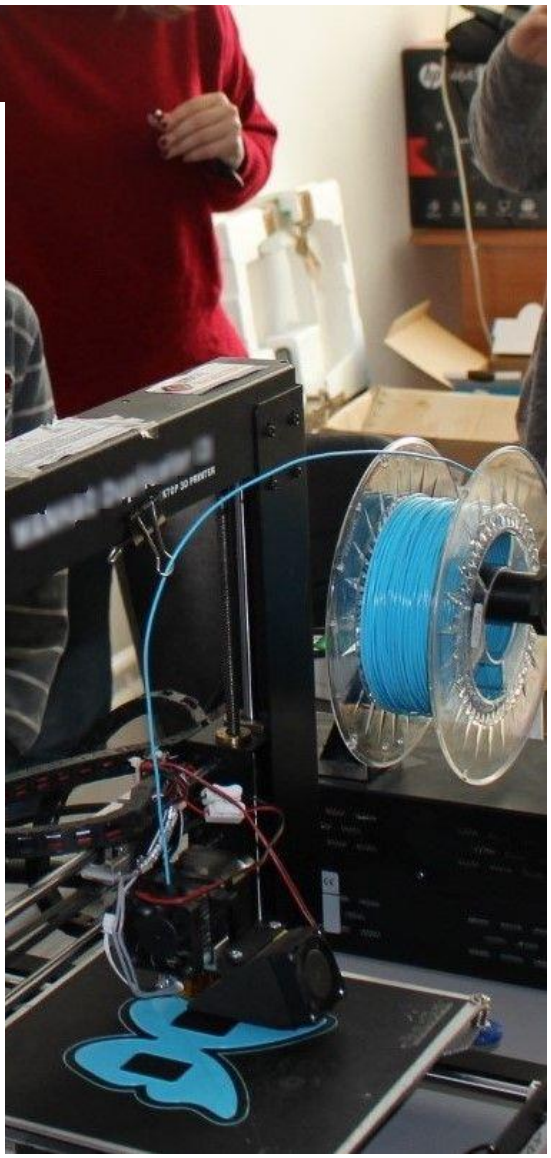
3DP Teacher's Guidebook



3DP TEACHER - implementation of 3D Printing in future education

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Introduction

3D printing (3DP) is poised to have a significant impact on many aspects of our lives and work in the near future. Some effects on the market and on the society are already visible and many other transformations are expected. 3DP market is developing fast as 3DP is implemented in many applications in more and more various areas. The job market is also significantly affected by 3DP and a growth in the number of related jobs is expected.

3DP is increasingly used in schools all around the world, and its potential is becoming widely recognized. Many teachers consider this innovation in the sector welcome and necessary, but they very often lack the specific knowledge required to master this technology. The present material aims at providing basic info on 3DP in order to help teachers to understand what 3DP is and how it works, its applications in various sectors, its impact on the market, future trends, and what benefits it may bring to education.

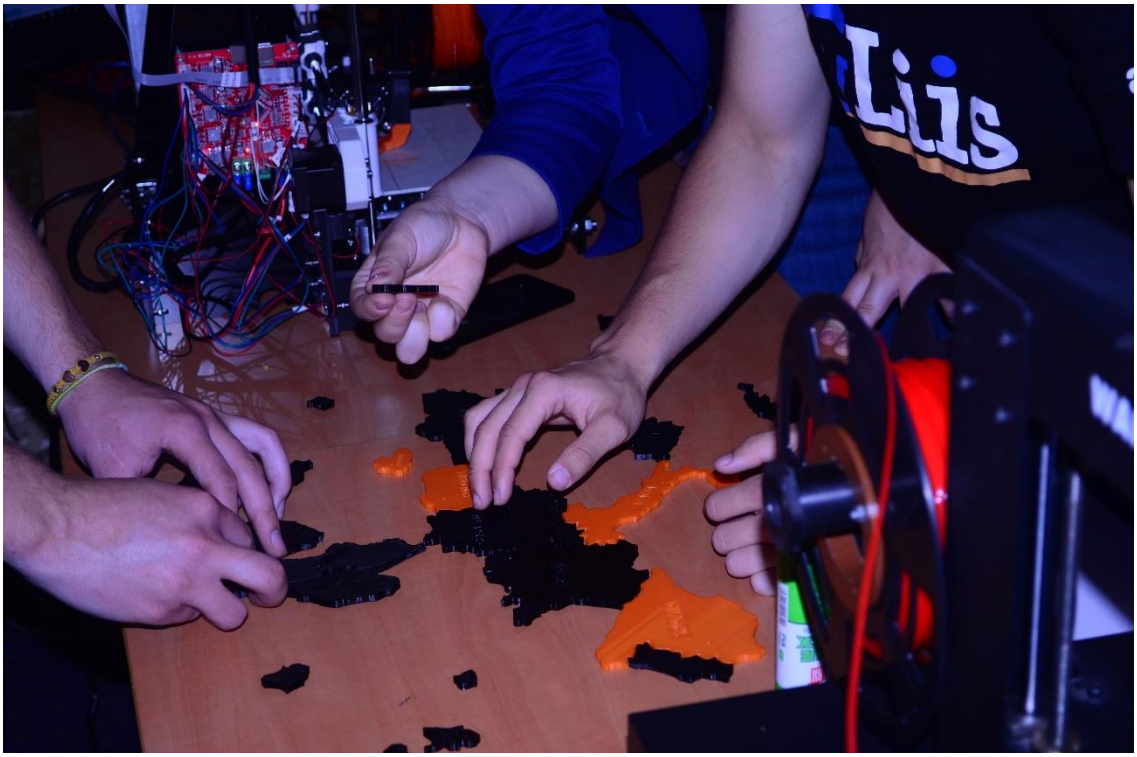


Figure 1 – Students and 3DP

What is 3D printing?

3D printing is a general term for a set of technologies that can build three-dimensional objects from a digital file by adding material layer after layer. Nowadays, there are many 3DP technologies available based on different approaches and making use of various materials (plastic, metal, concrete, chocolate, etc.) in several forms (liquid, solid (sheet, filament, and pellet), powder, and slurry).

For example, the technologies called Stereolithography (SLA) and Digital Light Processing (DLP) create objects by selectively curing a liquid photopolymer resin using a light source (a laser or projector) while Selective Laser Sintering (SLS) uses a laser which selectively induce fusion between powder particles inside a build area to create a solid object. Other technologies lay down molten chocolate, deposit droplets of materials, which are then selectively cured, jets binder on powder, etc.

Most of these technologies cannot be used in the classroom because are too complicated, too expensive or require special facilities. The most suitable for use in a school environment is Fused Deposition Modelling (FDM) that is, also, the most popular and affordable 3DP technology.

Fused Deposition Modelling

Fused Deposition Modelling creates objects by melting a plastic wire (called filament) and applying it, layer after layer, through a heated nozzle.

The process is schematised in Figure 2. The filament (2), usually wound on a spool (1) held on the sides or at the back of the printer, is fed through the gear mechanism of the extruder (3) that pushes it towards the heater (4) where the solid filament is heated to its melting point. Finally, the molten filament is ejected from the nozzle (6) onto the print bed (7) in the desired geometry. After each layer, the print bed (or the nozzle) moves on the vertical axis and the next layer is added. After printing, the object can be removed by hand or with a simple scrapper. If necessary, the parts can be further processed by sanding, polishing, painting, etc.

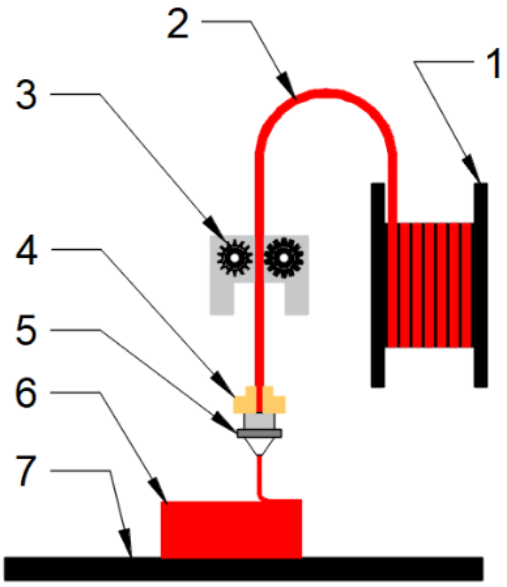


Figure 2 – FDM Process

1-filament spool; 2-filament; 3-feeder; 4-heater; 5-nozzle; 6-3d printed object; 7- print bed

