankfully, a lot of free CAD software is now available and is nearly as excellent as some of the paid versions out there. Many commercial CAD programs also have free/limited license versions which allow you to further engage in the world of CAD design and 3D printing without spending thousands of dollars.

Chapter 4:

Introduction to Tinkercad

Tinkercad is a free web-based 3D modelling and printing application that can help anyone get started designing and printing 3D objects.

Anything you create with Tinkercad is stored in your account and will be available whenever you log into. You can return to your designs and tinker with them anytime from any internet enabled computer.

Go to www.tinkercad.com and click SIGN UP on the button to create a free account.

To start creating an object, click on Create new design the button in the *My Recent Designs Section*

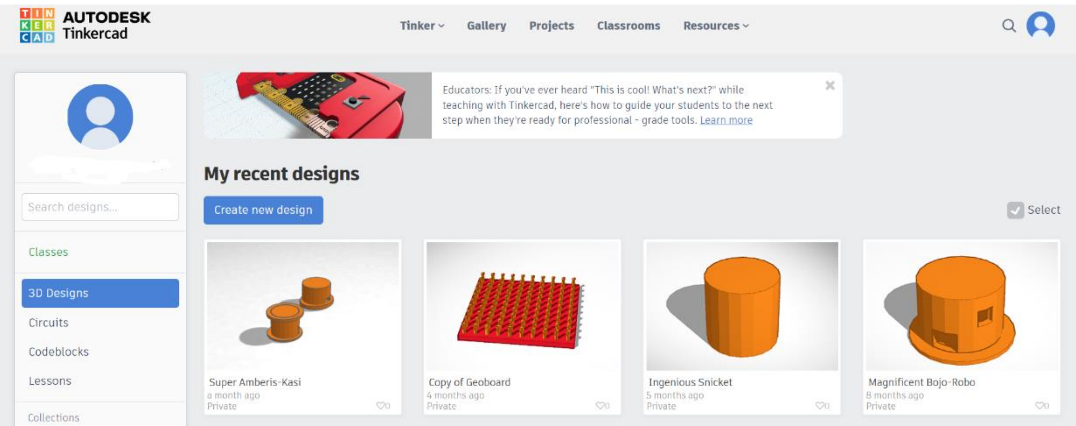
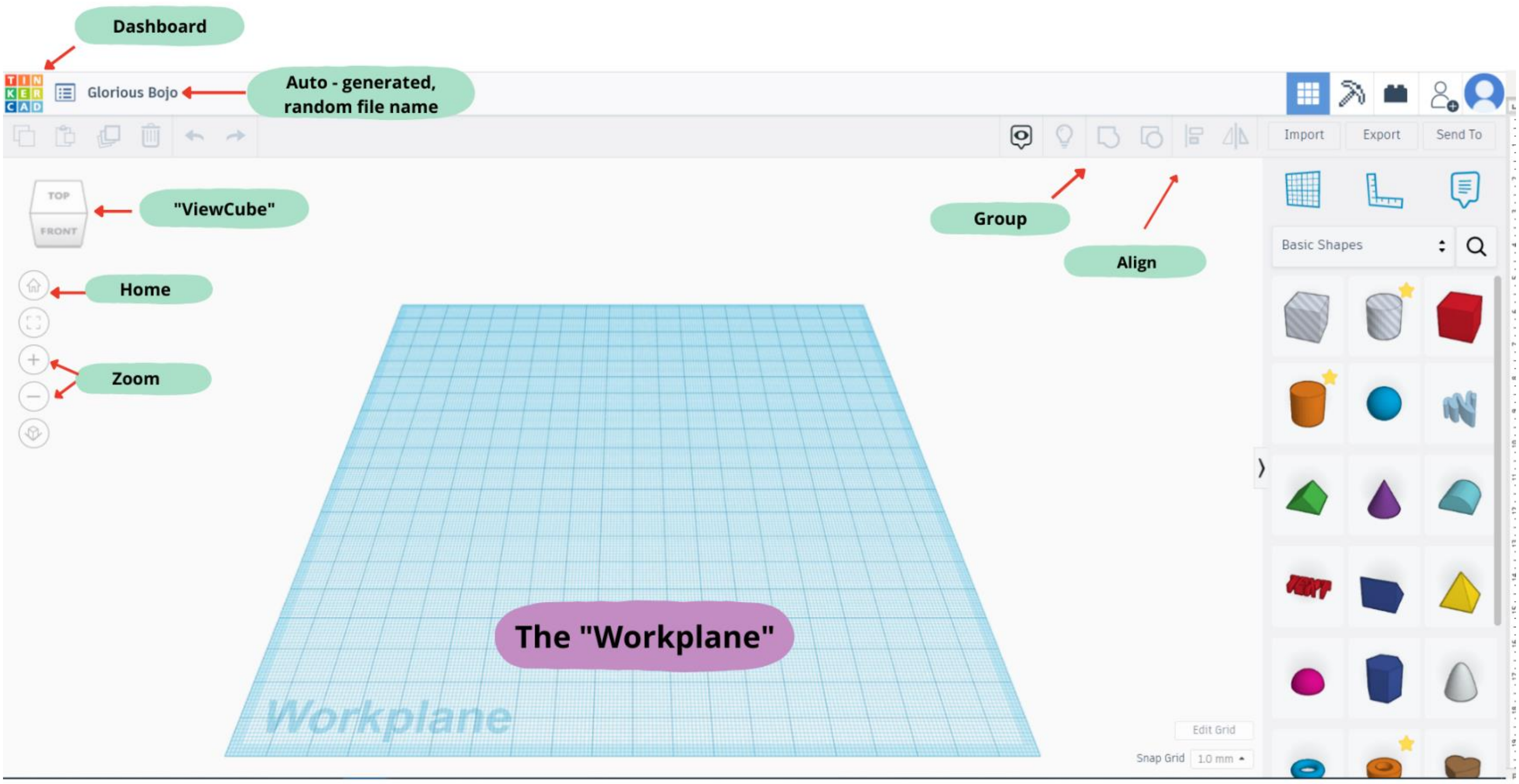


Figure 30 / Creating a New Design

Tinkercad Interface



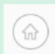
Once you start creating your own design, the working environment will look like this:

Navigating the Mouse

You can use the tools to the left of the Workplane or the mouse to manipulate the Workplane. Use the mouse to:

- Zoom in and out with the mouse scroll wheel
- Rotate the workplane by right clicking and dragging
- Change the view by clicking on a side of the *View Cube*

- Return to the default viewing perspective by clicking the home icon

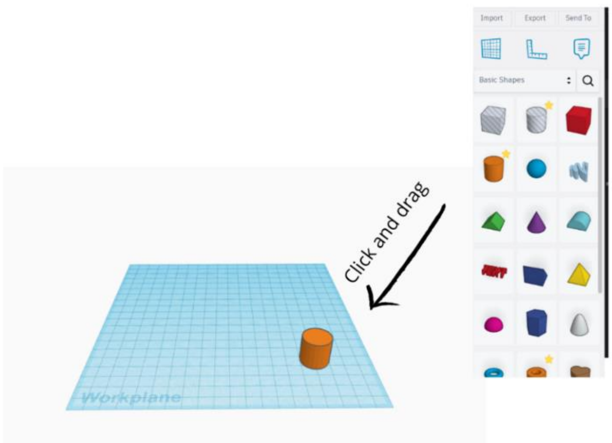


The Shapes Menu

The shapes menu is on the right side of the interface.

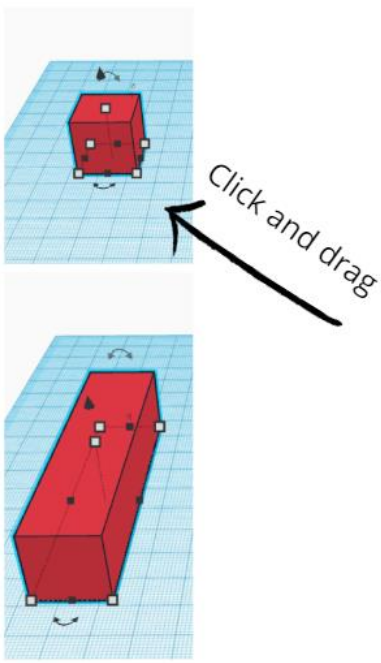
You will use these shapes to design your object.

Practice moving these shapes by **clicking and dragging** some of the shapes to the WorkPlane.



A first example: Modelling a simple car

Modifying 3D Shapes



Notice the small white boxes around the shape.

Stretch or reduce the shape by clicking and dragging the small white boxes at the corners.

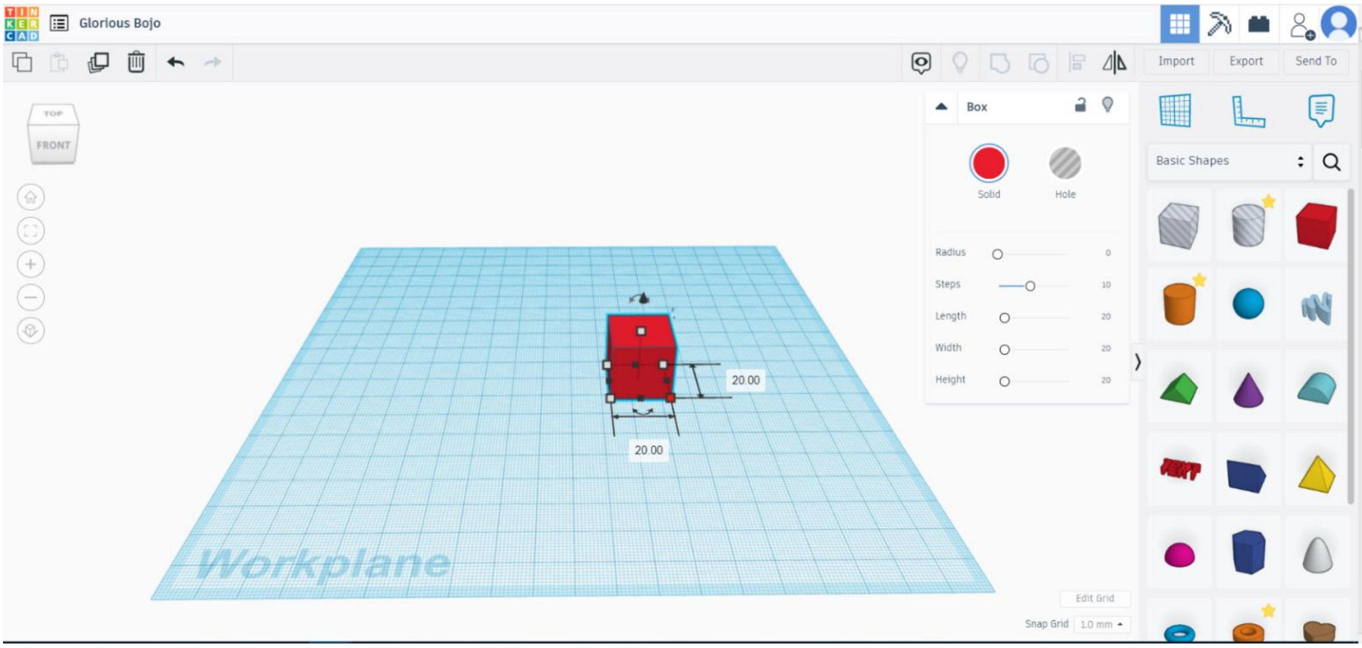
Change the **height** of the shape by clicking and dragging on the small white square on the top of the shape.