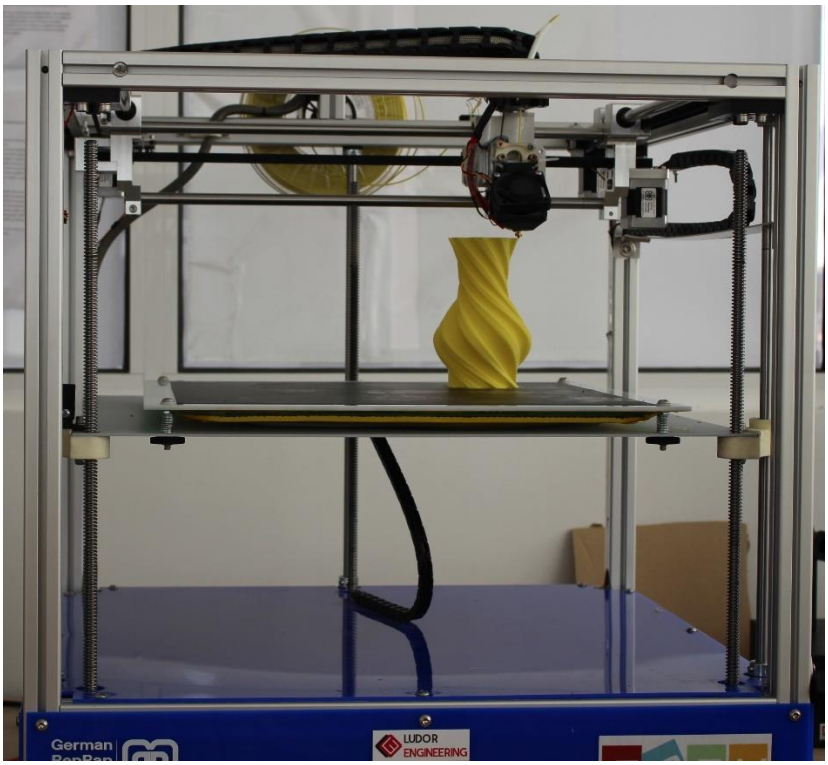


Figure 3 – FDM 3D printing

The 3D printing workflow

In general, regardless the specific technology, 3DP involves the use of a computer, a digital 3D model, a 3D printing slicer software, a 3D printer and raw materials. Typically, schematised in Figure 4, a 3DP process is composed from the following steps:

1. The 3D model of the object to be 3D printed is obtained through one of the methods discussed below.
2. If necessary, the 3D model is translated into a 3D printing file, usually STL type.
3. The 3D printing file is prepared for printing, process finalised with the generation of a G-code file that includes layer-by-layer toolpath with specific machine settings and preferences.
4. The G-code file is run on the 3D printer and the model is printed.
5. If necessary, the part is finished (cleaned, polished, painted, etc.).

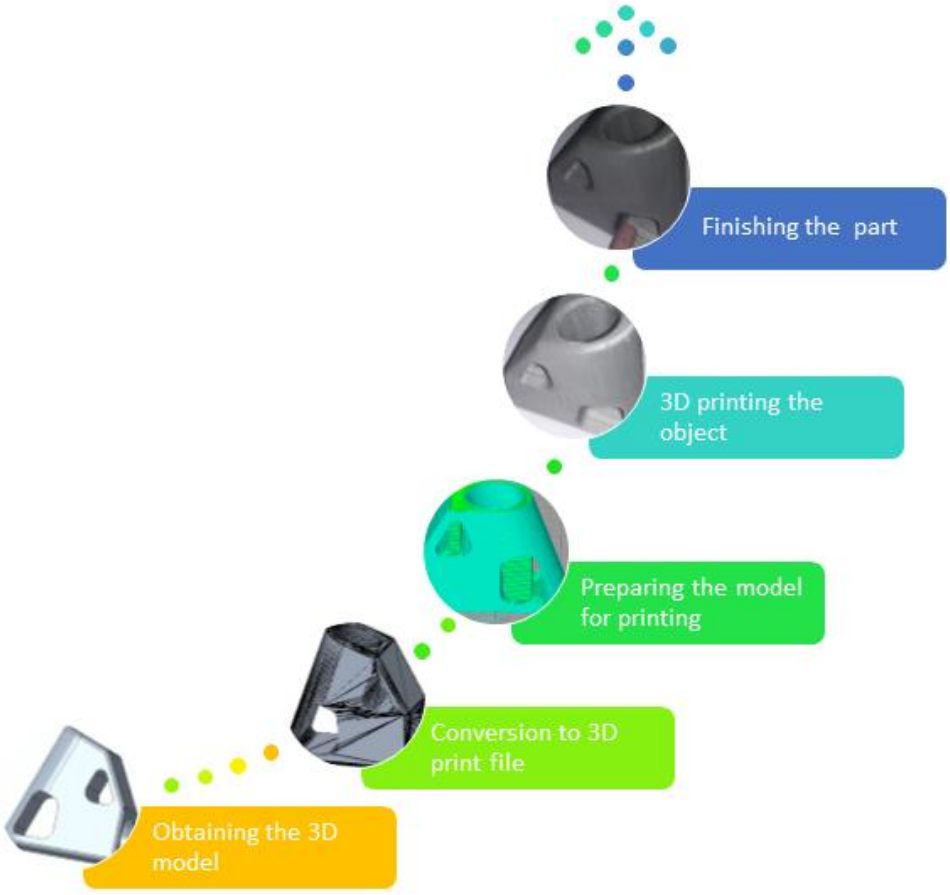


Figure 4 – 3DP steps

Obtaining the 3D model

3DP starts with the 3D model of the object to be printed. This can be obtained by computer modelling it, from 3D scanning or can be downloaded from a 3D model repository. The main advantage of creating the model through 3D modelling is the ability to design exactly what desired as opposite to 3D scanning (only already existing objects can be scanned) or repositories.

3D modelling

There are many different 3D modelling software tools available, from very expensive industrial grade software to free open source software. Some examples are given in the below table. A very good option for beginners is to start with TinkerCAD that is free and does not require installation on the computer.

Table 1 – 3D modelling software tools

Name	Link	Level	Free/paid
TinkerCAD	www.tinkercad.com/	Beginner	Free
Blender	www.blender.org/	Intermediate	Free
FreeCAD	www.freecadweb.org/	Intermediate	Free
OpenSCAD	www.openscad.org/	Intermediate	Free
Autodesk Fusion 360	www.autodesk.com/products/fusion-360	Industrial	Paid*
SolidWorks	www.3ds.com/	Industrial	Paid*
Creo	www.ptc.com/en/products/cad/creo	Industrial	Paid
SketchUp	https://www.sketchup.com/	Beginner	Free /Paid

*Students and educators can apply for a free Fusion 360 three-year license.

3D scanning

3D scanning captures the shape of an object with the help of a 3D scanner or a smartphone having a suitable application installed. Such an application for 3D scanning apps creates 3D models from 2D photos taken with the phone from different angles using a technique called photogrammetry. Some examples of 3D scanning apps are given in the next table.

Table 2 - 3D scanning apps

Name	Operating system	Free/paid
Qlone	iOS/Android	Free

Trnio	iOS	Paid
Scann3D	Android	Free
Cappy	iOS	Free
Heges	iOS	Free
Sony 3D Creator	Android	Free
Capture	iOS	Free
Scandy Pro	iOS	Free
display.land	iOS/Android	Free

3D model repositories

The simplest way to get a 3D model is by downloading it from one of the many available online repositories (see the below table). Many of these models are free and some repositories offer the ability to customise some of the models.

Table 3 – 3D models repositories

Name	Link	Free/paid
Thingiverse	www.thingiverse.com	Free
MyMiniFactory	www.myminifactory.com	Free, Paid
YouMagine	www.youmagine.com	Free
Cults	https://cults3d.com	Free, paid
STL Finder	www.stlfinder.com	Free, paid
Pinshape	https://pinshape.com/	Free, paid
SetkchFab	https://sketchfab.com/	Free
CGTrader	hwww.cgtrader.com	Free, paid
Yeggi	www.yeggi.com	Free, paid

Conversion to 3D print file

Depending on how it was obtained, the 3D model may need to be converted in a 3D printer file format. If it was downloaded from a 3D model repository specialised in 3D printing, the model should be already available as a 3D printer file. The 3D models obtained by modelling or scanning can be directly exported as 3D printer files from the software that created them. Otherwise,

there are many conversion software able to convert any type of digital 3D model in a 3D printing file like, for example, www.meshconvert.com or www.nchsoftware.com/3dconverter.

The most common 3D printer file formats are STL, OBJ, AMF, and 3MF but STL is used by most of the 3DP systems and software. For FDM applications in school, STL is the most practical and recommended type of 3D print file.
A STL file stores information about the 3D model, describing only its surface geometry without any representation of colour, texture or other attributes. As you can see in Figure 5, a STL file represents a 3D model as a mesh describing, in an approximatively manner, its shape.

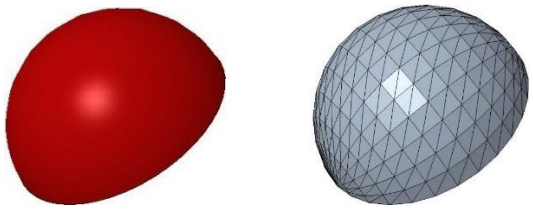


Figure 5 – A 3D model and its STL representation

Preparing the model for 3D printing

The next step is to prepare the 3D model for the printer and generate the G-code file that carries all the information needed by the 3D printer to build the object. This process involves a series of actions:

- Checking of 3D printer file and repair it, if necessary
- Positioning and orientation of the 3D model on the printing bed
- Setting of 3DP parameters like material, temperatures, cooling, speeds, layer thickness, etc.
- Adding support structures, if necessary
- Slicing, i.e. dividing the model in a set of thin layers
- generating the G-code file
- saving and sending G-code file to the 3D printer

The model preparation is done using 3D printing slicer software. There are many such software available and most of them are free. The most popular once are given in the following table.

Table 4 - 3D printing slicer software

Name	Link	Users	Free/paid
Ultimaker Cura	https://ultimaker.com/software/ultimaker-cura	Beginners, Advanced	Free

Simplify3D	www.simplify3d.com	Beginners, Advanced	Paid
PrusaSlicer	www.prusa3d.com/prusaslicer	Beginners, Advanced	Free
Slic3r	https://slic3r.org	Advanced, Professional	Free
OctoPrint	https://octoprint.org	Intermediate, Advanced	Free
AstroPrint	www.astroprint.com	Beginners, Advanced	Freemium
3DPrinterOS	www.3dprinteros.com	Beginners, Advanced	Freemium
Repetier	www.repetier.com	Intermediate, Advanced	Free

3D Printing the object

The G-code file is then fed into a 3D printer that lays down successive layers of material, in a layer-upon-layer fashion to fabricate the desired 3D object.

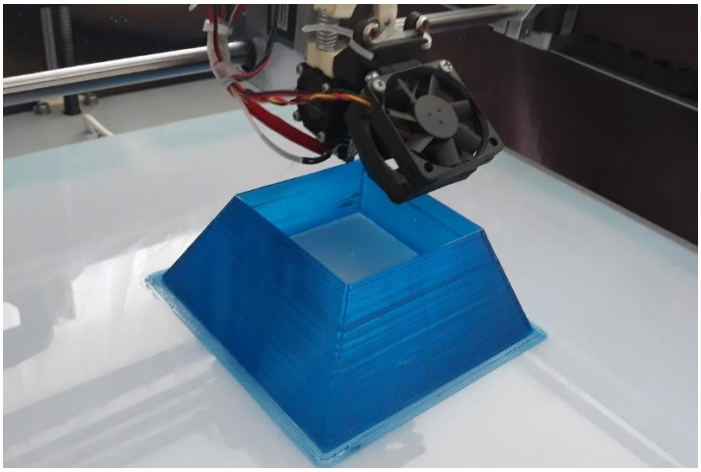


Figure 6 – 3D printing an object

Finishing the part

The 3D printed objects may require some additional operations after the completion of printing, in order to further enhance them. These operations may include:

- removal of the support structures using tools as knives or pliers

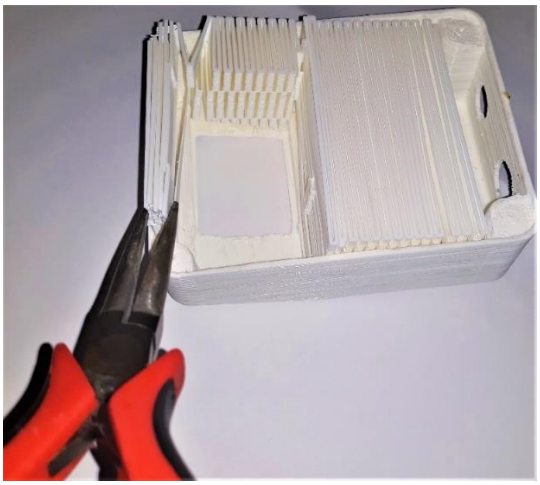


Figure 7 - Removal of the support structures

- removal of the brims (the single layer flat area around the base of the part, used to prevent warping – see the picture below) with a cutting plier or a cutter
- filling of the gaps in the print with materials like epoxy resin, auto body filler, ABS and acetone compound
- part's surface polishing by sanding or grinding

Figure 8 - Removal of the brims

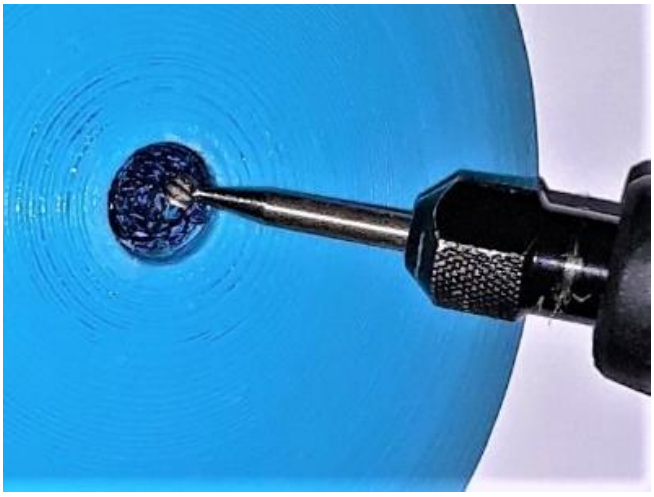


Figure 9 – Surface finishing

- Vapour or chemical smoothing in order to melt away the layer lines and to give a glossy look to the 3D printed objects. Acetone is often used for objects printed with PLA and ABS.

Figure 10 – A 3D printed object, before and after vapour smoothing. Source: www.geeetech.com

- Brush, airbrush or spray painting

Figure 11 – FDM parts painting

- Coating with epoxy, metal, etc.

Figure 12 – Gold plated 3D printed part. Source: https://i.materialise.com/

3D printing applications

3DP has many applications in various sectors from education to industry, and in the whole value chain from prototypes to spare part management. FDM technology is the favourite for hobby use and education but it is also used in some professional areas.
In this section we will discuss only few of the 3DP applications, with a focus on FDM technology and education.

Education

3DP is more and more implemented in the educational programs carried out by schools, universities, libraries, adult education institutions, special education institutions, makerspaces etc. The main applications are:

1. **Teaching educators about 3D printing.** This is very important as teacher attitudes and beliefs and teacher knowledge and skills could be barriers to the 3DP integration into the education system.
2. **Teaching students about 3D printing and developing their 3DP skills.** Usually, the students learn about the 3D design process, 3D modelling software and the basic operation of 3DP. In addition, the students are encouraged to engage in problem solving, to practice their communication skills while working in project teams.

Figure 13 – Teaching 3DP

3. **Using 3DP as a support technology during teaching.** 3DP helps improving student understanding of various topics: atomic structure, biological molecules, geometry, material properties, etc.

4. **Using 3DP to produce artefacts that aid learning.** 3D printed artefacts are currently used to support teaching in anatomy, chemistry, math, geosciences, physics, zoology and many others. The 3D printed replicas and models of cultural heritage allows students to examine them without damaging the originals. 3D printed models in anatomy and chemistry are also much cheaper than commercially available models.

Figure 14 – 3D printed artefacts for anatomy teaching

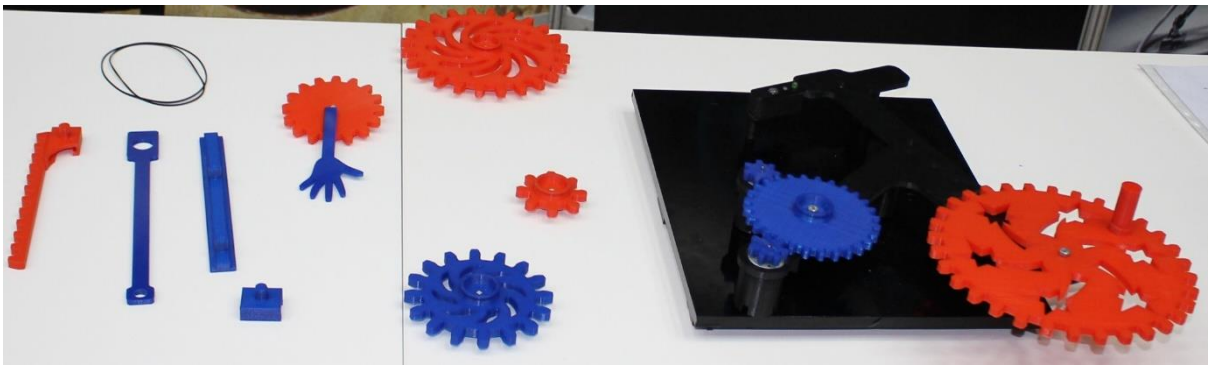


Figure 15 – 3D printed artefacts for physics teaching

5. **Creating assistive technologies.** 3DP is very helpful in creating artefacts for students with special learning needs, such as tactile artefacts including graphics to assist with the teaching of programming, mathematics, literacy, geoscience maps, astronomical maps and history textbooks.

More and more schools are incorporating 3DP in their educational programs as it helps to better prepare students for the future. It is a great tool to explain abstract concepts with the help of tangible objects, to increase the students' motivation to study STEM subjects and to boost their creativity by facilitating the prototyping of their ideas. 3DP promotes the development of students' critical and creative thinking as well as their collaboratively solving problems skills.

Numerous educational models are available for teachers to use in their classes. For example, among the over 1.7 million 3D models uploaded on Thingiverse there are many educational ones. In addition, there are over a hundred free 3DP-based lessons on https://www.thingiverse.com/education for a variety of grade levels and subjects.

Prototyping and manufacturing

The flexibility and versatility of 3DP makes it ideal for small-scale manufacturing and prototyping. In addition, as it does not require the initial cost of moulds, jigs or other specific tooling specific for traditional manufacturing, 3DP is very convenient for production of prototypes, unique parts or small batches. Industries like automotive, medical equipment and aerospace are extensively using 3DP for both prototyping and functional parts production.