You can also change the dimensions by selecting the numbers and entering the numbers you want.

The numbers you see are the dimensions in millimetres.

Let's start by creating a simple car, navigating the different functionalities and tools in Tinkercad!

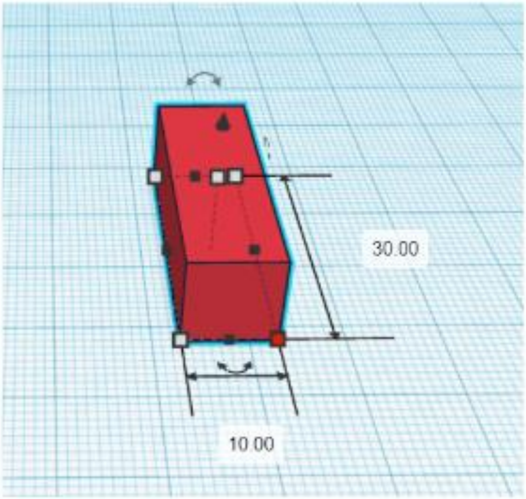
Start by **dragging a solid box** to the Workplane. If you click on the bottom left corner of the square, you will see the length and width of the square.



To change it, just click on the numbers and enter the ones you want (remember, we are working in the default scale of millimeters). To change the height, you can click on the small square on the top and change the dimension. Since we are creating a car, change the dimensions to 10 by 30 by 10. This will create a **rectangle.**

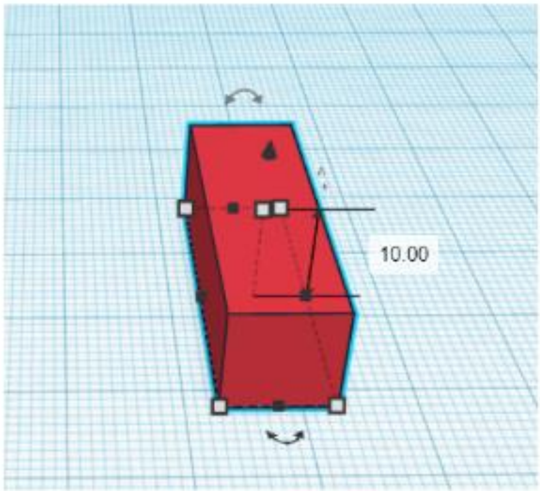
Rectangle's Dimensions

- Width: 10 millimetres (mm)
- Length: 30 mm
- Height: 10 mm



Width: 10 millimetres (mm)

Length: 30 mm

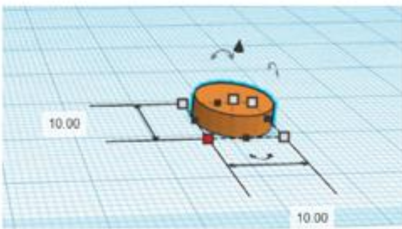


Height: 10 mm

Now that the rectangle is in mid-air, take one cylinder and set the dimensions to 10 by 10 by 3. This will create **one wheel.** Rotate the wheel using the side-ways arrows to change the angles.

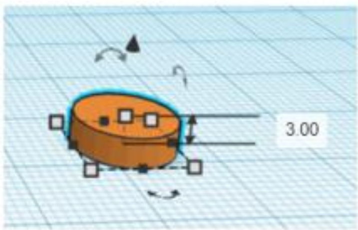
Wheel's Dimensions

- Width: 10 millimetres (mm)
- Length: 10 mm
- Height: 3 mm



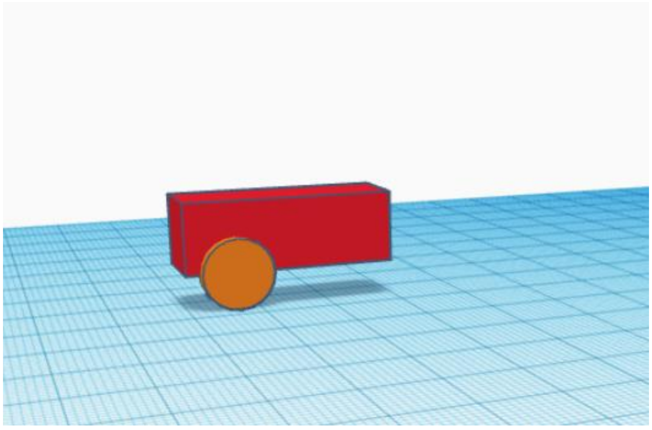
Width: 10 millimetres (mm)

Length: 10 mm

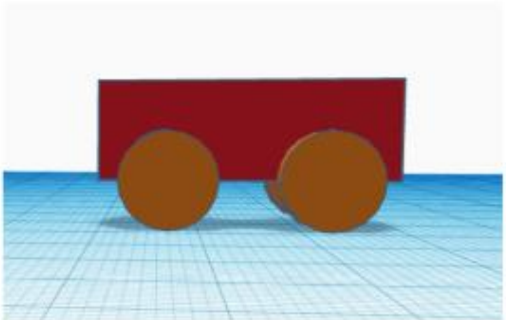


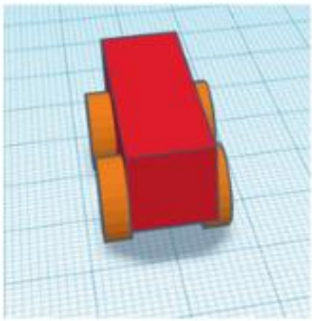
Height: 3 mm

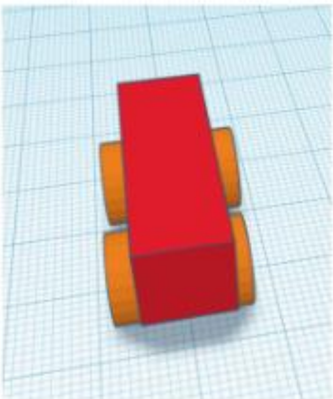
Rotate the wheel, using the side-ways arrows to change the angles.

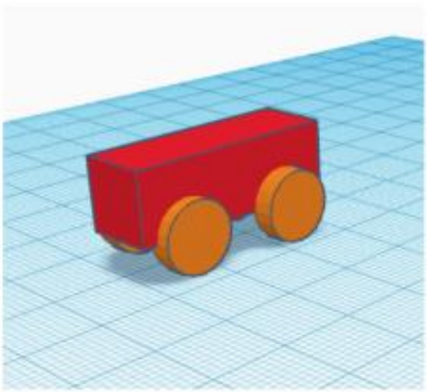


Copy the wheel 4 times **(Ctrl C + Ctrl V)** and place them in their respective locations.









Navigate your model from different perspectives to make sure you have the desired result.

Next, we will add a window to this car. Drag a square and make the dimensions 2 by 5 by 2.

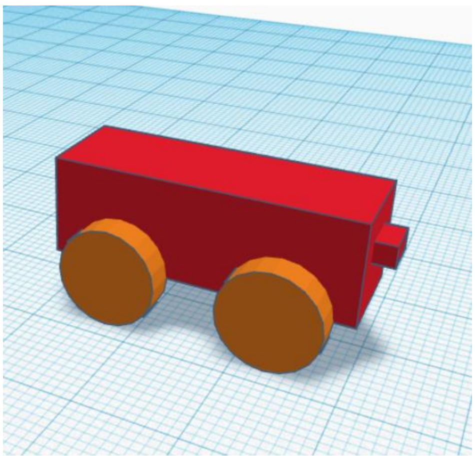
Place the rectangle right in front of the car.

Window's Dimensions

- Width: 2 millimetres (mm)
- Length: 5 mm
- Height: 2 m

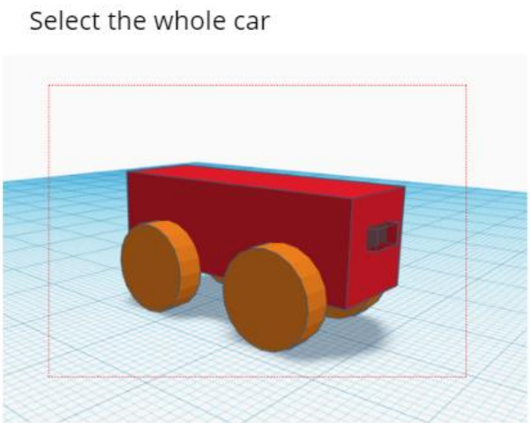
Creating a hole

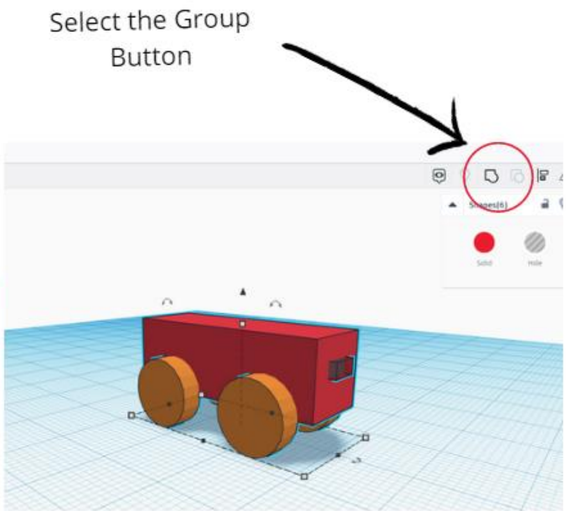
To add a window to the front of the car, move the rectangle - window so that it touches the body of the car. Your car at this moment, should look like this:



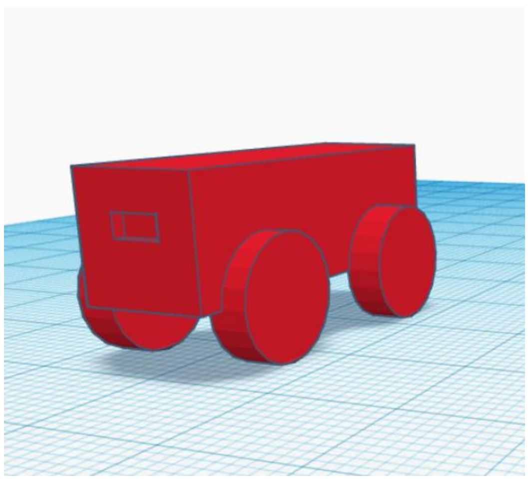
Once that happens, **double-click** on the window, and select **the hole** feature in the menu for the shape.