Figure 16 – Prototype created by 3DP

Figure 17 – Parts made by 3DP

Medicine

Medicine is one of the sectors that benefits the most from 3DP. Among the applications, we can count prosthesis, made-to-measure implants, orthodontic parts, customized drugs or bio-printed organs. Doctors are using 3D printed models of patients' body parts or organs to plan treatment and to visualize, plan and practice surgeries. Nowadays, 3DP is routinely used in the production of medical devices like prosthetic hands, artificial hip joints or dental crowns and bridges.

Figure 18 – 3DP used in medicine

Construction and architecture

3DP offers huge creative opportunities to architects and completely changes the way of making architectural models. 3D printed models are much less time-consuming and labour-intensive than the traditional ones, allowing for inexpensive changes and iterations.

Figure 19 – Architectural model made by 3DP

3DP has been also used for construction of various buildings and bridges. In these cases, the 3D printers are using materials like concrete, wax, foam and polymers. The main advantages are related to design complexity, faster construction, lower labour costs and less waste.

Figure 20 – 3D printing a building

Art, jewellery and fashion

Due to its ability to create complex shapes and geometries, 3DP allows for great creativity freedom and it is increasingly adopted by designers, jewellery makers and artists. Thanks to 3DP, it is possible to easily experiment various designs and to produce individual, unique and customised pieces much cheaper than with traditional methods. Materials like plastics, ceramics, gold or platinum can be 3D printed to obtain awesome objects.

Figure 21 – 3D printed bracelet

Figure 22 – 3D printed fashion. Source: Financial Review

Figure 23 – 3D printed jewellery. Source: sculpteo.com

3D printing effects on the market

3DP affects market structure and has significant implication on various areas, including industrial sector, healthcare, education, services, etc. It not only has direct effects on companies' production processes but also made possible a growing community of makers who develop and share 3D models, sell 3D printed products, develop and provide their own 3D printers for home use.

Democratization of technology

3DP was invented in the 1980s but it was too expensive, with very limited production capacities and only large companies were able to use it. Since then, huge progress has been made in terms of both capabilities, complexity and costs and 3DP is rapidly becoming available to the masses and it is widely adopted across all industries.

Nowadays, 3DP technology, especially FDM, is widely affordable and it has the potential to democratize the manufacturing of certain goods. In some cases, the consumers themselves can make some objects using their own 3D printer or 3D printing service like 3D Hubs, Shapeways, Sculpteo, etc.

In addition, small companies and start-ups are able now to get their products on the market quicker than ever, without necessarily building a manufacturing facility and reducing the risks through low volume production and cheap rapid prototyping.

Boosting innovation

3DP has the ability to disrupt many industries, to open up new market opportunities and to transform the supply chains. The ability to prototype faster and cheaper allows companies and individuals to boost their creativity and to innovate hence bringing new products and solutions to the market at a rapid pace. Some fields, where 3DP makes possible cost reductions along with better results, are already transformed: the way of making dental models, crowns or aligners, the production of anatomic, architectural and educational models, the process of making jewellery or movie props.

Mass-customization

As 3DP renders very low volume production economical it greatly promotes mass-customisation, a production process that provides customers with personalised products at near mass production prices. In addition, it creates opportunities for co-creation, a design process in which the input from customers and other stakeholders plays a central role in the development of a

product. For example, a company called Local Motors developed several cars making use of co-creation and 3DP.

Figure 24 – Olli, a co-created electric shuttle. Source: https://localmotors.com

By making possible the fast and low-cost production of personalised objects, 3DP revolutionised numerous areas, including the prosthetics market.

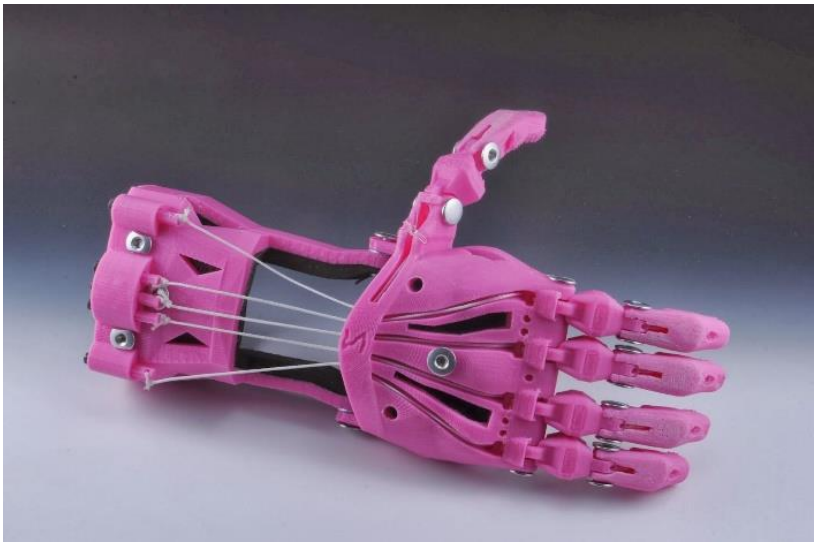


Figure 25 – 3D printed prosthetic hand. Source: http://enablingthefuture.org/

3DP effects on the job market

3DP is also a powerful driver for changes in employment and it is affecting the global job market in various ways. New jobs linked with 3DP are frequently advertised, for industrial and mechanical engineers, software developers with 3DP expertise, software engineers specialized in 3DP, designers with 3DP knowledge, 3D printer technicians, 3DP material experts, post-processing specialists, 3DP consultants, etc.

The number of new jobs created thanks to 3DP will grow in the next years, as there will be a need for people to fabricate, sell, operate, maintain and repair the 3DP equipment, and manage the supply chains, production and the companies that do all this.
3D modelling software, simulation software dedicated to 3DP and other specific software applications are also creating new jobs for programmers, software developers, IT&C specialists, etc. In addition, entirely new job categories are created thanks to the new wave of innovation brought on by 3DP, like biological and scientific modellers, legal experts with 3DP expertise, etc.

Some existing jobs will be transformed by 3DP, requiring new skills and different ways of working. For example, designing parts to be fabricated by 3DP requires specific knowledge and skills related to 3DP process and materials.

Undeniably, a big number of jobs, especially from the manufacturing sector, will disappear. As 3DP simplifies the production process, there will be less staff needed on the production lines for machining, welding and assembling operations. In addition, many jobs in jewellery and craft sectors are at risk given the powerful capabilities of 3DP.
3DP has the ability to efficiently manufacture products in local markets so it is expected that many manufacturing jobs currently outsourced in China or other low-wages countries will come back in Europe.

3D printing benefits for Education

3DP has the potential to facilitate learning, develop skills, inspire creativity, improve attitudes towards STEM subjects and careers and increase student engagement. In the same time, it can increase teachers' interest and engagement.
Learning with 3DP is also very exciting because students can get the first-hand experience of a subject matter, especially in STEM subjects.

Improving student participation

3DP allows teachers to illustrate difficult concepts and increase students' engagement through active learning. By increasing engagement within the classroom, the student participation can be improved and a satisfying learning environment can be created for all.
The students are particularly engaged when using their hands and creating something that they can see, touch, show, explain and when they can use the physical results of their efforts. All of these are possible by implementing 3DP in the classroom.

Promoting active learning

Active learning aims to engage students and encourage them to interact with the learning process, as opposed to passively taking in the information. 3DP promotes active learning practices by allowing students to investigate, explore, design or build various things and to experience objects by touch and feel. When are involved, the students can discover their talents and can develop critical thinking and problem solving skills. Also, 3DP helps students to understand that it is OK to fail and to see failure as an opportunity to persist and get better.

Using 3D printed object in the learning process helps students grasp the subject matter and retain information.

Encouraging creative thinking

With 3DP, students can experiment an idea through trial and error and this encourage them to be innovative and creative. Consequently, they are more likely to remember the facts and lessons learned. The learning is enhanced as, during the process, they are trying new things, test theories and think more creatively.

Raising students' interest in STEM education

3DP provides exceptional learning opportunities across science, technology, engineering, art, and maths, allowing students to easier learn complex concepts and providing teachers with new tools.

The students are often bored or frustrated with STEM classes taught from textbooks and fail to understand the relationship between these subjects and real-world applications. 3DP gives students the chance to experience STEM subjects in an engaging, exciting, and hands-on way and to see the connections between these ones and the real life. 3DP can inspire curiosity in STEM subjects and encourage them to experience and explore a career in science or engineering.

Providing opportunities for practicing different learning styles

3DP facilitates the implementation of concepts like “learning by doing”, “experiential learning and failure” and “enjoying while learning”. It encourages creative experimentation, enables product innovation and entrepreneurship, supports the integration of technical knowledge from other courses and facilitates multi- and interdisciplinary approaches.

3DP is not just a way for students to experiment but it could inspire the next generation of engineers, architects or designers. It can also help students that may struggle with the traditional learning theories and topics from a textbook, but are much more capable and successful when working with physical objects.
3D printers are able to bridge the gap between the scientific and artistic sectors, enhancing students’ learning and productivity.