Now, select the whole object you create and click on Group Button 





A final version of your car is now created! You can make any adaptions you want, from changing the colours to having heart wheels!

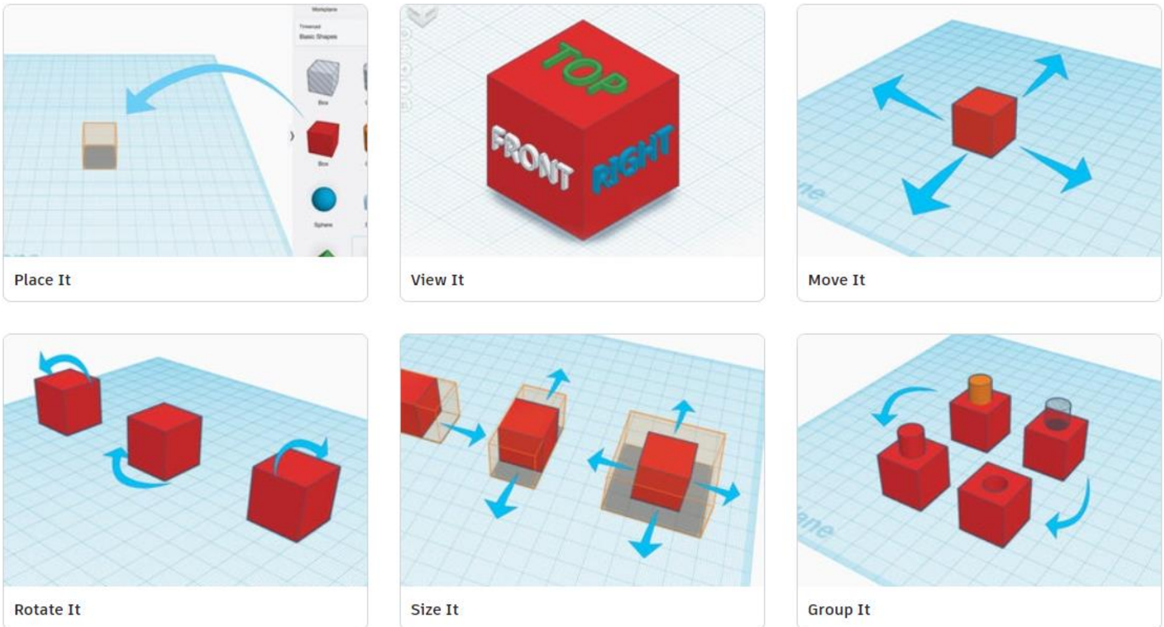


Practice Makes Best: Start Tinkering!

To start exercising on 3D Modelling, you must familiarize with the environment and basic functionalities of the Workplane.

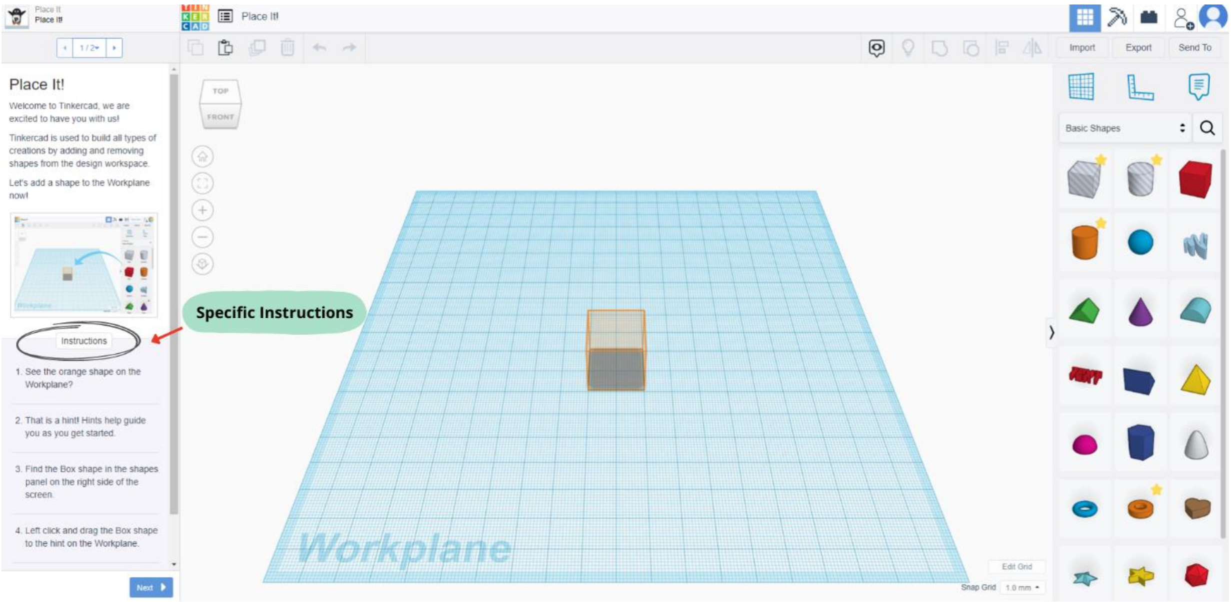
Basic Functions

You can find all the lesson here: https://www.tinkercad.com/learn/designs



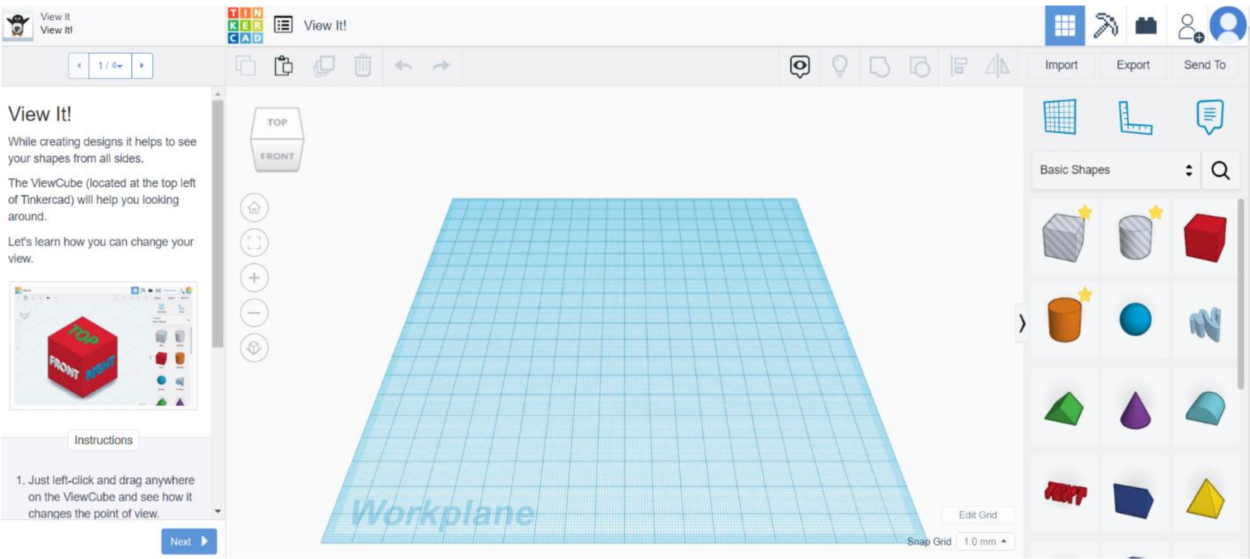
➢ Placing an object on Tinkercad

Placing shapes is one of the most common actions taken in Tinkercad and is simply the act of getting a shape into the design and onto the Workplane.