3DP opens up new learning possibilities allowing students to see their ideas come to life and to interact with the objects they created in ways that were not previously possible. In addition, teachers and students are able to duplicate museum items like fossils and historical artefacts in order to study them in the classroom, to design and make 3D models that help better understanding of notions from math, chemistry, biology, geography etc.

As 3DP is going to be a part of the future, both professional and personal, it is very important to introduce it into school education.

3D printing trends

3DP is a very dynamic industry with rapid developments in many different areas: equipment, software, materials, applications, legislation, jobs, etc. It will significantly affect the future of peoples and companies. Consequently, there are many probable 3DP trends and possible directions of expansion. In this section, we will discuss only some of them that are relevant for our target group: secondary school managers, teachers and students.

A first trend is the continuous reduction of 3D printers and 3DP materials costs' combined with an improvement of the offered capabilities, making 3DP more and more accessible. In addition, thanks to the software and hardware improvements, the 3D printers and 3DP process will be simpler to manage, the 3D models easier to obtain (easier 3D modelling and 3D scanning) and the quality of final parts greatly improved. This will contribute further to the spread of 3DP in homes, schools and companies with big effects on economy and society.

3DP promotes the democratisation of manufacturing and more and more people will be able to make various products, creating new opportunities for innovation and entrepreneurship. Artists, crafters and designers will increasingly use 3DP to create artwork, fashion goods, unique pieces. Makers will be able to build more and more things as the capabilities of 3DP are expanding.

A significant growth of the global 3DP market is expected in the next years. 3DP will be more and more adopted in different industries, its expansion will lead to an increase in sales of 3DP products and services as well as a rise in the number of new jobs available for people with relevant skills and knowledge related to 3DP. Consequently, the students exposed to 3DP in school will have a big competitive advantage on the job market.
In the coming years 3DP will become, in many cases, an alternative to current manufacturing technologies. While nowadays, 3DP is used mainly for prototypes and small batch fabrication, in the next few years it is expected to become widely used in all kinds of manufacturing.

3DP technologies will continue to develop at a fast pace, allowing for stronger, larger and better-quality parts, higher printing speeds, lower costs, wider range of materials and new applications. New materials are expected to be developed in addition to a larger use of material like metals, ceramics, biological materials, food, etc. Multi-material 3D printing is also expected to become reality.

Figure 26 - Concept for a large 3D printer. Source: modix3d.com

3DP makes possible the production of goods when and where are needed. For example, various components and spare parts can be stored as digital files that can be 3D printed on demand, reducing physical inventory and the relative warehouse space, costs and risks. Also, in the future, it is likely that instead of large centralised factories there will be small local 3DP shops. This will eliminate the need of transporting manufactured goods, saving the fuel, time and labour and reducing the pollution.

With 3DP, various products and parts can be made not only in every corner of the Earth but even outside the Earth. There is already a 3D printer on the International Space Station and there are ideas to build bases on the Moon, Mars or beyond using 3D printers and local materials. European Space Agency (ESA) is studying the feasibility of 3D printing using lunar soil while NASA organized the “3D-Printed Habitat Challenge”, a competition to create suitable shelters using resources available on-site in Moon, Mars or other such locations.

Figure 27 – A 3D printer on the International Space Station. Source: https://madeinspace.us

Figure 28 - Concept of 3D printed construction on Mars. Source: NASA

However, in order to avoid the obstruction of 3DP's wider adoption, all these technical advances must be accompanied by education and skills development. This can be done through a large-scale implementation of 3DP in education, made possible by suitable trained teachers and appropriate equipment, materials and programs.

Conclusions

3DP started to impact many aspects of economic and social life and the impact is going to be even bigger in the future in terms of applications, jobs, industries disruption, entrepreneurship,

etc. Consequently, suitable skills and knowledge related to 3DP will be needed in order to benefit from the resulting opportunities and to adapt to the changes. The education sector can support both the 3DP market development and people familiarisation with technology by implementing 3DP in school, thus preparing the students for the future. One of the requirements to make this possible is to have suitable trained teachers.

Figure 29 – Teachers and 3DP

Technical Aspects of using 3DP

Introduction

Choosing the right 3D printer can be quite a challenge. Especially when it comes to buying a printer for school. Then we have to pay attention both to the safety and possibilities offered by the printer and on the other hand take into account the financial possibilities of the school and the costs of using the printer. Therefore, the following text will familiarize you with some of the specifications and features of printers that are worth paying attention to in order to make an informed purchase and make sure that the printer will be helpful in the educational process.
The following text will provide you with knowledge of the basic components that a 3D printer consists of, and will show you the 3D modelling software and software for the slice your model to a format that can be printed. This chapter will also provide you with an overview of the steps you need to take to prepare your first model and print it.
The text also presents examples of printers, their specifications and presents 3D pens, which can be an interesting alternative and the first step in the process of teaching students about 3D printing. The text ends with a short instruction on how to be aware of the dangers of 3D printing, especially in school.
At the very end you will find useful addresses that will help you in your work.

Main components of 3D printer

The first step to understanding how a 3D printer works is to explore its main components. This chapter will present several important parts of printer, you should know.

Controller Board.

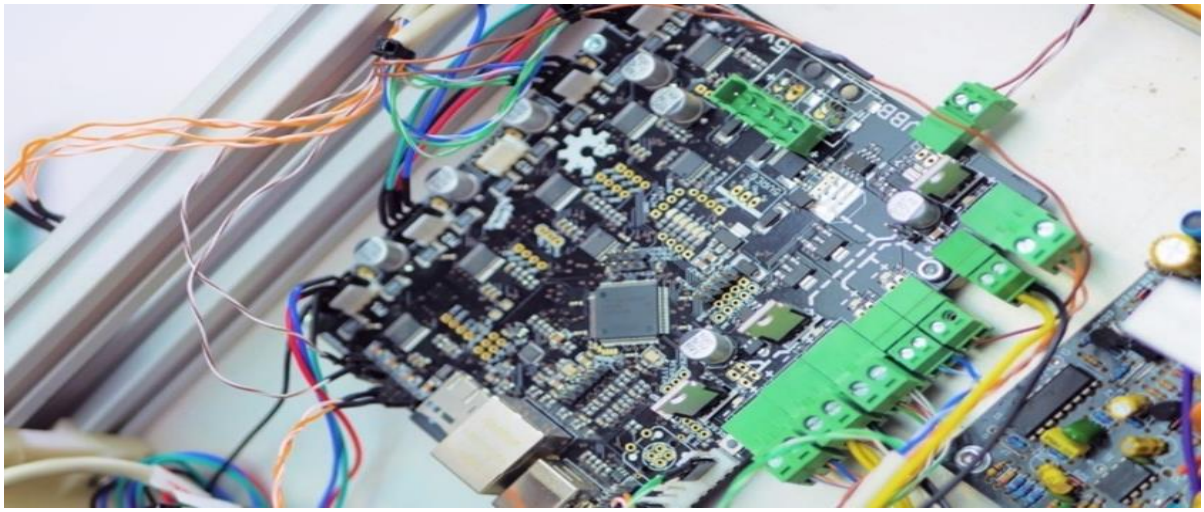


Figure 30 - Controller Board. Source: https://all3dp.com/2/5-fantastic-3d-printer-controller-boards/

Controller board (sometimes it's called motherboard or mainboard) is the main part of 3D printer. This section is responsible for managing the printer and reading G-code*.

It affects the quality of the 3D printer. For a reason it is often called the "brain" of the printer[1].

*G-code is just a set of simple commands, and they are a sort of a set of instructions for the printer.

Frame

The frame is the base for all other parts of the 3D printer. One of its main goals is to ensure stability so that the printing process runs under the best possible conditions. Of course, it is good to focus on the frame's durability when purchasing. Basically, you can now find frames made of metal or acrylic. Due to the characteristics of metal, it will be a good choice, especially considering the fact that 3D printers in the low price range are already more and more often available with metal frames. Another thing worth paying attention to is what kind of frame we will choose. There are open and closed constructions (you can also meet semi-enclosed frames, but this is rather rare)[2]. Closed frame will be a better choice (practically necessary) when working with ABS material because such a construction allows to maintain high temperature (which is not possible in open construction) required by this type of filament.

Print Materials

Figure 31 - Filaments. Source: https://www.allthat3d.com/3d.com/3d

[1] https://pick3dprinter.com/3d-printer-parts/#motherboard-or-controller-board
[2] https://pick3dprinter.com/3d-printer-parts/#frame

PSU

PSU (power supply unit) is often already built into your printer's frame. It can also be a separate product. Its purpose is to supply power to your 3D printer. Make sure that your PSU is compatible with your printer. When ordering a printer from another country (for example, China), also make sure that the PSU is compatible with the voltage used in the country where you live[3].

Extruder / Print Head

Extruder is a device whose purpose is to extrudes the filament. It itself consists of several important parts, which are presented in the figure below.

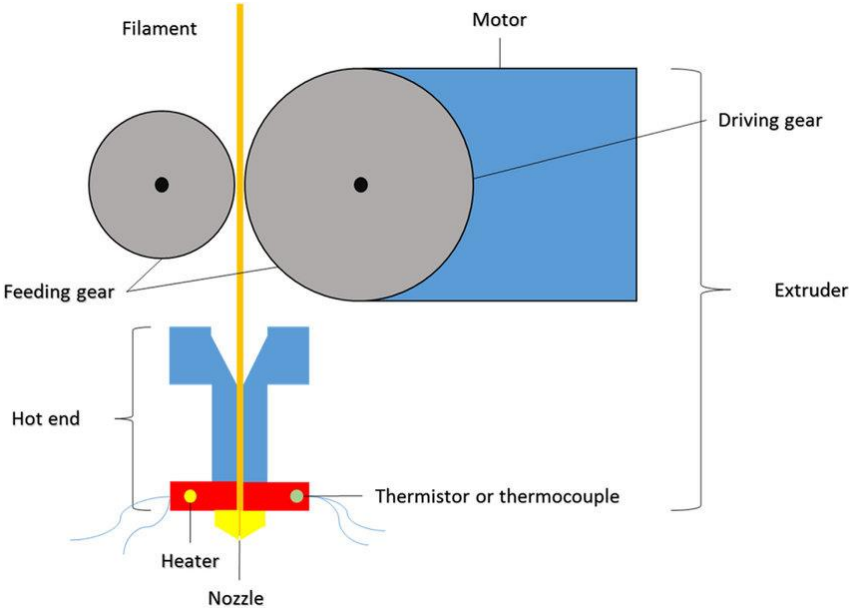


Figure 32 - Extruder. Source: https://www.researchgate.net/figure/Schematic-picture-of-3D-printer-extruder_fig4_311883713

The most important thing you should know is that the extruder is basically divided into two parts: hot end and cold end.

The cold part consists of a motor and feeding gear, and their purpose is simply to move the filament towards the nozzle. The hot part consists of heater, nozzle and thermistor of thermocouple. In this part, the pillar is heated and extruded by the nozzle at the right temperature. It is worth knowing that there are many different possibilities when it comes to the nozzle. You may find different sizes of nozzle: larger (>0.4mm) and smaller (0.4mm). You may notice that they are made of different materials and designed for different filaments[4].

[3] https://3dinsider.com/3d-printer-parts/
[4] https://all3dp.com/2/3d-printer-nozzle-size-material-what-to-know-which-to-buy/

3D Printing bed

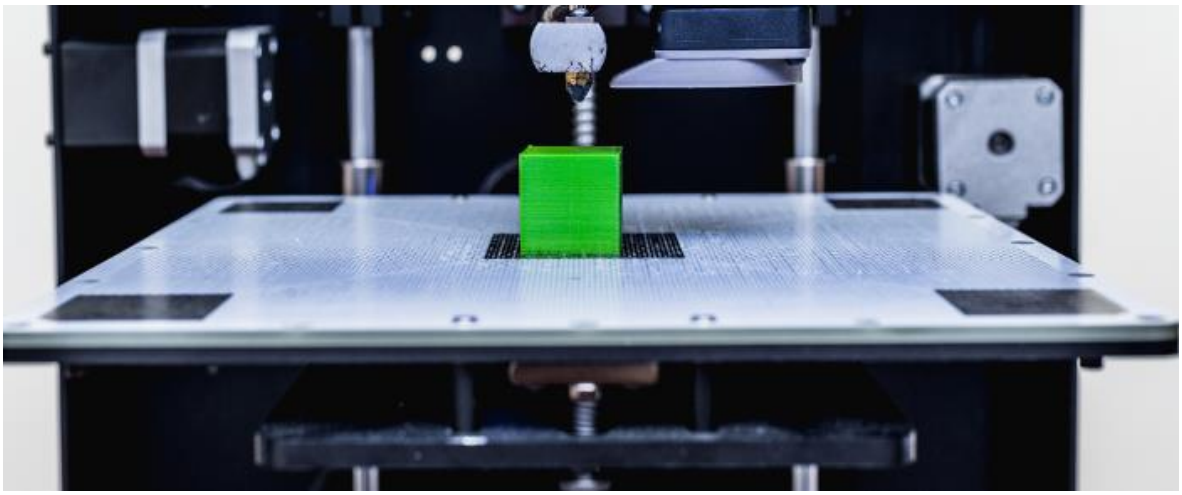


Figure 33 - 3D Printing bed. Source: https://www.sculpteo.com/en/glossary/printer-bed-definition/

Simply put, this is where the final product is created. Some printers use heated printing bed and some of them don't. Basically, when using PLA material there is no need for a heated printing bed. It is different with ABS and other more advanced filaments, where it is actually necessary. The printing bed itself is made of different materials (for example glass/aluminium). It is worth noting whether they calibrate automatically for printing or whether the user must do it manually[5].

[5] https://www.sculpteo.com/en/glossary/printer-bed-definition/

Choosing a 3D printer

To be able to choose the right printer for your school, you must first understand what the individual specifications that are listed in the product description mean. Furthermore, you should have a vision of how the pupils will work in the classroom so that you can better meet their expectations. Later in the text you will find examples of printers and their specifications.

When buying a printer for school, we consider amateur equipment rather than very professional. After all, the printer is designed to teach the basics of 3D printing and convey ideas and the necessary knowledge to understand the printing process. It is not possible to become an expert in just a few school classes and have the need to use very professional equipment.
So let's look at a few choices and their specifications:

3D Printing Pen

Description: The first product is not so much a printer as a pen, which will allow us to create things in 3D. Its main advantage is the price. The pen is cheap, but it is made in such a way that the pupils can understand how 3D printing works. There is a special filament in the pen (most often it will be ABS which is a acrylonitrile butadiene styrene) . It is then heated up and "comes out" through the pen as a liquid, which almost instantly freezes in the air.

Figure 34 – Example of 3D PEN. Source: https://3dprint.com/119065/colido-3d-printing-pen/

How do you use it in class?

The pen can be used while learning the youngest because it is completely safe. Thanks to this, they will understand how 3D printing works and will be able to practice their artistic skills. As the results of working with it are visible immediately and you don't have to wait for them, it can be very effective. Filaments are relatively cheap and easily accessible. Apart from that you can buy additional stencils allowing you to create interesting projects[6]. What is interesting is that some companies, like **3Doodler**, offer ready lesson plan and learning packs, which schools can use.

Example of products:

- **3Doodler**

Shop: https://intl.the3doodler.com/pages/pricing

- **3Dsimo MultiPro**

Shop: https://3dsimo.com/multipro

3D printers for schools

Description: Among the 3D printers that can be used for amateur purposes or to teach 3D printing, it is best to use models that are relatively cheap, as we should not care about the high quality of the print, but more about teaching the functioning of this technology.
When it comes to amateur products, it is worth focusing on a few of their elements, such as the **frame** - *make sure that the structure is strong and as rigid as possible*, or the **filament** - *make sure that the filament can be mounted quickly and easily on the handle*.

How to use in class?

The use of 3D printing in the classroom can be done on many levels. From learning the theoretical printing process to creating and printing models.
When it comes to printing models, they can generally be taken from five places:

- Do it yourself;
- Download free models from the internet;
- Buy a project from the internet;
- Have someone prepare a project for us;
- Use 3D scanner on the object[7].

Some examples of pages with free and paid projects:

[6] https://3dpenhub.com/3d-pens-how-do-they-work/
[7] https://3dprintingcenter.net/2020/01/11/5-things-that-need-to-be-considered-when-buying-a-3d-printer/

- https://www.thingiverse.com/
- https://www.myminifactory.com/store
- https://www.instructables.com/
- https://www.prusaprinters.org/
- https://cults3d.com/en

As you can see, many models are available to download for free. These are of course usually very simple designs, but they are great for presenting a printing in class.

3D modelling software

If you want to create your own 3D model you will need to use Free modelling software. Here are some software you can use to do this. You have both free and paid options available. Depending on your skills you can also use more or less professional tools. The prerequisite for this program is that it must save the finished model in STL format.

STL Format - this is a format created for additive manufacturing by 3D Systems. It's a end product of CAD modelling (usually). It encode the geometry of a 3D object[8]*.*

1. FreeCAD

It is open-source program and it is fully free.
In order to use it you need to know the requirements for the current version of the program. At the moment you can download it to Windows (minimum Win 7); Mac (minimum Mac OS X 10.11 El Capitan) and Linux[9]. You simply need to download and install it and you can start creating your models.