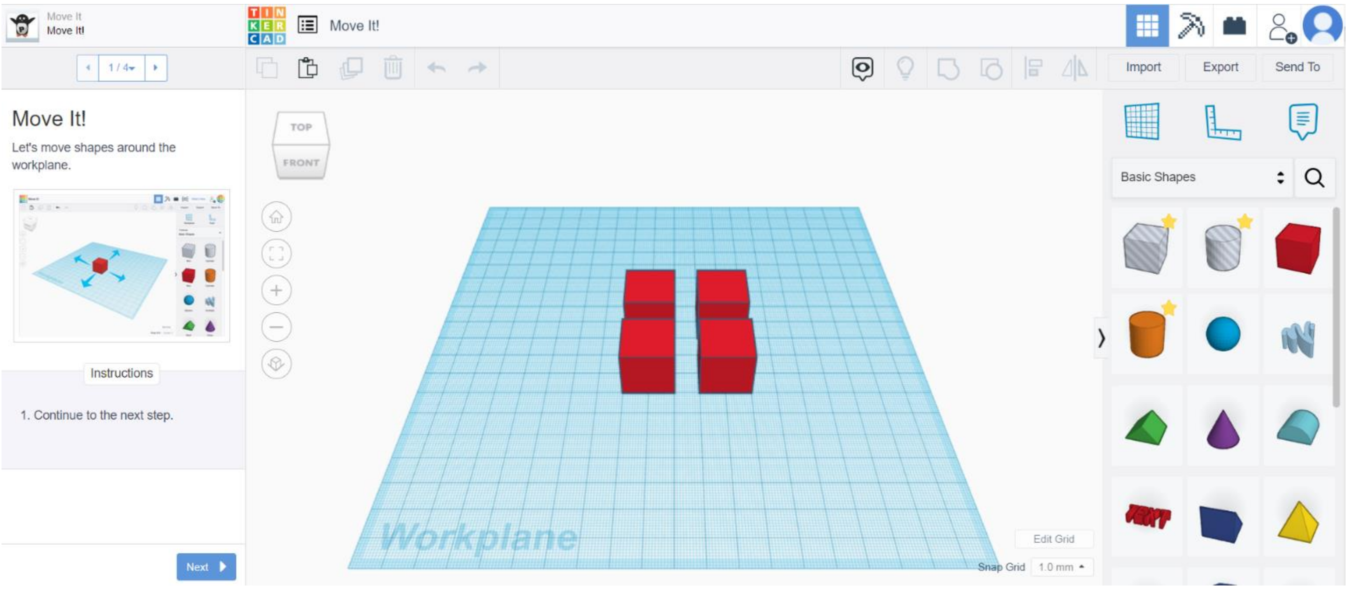
➢ Viewing an object from different perspectives

While creating designs it helps to see your shapes from all sides.
The **ViewCube (located at the top left of Tinkercad)** will help you look around.
Let's learn how you can change your view.



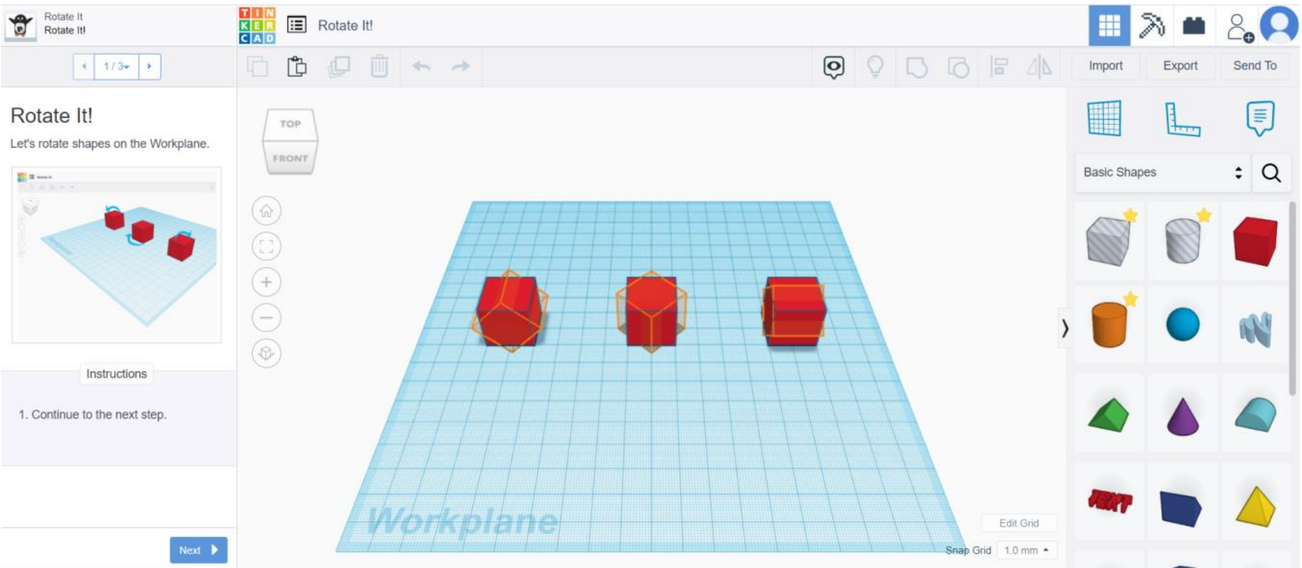
➢ Moving an object on the Workplane

Moving, rotating, and arranging basic shapes is what allows creativity in Tinkercad. The combination of simple shapes allows the creation of more complex and creative designs.



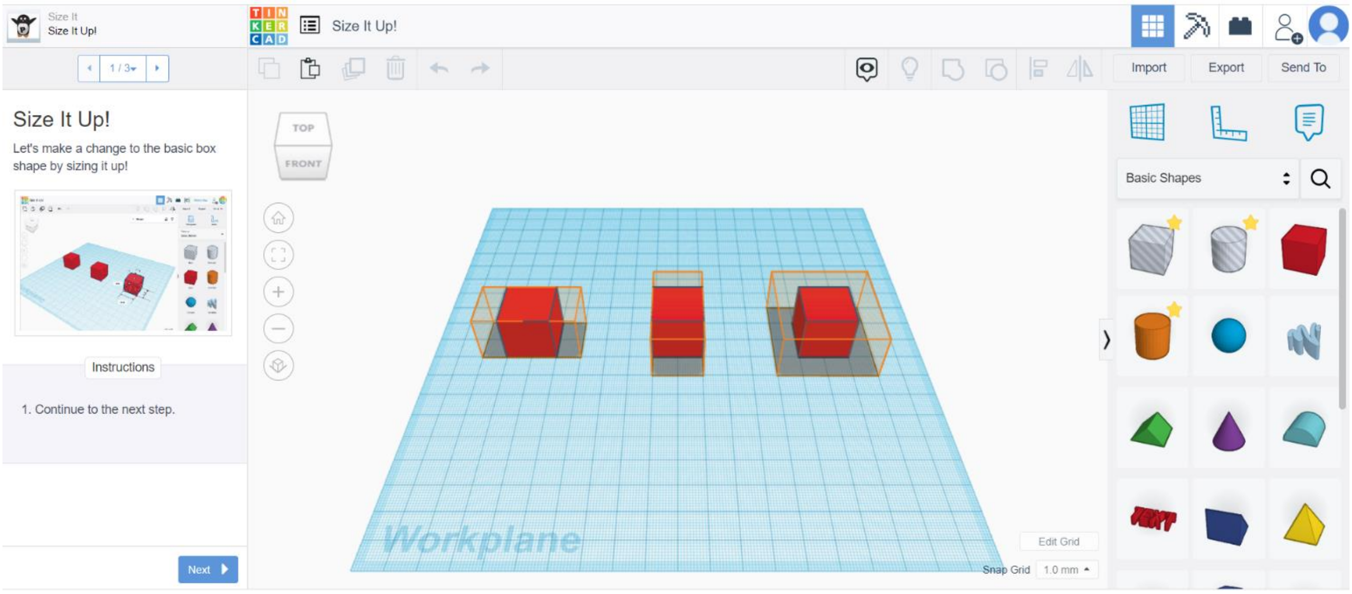
➢ Rotating an object

Let's learn how to rotate shapes on the Workplane.



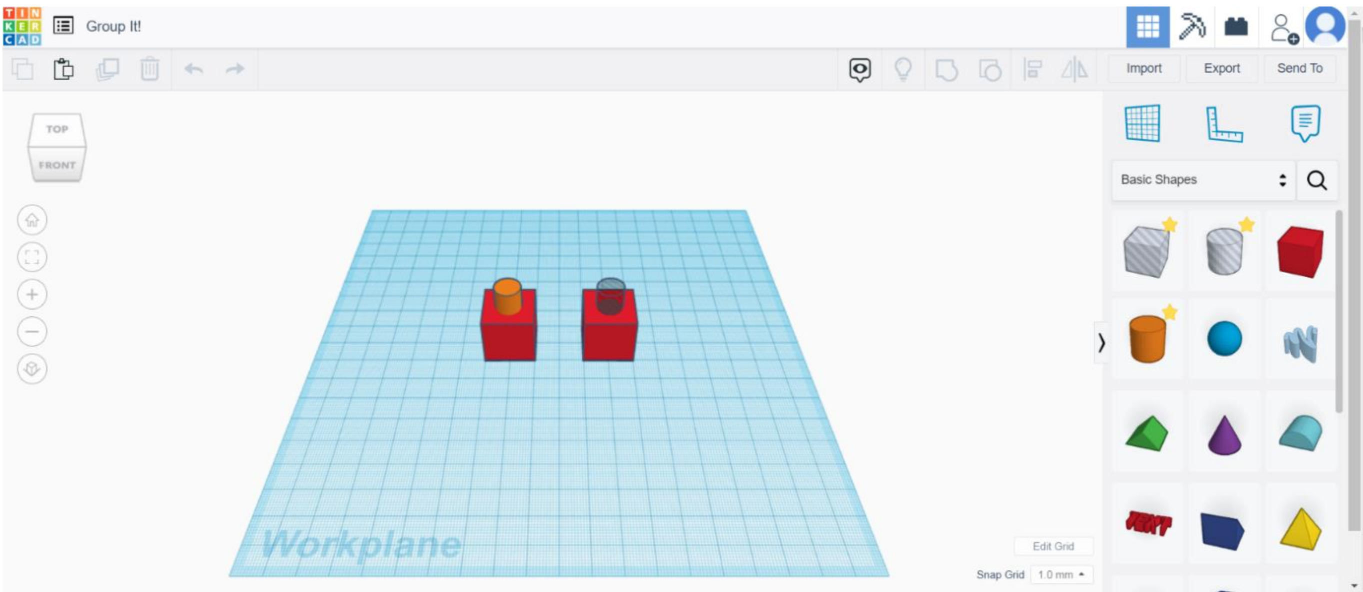
➢ Sizing on Tinkercad

Learn how to change a shape's scale by sizing it up or down.



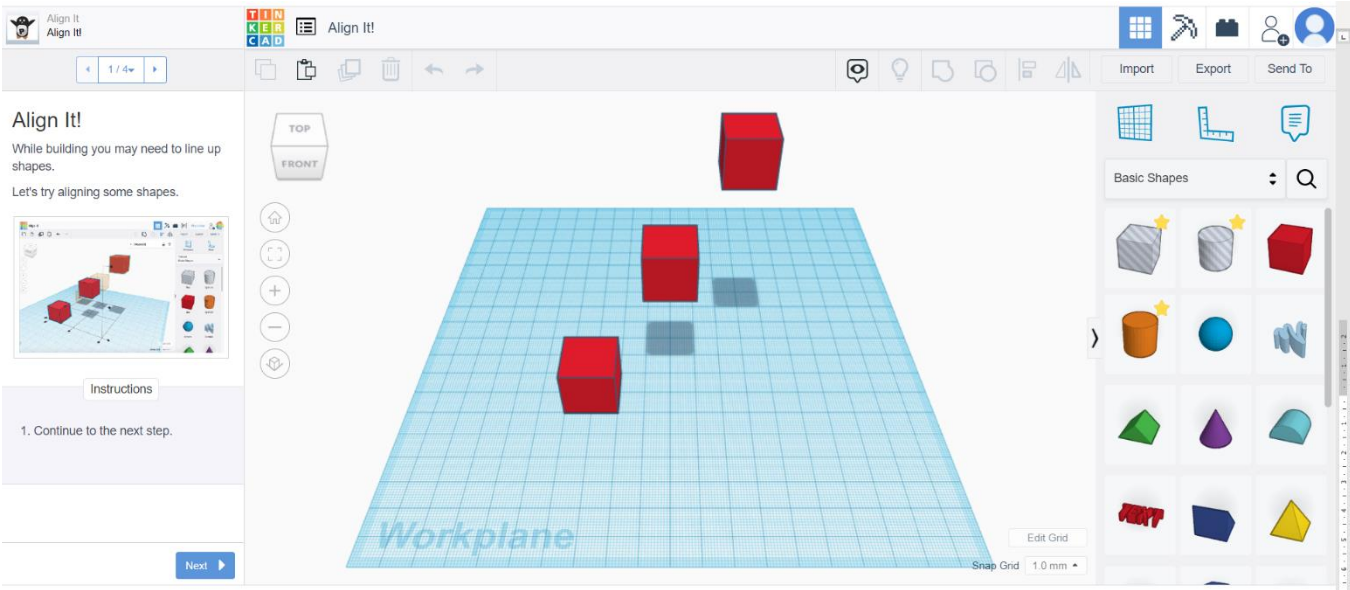
➢ Grouping shapes

Grouping shapes lets you combine shapes into a single object. Any shape in the group can be used to add or remove material from the other shapes it is combined with.



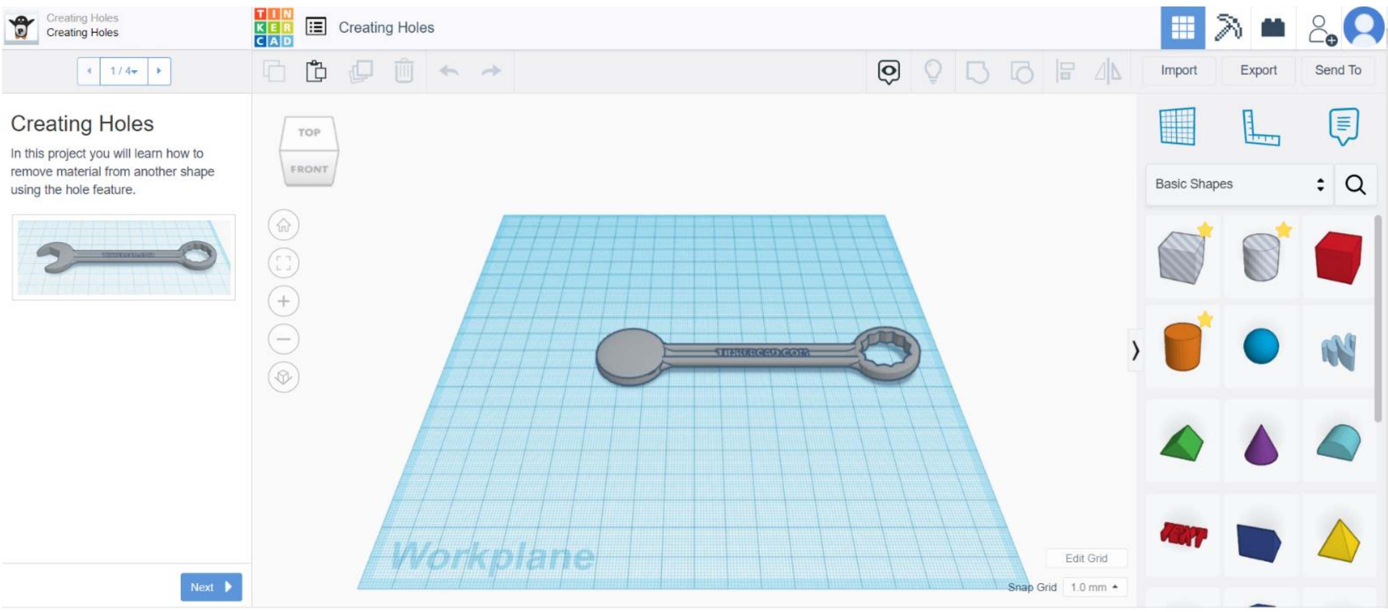
➢ Aligning shapes

While building you may need to line up shapes. Let's try aligning some shapes.



➢ Creating Holes

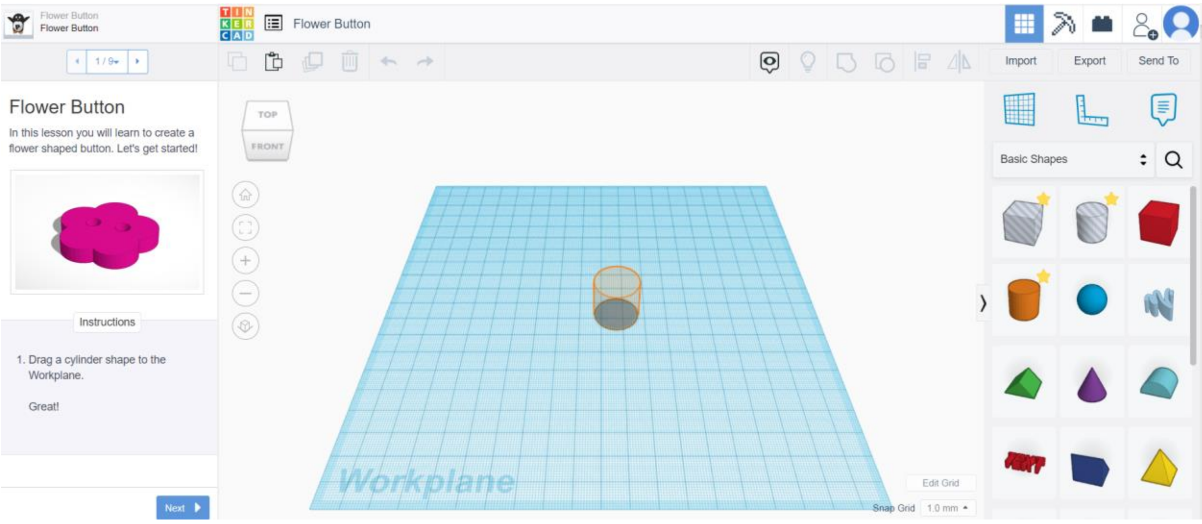
In this project you will learn how to remove material from another shape using the hole feature.



Small Projects to practice on

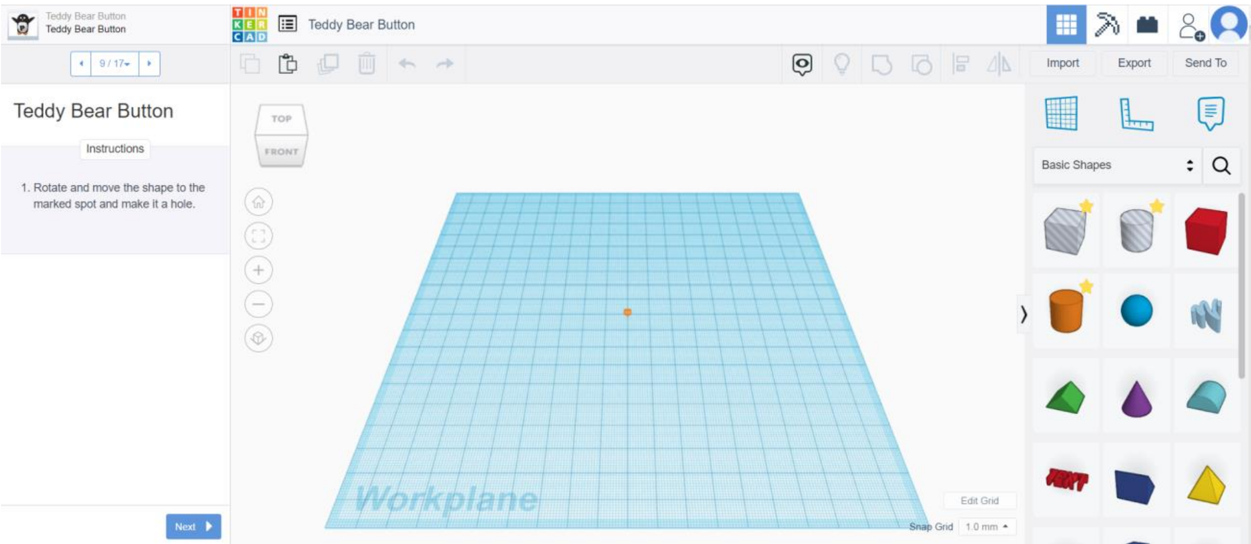
Flower Button

In this lesson you will learn to make a flower shaped button using cylinder shapes.



Teddy Bear Button

In this lesson you will learn to make a teddy bear shaped button with simple shapes.



Bowling Exercise

- Drag and drop the cylinder onto the Workplane.
- Create a total of 6 cylinders on the Workplane using the duplicate or copy and paste methods.
- Position the cylinders so that they form a triangle (three in the back row, followed by two in the middle row, followed by one in the front row).
- Drag and drop a sphere on to the Workplane.
- Lift the sphere 2mm up off the Workplane.
- Take a look of the finished exercise from multiple angles, practising on the rotation and different views of the Workplane.