Price: Free
File Formats: STEP, IGES, OBJ, STL, DXF, SVG, DAE, More

[8] https://all3dp.com/what-is-stl-file-format-extension-3d-printing/
[9] https://www.freecadweb.org/downloads.php

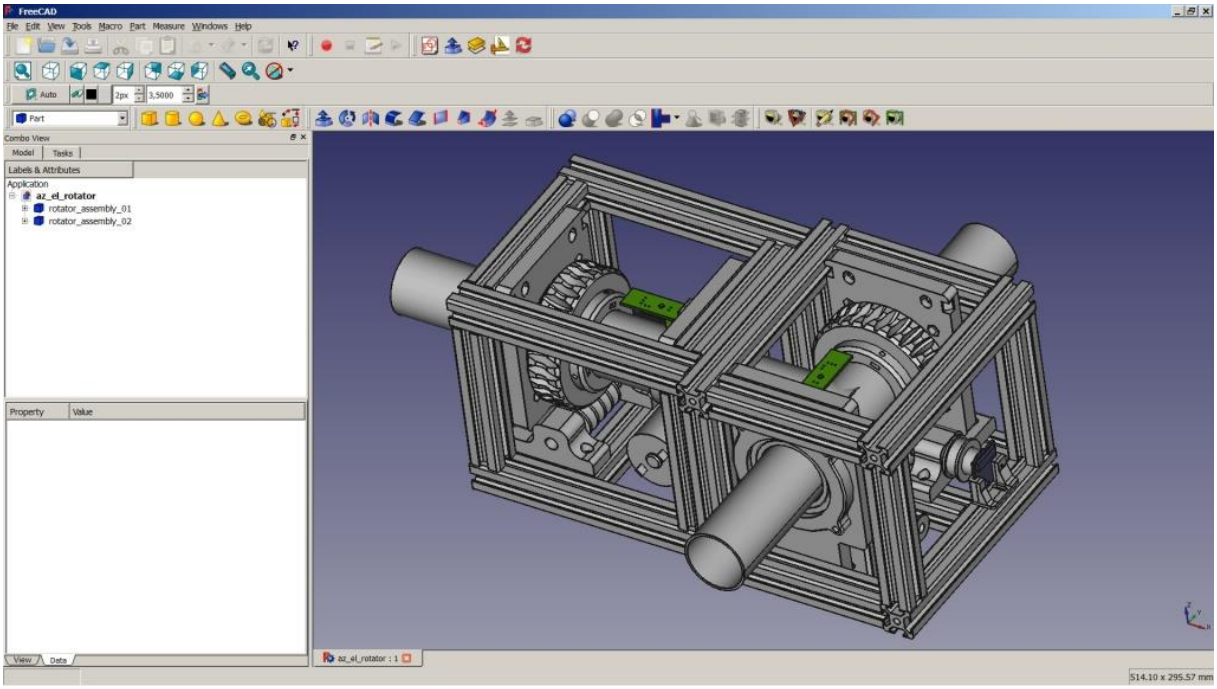


Figure 35 - FreeCAD. Source: https://wiki.freecadweb.org/Release_notes_0.16

2. SketchUp

SketchUp is a another program offering you a possibility to create 3D models. It can be used for free but in this case it's limited. There are different plan and pricing depend on what type of costumer you are. It can be lunch by a browser.

- For Personal;
- For Professional;
- Higher Education;
- Primary & Secondary.

If you choose free option, the only thing you need to do is register on the platform.

Price: Free option is available but limited.
File Formats: SKP, STL, PNG

3. TinkerCAD

TinkerCAD is interesting because you can design in a browser, so you don't need to install anything. It's really easy and simple tool so it's good for beginners to learn. All you need to do is create an account on the platform and you good to go. So you can use it to 3D printing.

You can use ready-made 3D lessons to learn how to design different models.
Price: Free
File formats: OBJ, SVG, STL, PART

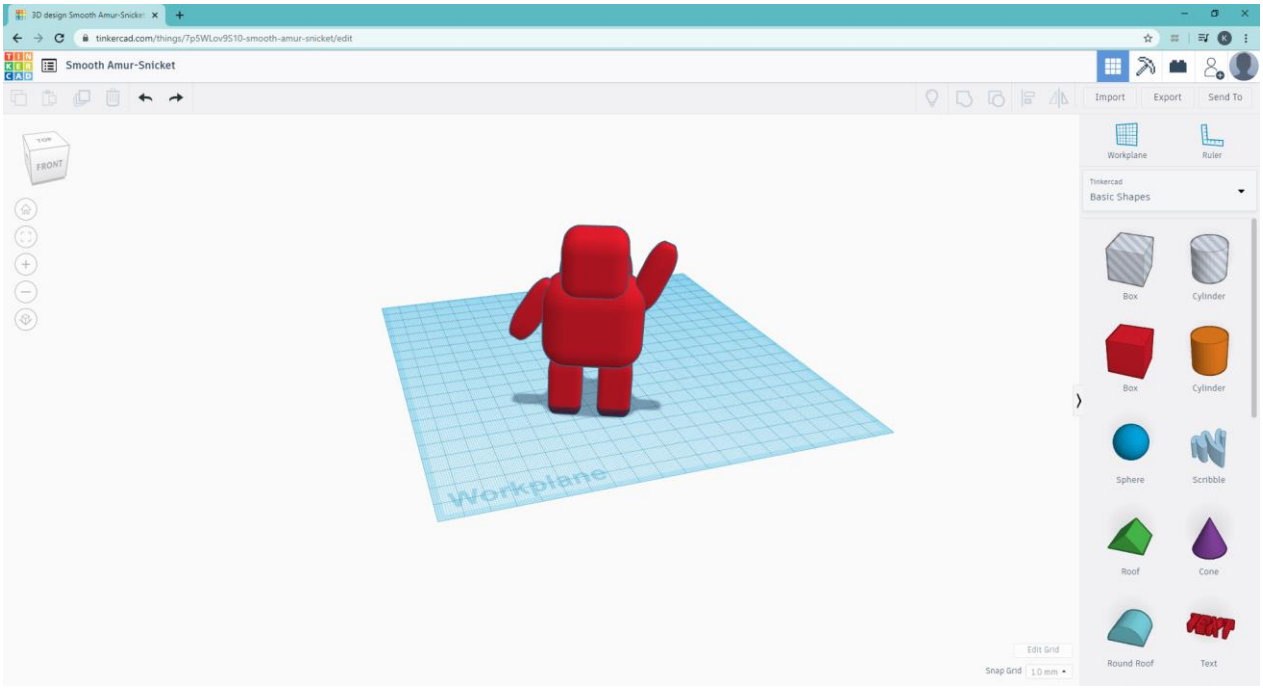


Figure 36 – TinkerCAD

There are much more programs / platforms to create such models. The choice should usually depend on your experience and how complex models you want to create. For total novices, the best option is probably TinkerCAD.

3D slicing software

Once you have your model ready, the next thing you need to do is to convert it through a 3D printing slicer. You can find a lot of free software providers such services.

The aim of this software is to convert the prepared model in STL format (most often it will be STL but it can be other formats such as AMF or OBJ) to printer commands (G-code), the next thing is to transfer the G-code[10], (for example via USB) to the printer and print the model itself.
Slice software has the role of dividing the model into layers but is also responsible, for example, for creating supports structures. Supports are necessary if the shape of the printed object requires it. They provide stability during the printing process and prevent the filament from spilling out. You don't have to place the supports during the modelling process in your software, the slicer will do it for you to indicate where they will be needed. Of course, after printing the supports you have to get rid of them.

[10] Evans, Brian. Practical 3D Printers: The Science and Art of 3D Printing. apress. ISBN 978-1-4302-4393-9.

Also, Slicer will allow you to manage several variables that affect the quality of your final product. These include: layer height, wall thickness, filling density, printing speed. After setting these criteria, the process of slicing is automatic. The result of the slicer is the G-code.

There are a large number of the slicers on the market. Examples are:

Cura

Figure 8 – Cura. Source: https://en.wikipedia.org/wiki/Cura_(software)

Cura is free software and is designed for all types of users from beginners to advanced. It is definitely one of the most popular slicers. Cura supports such formats as: STL, 3MF and OBJ. An interesting solution offered by Cure is, for example, the ability to view the print time or see an estimate of how much material will be used[11].

SLic3r

Figure 37 – Slic3r. Source: https://amtech3d.com/software/slic3r-logo-with-text/

[11] https://all3dp.com/1/best-3d-slicer-software-3d-printer/

Slic3r is another very popular free software dedicated to slice 3D models. Slic3r is characterized by a multitude of settings and options. Many of the settings that we consider to be standard today have their origins in this particular software[12].
Other features of this software are that it is very fast and easy to use. It supports the STL, AMF and OBJ formats. In the case of Slic3ra there is no print time shown and you cannot see any estimates of the amount of material (as it was in Cura).

Netfabb Standard

Figure 38 – Netfabb. Source: https://cimquest-inc.com/netfabb/

This is another solution (slicer) that prepares models for 3D printing. It is very complex but it is paid. It costs $30 per month (you can also choose a longer contract, for example, an annual contract and then the monthly price will fall). Netfabb offers some other products such as Netfabb premium / ultimate. This software is owned by Autodesk (acquired in 2015)[13]. This software of course allows you to manage an STL file, for example by analysing it and editing and fixing it. This is an advanced tool, so it is rather for professional users.

However, regardless of what software you decide to use for slicing, what matters is the end result, which is the final product.
Let's sum up the knowledge we already have and follow the whole printing process

[12] Ibidem.
[13] https://www.autodesk.com/products/netfabb/overview?plc=NETFS&term=1- YEAR&support=ADVANCED&quantity=1

Steps to print the 3D model.

Step 1. Thinking about what we want to create. We must also remember about the limits of 3D printing technology and our printer (for example, building area of specific sizes etc.).
Step 2. Prepare a model in the program to create 3D models such as the FreeCAD, SketchUp, TinkerCAD or any other model you like and have access to. Ideally, the end result of the modelling should be a .stl / .obj file.

Step 3. Use a slicer application such as Cure, which converts your model to G-code, which can be "read" by a 3D printer. Here you can set a lot of variables that affect the final product (for example, print temperature / speed).