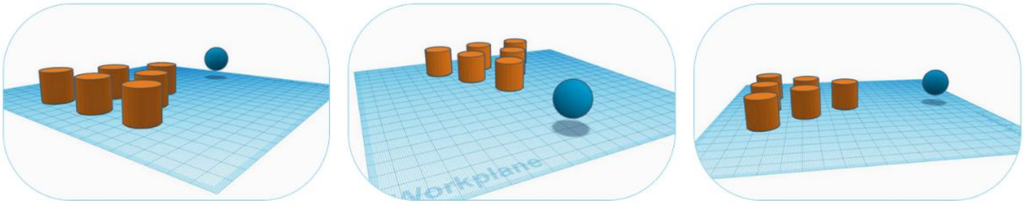


Figure 31 / Bowling exercise

Source: promoambitions.com

Tinker Cup

- Add a cylinder to the Workplane and change the dimensions to… (Side: 60, Bevel: .75, Segment: 10, Length: 20, Width: 20, Height: 30)
- Add another cylinder to the Workplane and change its dimensions to… (Side: 60, Bevel: 0, Segment: 1, Length: 17.5, Width: 17.5, Height: 32)
- Turn the second cylinder into a hole.
- Using the Alignment Tool, place the hole cylinder in the centre of the Solid Cylinder, making sure the hole cylinder is 2mm off the Workplane (to ensure it doesn't cut off the bottom of the cup when grouped).
- Group them together to create your mug.

Bonus: create a handle using a torus and attach to the cup. (Make sure the handle does not protrude into the inside of the cup).

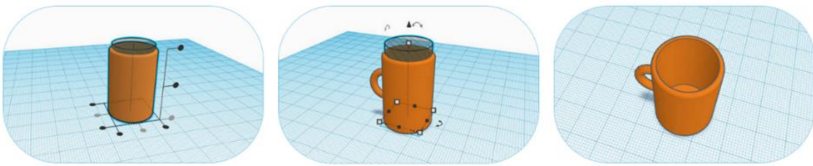


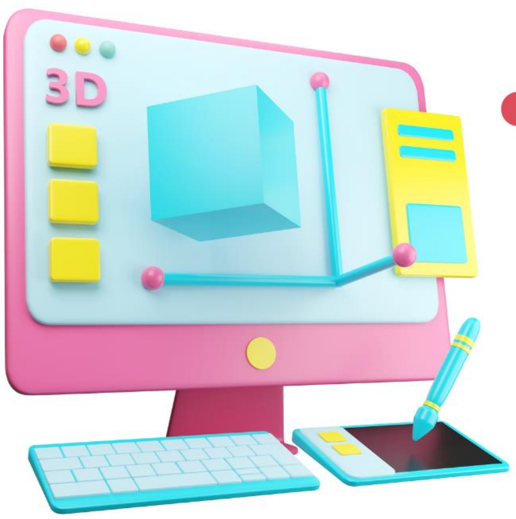
Figure 10 / TinkerCup exercise

Source: promoambitions.com

Unit 4

Slicing your model

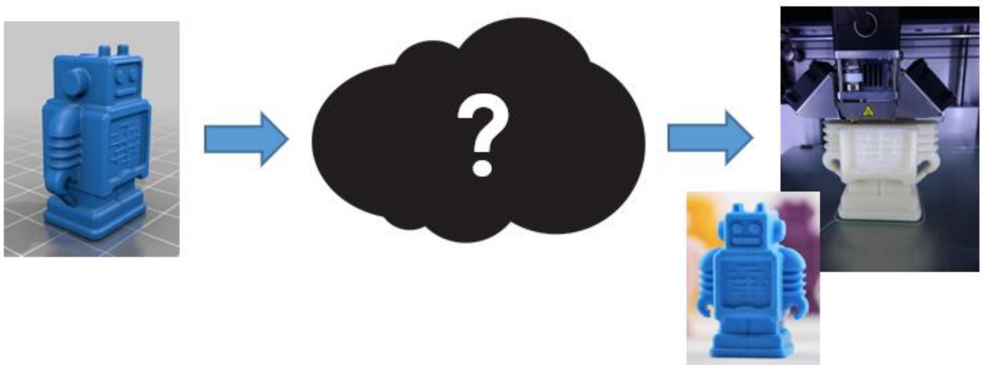
Introduction to Cura



Chapter 5:

Slicing Software: Introduction to Cura

As we now have the knowledge to 3D Model an object, the main question is:
How can we get from a 3D model to a 3D printed object?



We know that several supporting tools are necessary for 3D Printing. We obviously have the 3D model and the 3D printer, but there's an instrumental piece to the puzzle between those two points. **3D printing slicer software** acts as the middleman between the 3D model and printer.

Slicing a 3D drawing translates the 3D drawing into a language that a 3D printer can understand and print.

Slicing software is an essential part of 3D printing because 3D printers cannot translate CAD drawings themselves. A 3D printer needs the specifications of the object it is designing to be translated into a language that it can interpret.

If you want a slightly more technical explanation, slicing converts a digital 3D model into **G-codes** (a generic term for a control language) that a 3D printer can understand.

G-codes contain instructions for the 3D printer. In other words, G-code tells the 3D printer how to print the model. Without G-code, a 3D printer is useless!

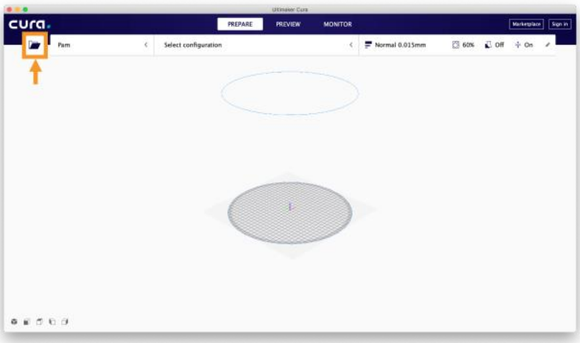
General Introduction

Basic slicing software – in fact, all slicing software – will create paths for a 3D printer to follow when printing. These paths are instructions for geometry, and they tell a 3D printer what speed to print at for various points and what layer thicknesses to adopt, if applicable (sometimes it is best to do this manually). There are many slicing softwares someone can use.

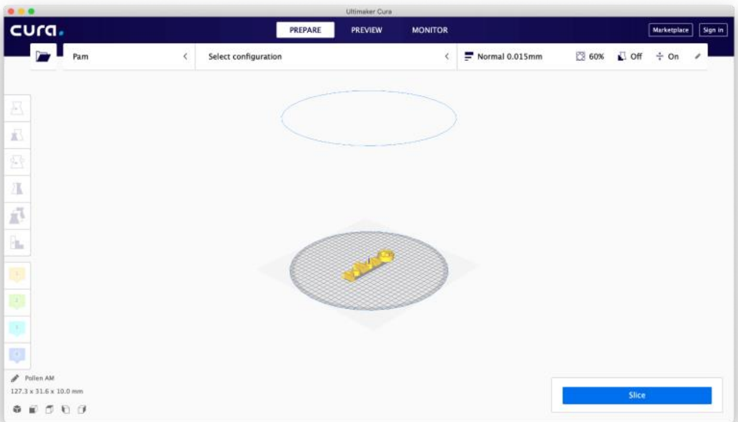
One of the most preferred software, Cura was developed by Ultimaker to make 3D printing as easy and efficient as possible. **It contains everything you need to prepare a 3D file for printing.** It is fully preconfigured to work on every Ultimaker model. Cura comes with an easy-to-use setup program that helps you install the latest firmware and to calibrate your printer. While you are making decisions about the appearance and quality of your 3D object, Cura's slicer engine prepares your model in the background faster than ever before. From there It is just seconds away from your printer and ready to become your physical object. This program is not only free for you to download, but it is also open source.

Import 3D file

Cura slicing software recognizes a wide range of file formats (STL, OBJ, X3D, 3MF, BMP, GIF, JPG, PNG, etc.). They differ from the file formats that are native to the CAD software used. These file formats are triangulated 3D files.



Unlike common CAD 3D files, a triangulated 3D model holds only the surface of the object and not the individual primitives and editable content. The surface of the object then consists of an accumulation of triangles whose size can vary according to the resolution chosen when converting to the triangulation format.



A simple "Drag & Drop" action is necessary to import the 3D model to Cura slicing software.
It is also possible to click on the floating folder icon on the left or select File > Open File(s) from the top menu.

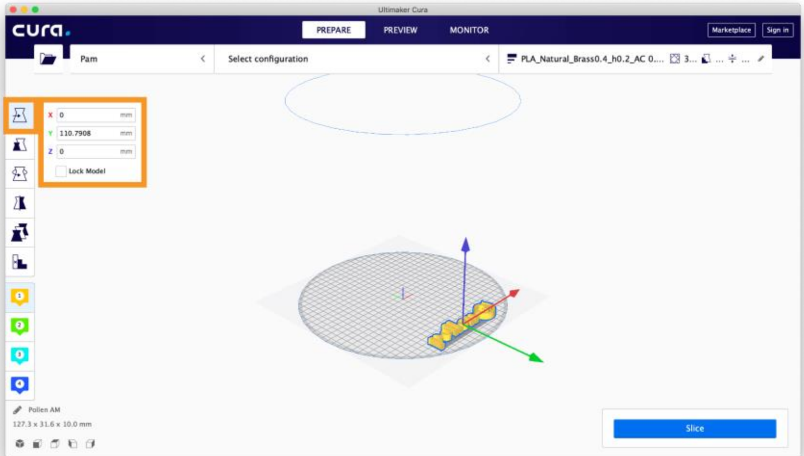
The model then appears on the build-plate, the waiting time for it to appear depends on the size of the 3D file.

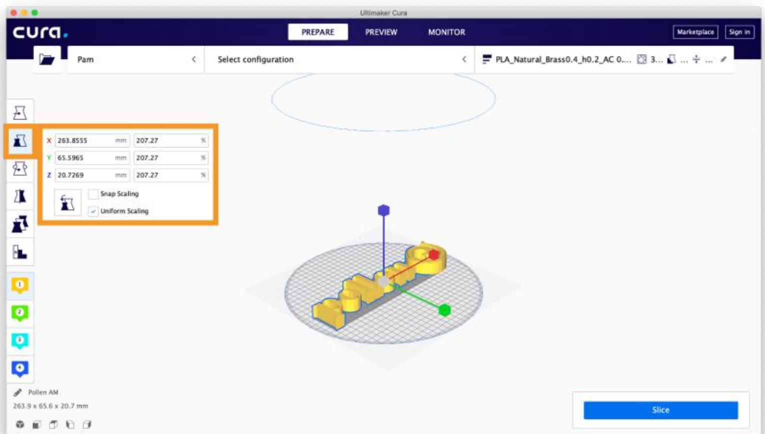
Prepare 3D file

Sometimes parts need to be moved, scaled, rotated or multiplied. This is fully accessible with just a few clicks thanks to the "Tools panel".

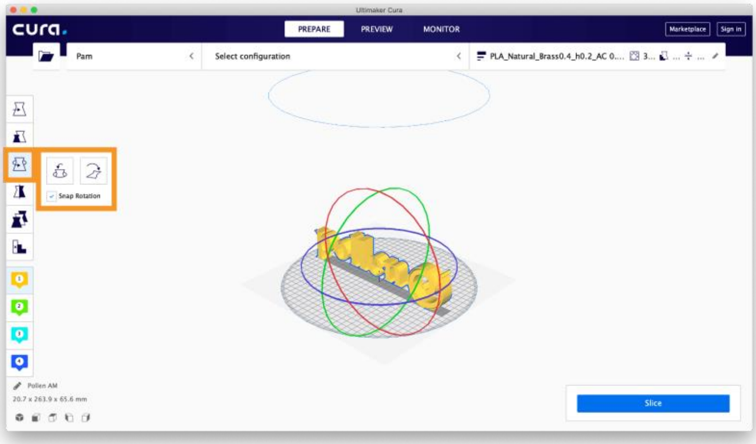
If the 3D model needs adjustments, all we need to do is click on the 3D part and then select the option from the "Tools panel" on the left.

Depending on the selected "Tool option", specific arrows or hoops will appear around the model.
To modify the part, you can either use the arrow/hoop that appears of enter the information directly on the open panel. The change can be cancelled by clicking right on the part then on the button “Reset”.



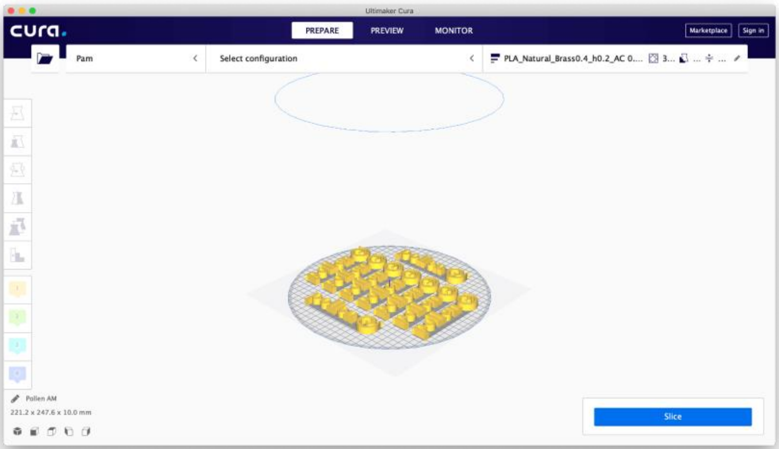


Example of a 3D model scale with the slicing software.



Example of a 3D model rotation with the slicing software.

On the plate, more than one model can be produced. The only limitation is the volume of the parts positioned on the build-plate.
To multiply the part, right-click and select duplicate. The additional parts will be automatically repositioned.

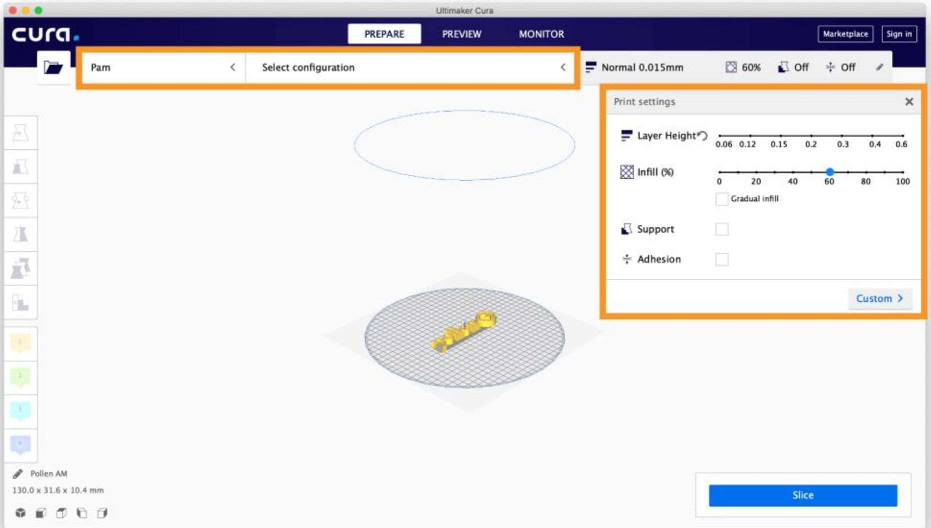


Example of a 3D model replicates with the slicing software.

Apply parameters to the 3D file

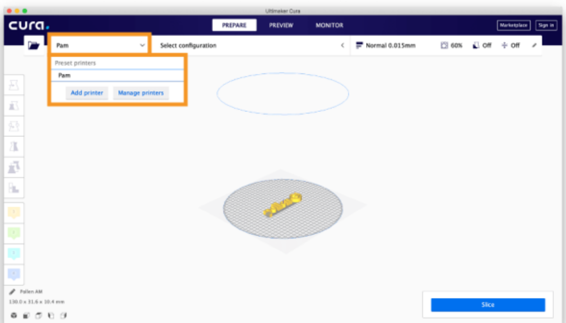
The slicing "Settings panel" is divided into two sections, one dedicated to the 3D printer settings and the other to the printing settings.

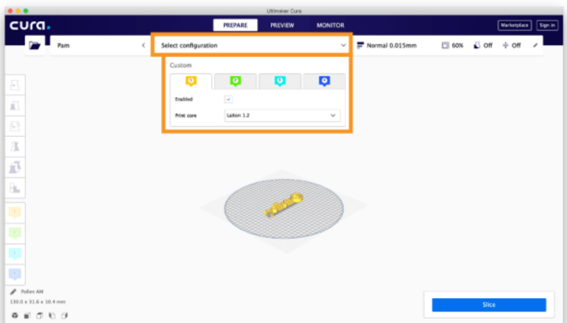
The top section of the slicing software is dedicated to the 3D printer settings and the right section to the printing settings.



Printer settings

This section allows the user to select the right 3D printer and its configuration (nozzle specifications).



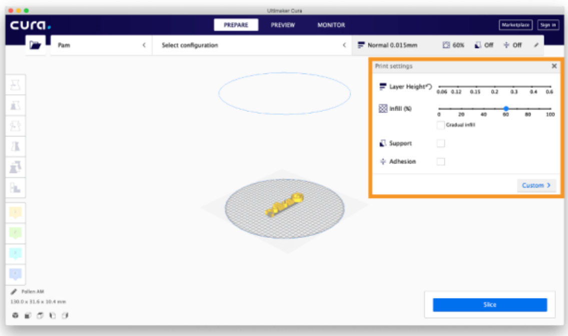


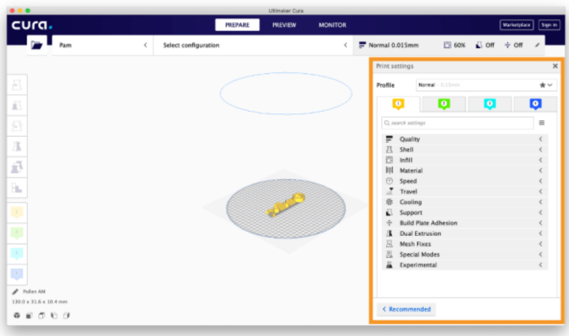
3D Printer: Select the 3D printer. If other 3D printers are installed, it is necessary to select the right one from the drop-down menu.

Configuration: Quickly select the mounted nozzle per each extruder.

Print settings

Two modes are accessible to the user, Recommended and Custom.





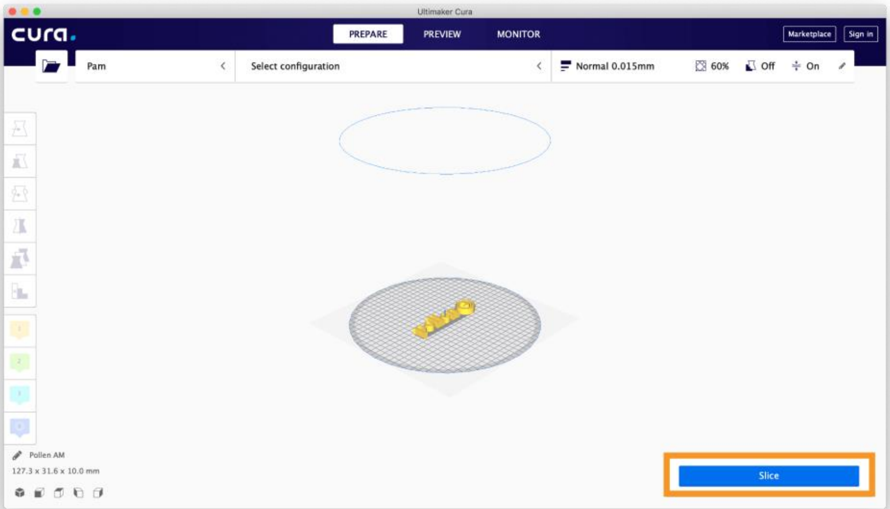
Recommended: Options are limited under the Recommended mode. It gives access to four mains 3D printing parameters: the layer height, the infill percentage, enable support structure and build plate adhesion.

Slice, visualize & export

The slicing procedure consists in interpreting the 3D file in a series of 2D plans according to the selected 3D printing parameters. This step will result in a digital interpretation that can be viewed in the slicing software. Once validated, it can also be assessed in a G.code file.

Slicing

An accessible button is present to allow the slicing procedure, by clicking it. The "slicing" button launches the analysis and interpretation process.



Once sliced, the parts interpreted in a succession of 2D plans can be analysed by the user. This way, the adequacy of the printing parameters with the 3D file can be checked.

Visualization

This section allows the user to select the right 3D printer and its configuration (nozzle specifications).

Selecting your 3D Printer

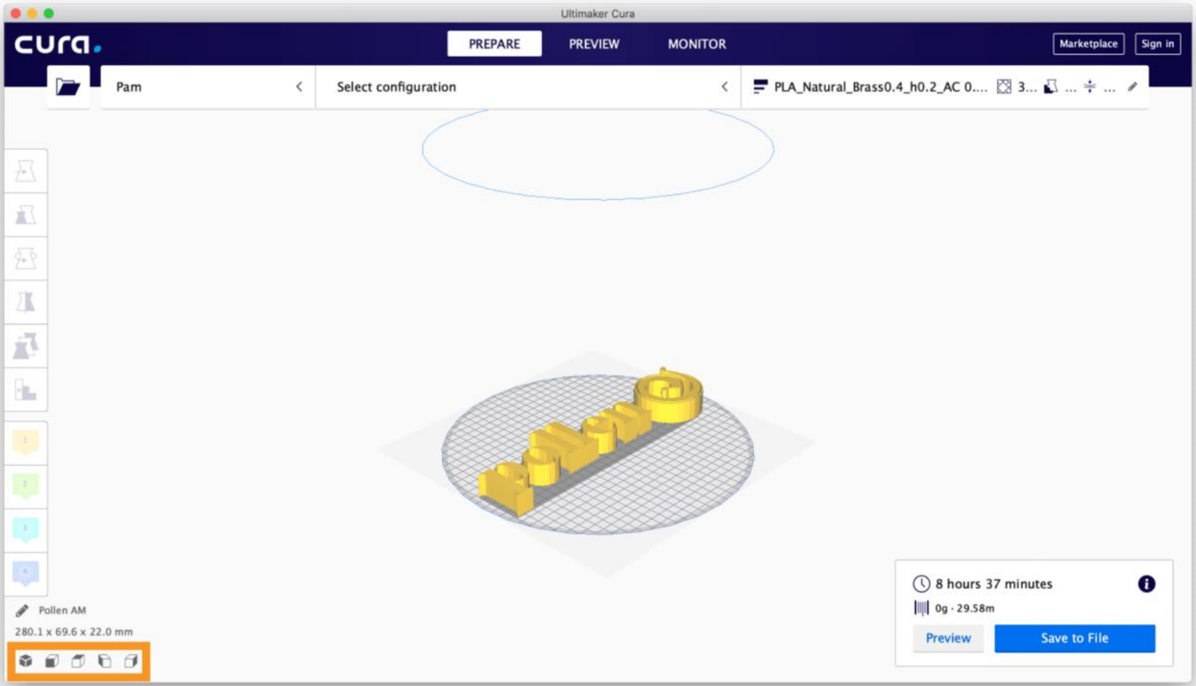
Select the 3D printer. If further 3D printers are installed, it will be necessary to select the right one from the drop-down menu.

Configuration: Quickly select the mounted nozzle per each extruder.

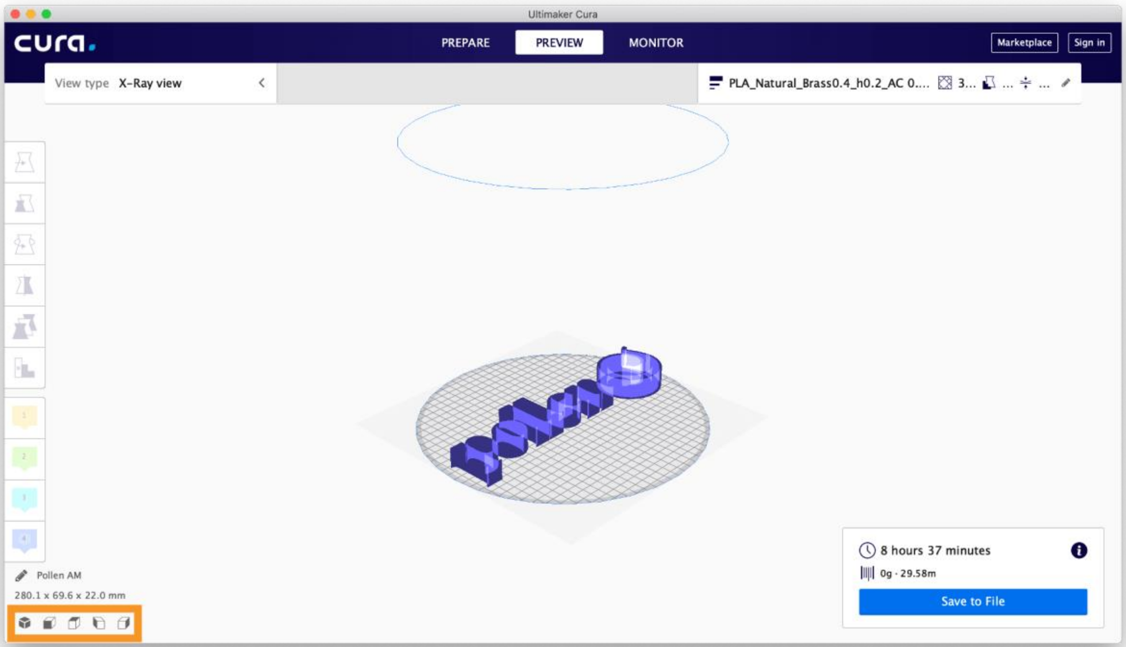
Print settings
There are three basic ways to view the model:

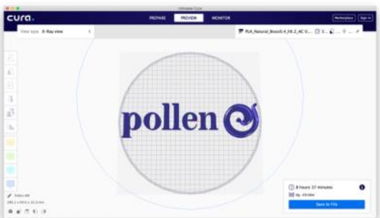
- Solid
- X-Ray
- Layers

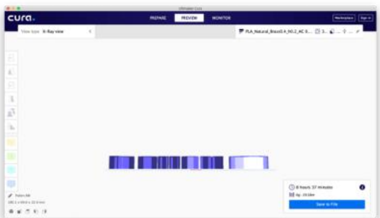
Solid visualization: this is the default view that enables to have a global vision of the part, size, printing orientation, etc.
Using the navigation settings to change the viewpoint can also be useful.



X-Ray visualization: available under the preview settings, this function allows analysing the internal structure of the 3D part, and to understand which part element needs to be reworked.
Using the navigation settings to change the viewpoint can also be useful.







Layers visualization: also available under the preview settings, this function is important to know, by using it allows to maximize the success rate of its prints and to check that the file has been interpreted correctly. This function allows the display of different elements, such as material, line type, federates and layer thickness.
The layer-by-layer material deposition strategy is also displayable.

Using the navigation settings to change the viewpoint can also be useful.

Sending the G-code to the 3D Printer

For the last part, we have to connect our 3D Printer with the model we have created.

In most cases, sending a G-code file to a 3D printer is a simple task that allows you to create beautiful and creative 3D printed models. After creating your G-Code file from your slicer, there are a few ways to send it to the 3D printer:

- **Inserting (Micro) SD Card into your 3D printer**
- **USB Cable connecting your 3D printer to a computer or laptop**
- **Through Wi-Fi connectivity**

Inserting (Micro) SD Card Into Your 3D Printer

Using an SD card is one of the most common ways of sending the G-Code to your 3D printer. Almost all 3D printers have an SD card slot and are often used for exactly this purpose.

You can easily send the G-Code to an SD or MicroSD card after slicing your CAD model on the computer or laptop. Many 3D printers come with a MicroSD card and a USB card reader, which allows you to save files directly.

AD

Save the G-Code file onto the MicroSD Card and insert it into the MicroSD card slot on the printer.

This is probably the most used method of sending G-Code files to a 3D printer, due to its simplicity and effectiveness to get the job done without extra applications or devices.

Try not to make the mistake of unplugging the SD card while in the 3D printing process or your model will stop.

USB Cable Connected to a Computer or Laptop

Instead of using an SD card, you can connect your 3D printer directly to your computer or laptop with a simple cable. This is a less common method, but it's especially effective in 3D printing.
The only downside to this option is that when you're using your laptop, you must keep your laptop running all the time because the sleep mode can stop the printing process and ruin your project.

Sending G-Code Through Wi-Fi Connectivity

An increasingly popular way to send G-Code to 3D is the Wi-Fi option. This option has changed the whole 3D printing scenario and taken the printing experience to the next level.

There are many applications and software that can be used for this process such as OctoPrint, Repetier-Host and AstroPrint.

Keyboard Shortcuts

Moving Object (s):

- ←/ ↑/ →/ ↓ = Move an object along ground plane (X/Y Plane)
- Ctrl + ↑/ ↓ = Move an object up or down (Z plane)
- Shift + ←/ ↑/ →/ ↓ = Move an object 10X faster along ground plane (X/Y Plane)
- Ctrl + Shift + ↑/ ↓ = Move an object 10X faster up or down (Z plane)
- Shift + drag = moves object in only one direction
- D = Drop selected object(s) to workplace

Press and hold the keyboard keys and then click/drag mouse for the below shortcuts…

- Shift + Right click = Pan view
- Alt+ left mouse button = Duplicate object(s)
- Shift+ left mouse button = Select more than one object
- Shift+ hold while rotating = 45-degree rotations

Helpful object action shortcuts…

- ctrl + C = Copy an object or selected objects
- ctrl+ V = Paste an object or objects
- ctrl+ Z = Undo action or actions
- ctrl + Y = Re-do an action or actions
- ctrl + D = Duplicate object or objects in place
- ctrl+ G = Group objects
- ctrl+ shift+ G = Un-group grouped objects
- Del = delete an object or objects

Object Options:

Select object(s) and then perform the following action(s)…

- T = Transparency Toggle
- H = Make an object or objects a hole
- S = Make an object or objects a solid
- ctrl + L = Lock or unlock selected objects
- ctrl + H = Make an object hidden
- ctrl + shift + H = Make all hidden objects visible again

Change the size of an object:

- Alt + click and drag side handle = Scale in one direction
- Alt + click and drag corner handle = Scale in two directions
- Shift + click and hold corner handle = Uniform Scale
- Alt + Shift + click and hold corner handle = Uniform scale from center

Tools and Views

- W = Create new workplane
- L = Align tool
- R = Ruler tool
- M = Flip tool
- F = A better view of selected objects
- Ctrl + A = select all visible shapes

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