Step 4. Printing and receiving the final product.

Step 5. After printing, you may find that the product is not perfect. You will then have to find a sensitive spot and correct the settings. So here are two paths. The first is to check for errors and correct them, and the second is that you get the final product (the design you wanted) and can print it over and over again, knowing that it will always be the same quality.

Technical specification of some popular 3D printers

Monoprice MP Select Mini 3D Printer V2

Figure 39 - Monoprice MP *Source: https://www.monoprice.com/product?p_id=21711*

The above printer costs about 200 Euro. It is relatively cheap, and its producer ensures that it is the best in its price class. The printer has a heated build plate and allows you to work on different filaments. You can connect to it also via WI-FI. The producer also ensures that the printer is already calibrated and ready to use, so there is no need to assemble it, etc. This will certainly save you time.

The printer is compatible with Windows and Mac operating systems, has a microSD card slot and a USB input.

The manufacturer also ensures that it is compatible with Cura, Repetier and many others. In addition to the printer, various other accessories such as micro USB cable, microSD card, scraper and many more are included. The support team helps before and after the purchase by providing technical support and also allowing you to return the product[14].

Technique: FDM
Build Area: 120x120x120mm
Nozzle Diameter: 0,4 mm
Filament Material: PLA / PLA+

[14] https://www.monoprice.com/product?p_id=21711

Creality Ender 3 Pro

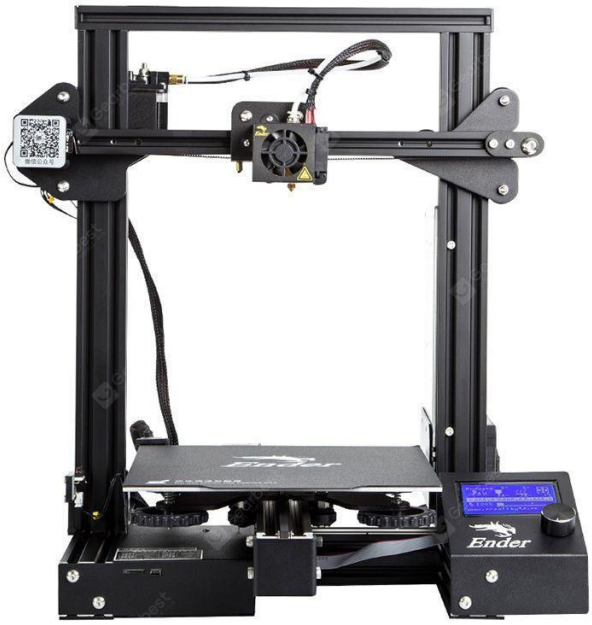


Figure 40 - Creality Ender 3 Pro. *Source: https://pl.gearbest.com/3d-printers-3d-printer-kits/pp_009869130016.html*

Another presented printer is Creality Ender-3 Pro. Its cost is about 300 Euro. It has a larger build space than the previous printer and more possibilities in terms of the type of filament that we can use. The printer should be folded, although it is already partly folded so it should not be very time-consuming. The producer will ensure that the heating up takes only 5 minutes and you can resume printing after switching it off (automatically). The producer also includes various accessories in the set[15].

Technique: FDM
Build Area: 220x220x250
Nozzle Diameter: 0,4 mm
Filament Material: PLA, ABS, Wood, TPU, Gradient colour, carbon, fibre, etc[16]**.**

[15] https://botland.com.pl/pl/drukarki-3d-creality/13447-drukarka-3d-creality-ender-3-pro.html
[16] https://www.drukarki3d.seb-comp.pl/drukarki-3d/273-creality-ender-3-pro.html

Recommendations regarding 3D printers for school applications

What steps should be taken before buying a 3D printer?

1. Specify the budget

The first step in choosing a printer should be to determine the budget. This will allow you to more or less define which segment of the printer you should focus on. We can find printers for a dozen or so euros (such as some 3D pence) and those that cost several thousand euros (for industrial use). Price will be one of the main criteria for many schools.

2. Costumer support.

Before buying a printer, it is a good idea to check whether the company selling the product has technical support for customers, what the return policy looks like and whether, for example, there is easy access to spare parts. This can be very important; given that it is not difficult to damage the print in class. Another issue is that technical support can be useful as early as at the software assembly and installation stage. Especially if teachers have not had the opportunity to use 3D printing before and don't have knowledge about electronics and automation.

3. Security

Given that the printer will be used for classroom learning and will be used by many people, it must be safe to operate. See chapter 4 for more about safety and what to watch out for when working with the equipment.

4. Size of the build area

This will tell us the size of the objects we can print. However, it is worth realizing that you will not need a large build area to learn 3D printing in any way. Large prints generate a lot of time (even a few days) and their cost (electricity, materials) is also very high. Besides, with larger prints there is a risk of damaging the model by an inexperienced person[17].

5. Printing technology

The previous chapter, ***Introduction to 3DP***, presents you with different printing technologies, check it out and think about your choice. The cheapest option will probably be FDM technology.

6. Product ready to use or requiring assembly

When buying a printer from a lower price range, we often encounter the fact that we will have to assemble it ourselves. In addition to the assembly, you also need to refine its settings, which

[17] https://www.tomsguide.com/us/3d-printer-buyers-guide,news-17651.html

can be time-consuming. Therefore, it is worth paying attention to the form in which the 3D printer will come to us[18].

Technical aspect of using 3D printer

Still the most popular and the most frequently used technology for making 3D products in an amateur way is FDM/FFF. Therefore, this part will focus on it as a good choice for schools.

It is worth starting with an explanation that FDM (Fused Deposition Modelling) technology is not the same as FFF (Fused Filament Fabrication) but there are so many similarities here that we can often find both forms mentioned by the seller. But to clarify this you should know that FDM technology appeared in 1989, and was created by a couple (Scott and Lisa Crump), who also founded Stratasys the same year. In 2005, the same technology was explored by Adrian Bowyer (British university lecturer), who created the famous "RepRap" printer project. The FDM patent expired in 2008, which opened the door for Bowyer to promote his solution. Since he couldn't use the name FDM (it was proprietary), he described his technology as FFF[19].

Printing in this technology is based on the fact that first the material (for example ABS) heats up in the head to the required temperature (usually between 180 - 260 degrees Celsius), which is then applied to the build area layer by layer. Working with FDM technology will often require add additional supports.
When it comes to 3D printing in school, this technology will work very well. Although the products produced will not be of the highest quality, they will be perfect for educational purposes.

Let's now look at some of the factors that will affect the quality and production time of models. This will allow us to learn some specific features of this technology.

Build area.
The size of the build area is given in 3 dimensions: X, Y and Z.

[18] https://3dinsider.com/guide-buying-3d-printer/
[19] https://3dprinterpower.com/fff-vs-fdm/

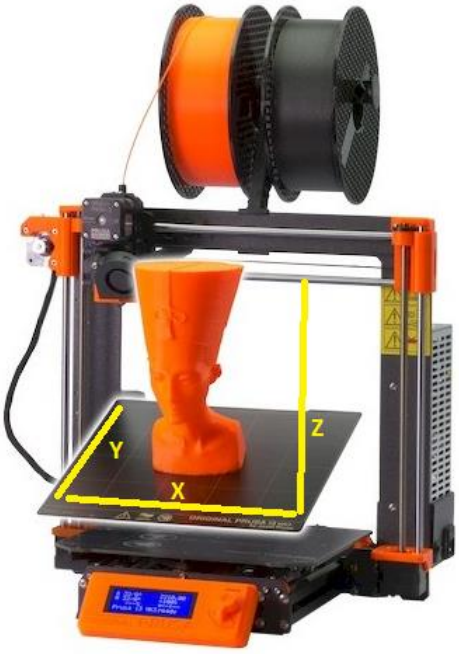


Figure 41 - Build area.Source: Based on: https://shop.prusa3d.com/pl/drukarki-3d/181-drukarka-3d-original-prusa-i3-mk3s.html

The size of the build area will be directly related to how large the objects can be printed. Another factor here will be the height of the applied material layer. It is also depending on the material. What you should know is that setting a smaller height will result in longer printing time but more accuracy. Setting it opposite will result in a faster finished product, but it will be of lower quality[20].

Among the materials that we can use in FDM printing we can mention:

- **ABS (Acrylonitrile Butadiene Styrene)**

It is one of the most frequently used materials. It is characterized by high strength and hardness. However, dangerous fumes are produced when working with it. You should have a well-ventilated room. Another feature is the high shrinkage of the material. Therefore, a high temperature (240-260 degrees) and a heated worktable should be used[21]. Among its disadvantages there is also a characteristic unpleasant smell.

- **PLA**

PLA (polylactic acid) is the second (next to ABS) most popular material used in 3D FDM printing. Its characteristic features include biodegradability and low processing shrinkage. It is often used as a material for the preparation of demonstration parts. It is worth pointing out that PLA does not need a heated table and printing it is quite fast[22].

[20] https://3dprinterpower.com/fff-vs-fdm/
[21] https://centrumdruku3d.pl/krok-10-abs-pla-nylon-i-inne-czyli-przeglad-filamentow-do-drukarek-3d/
[22] https://3dreaktor.pl/Filament-PLA-wlasciwosci-i-drukowanie

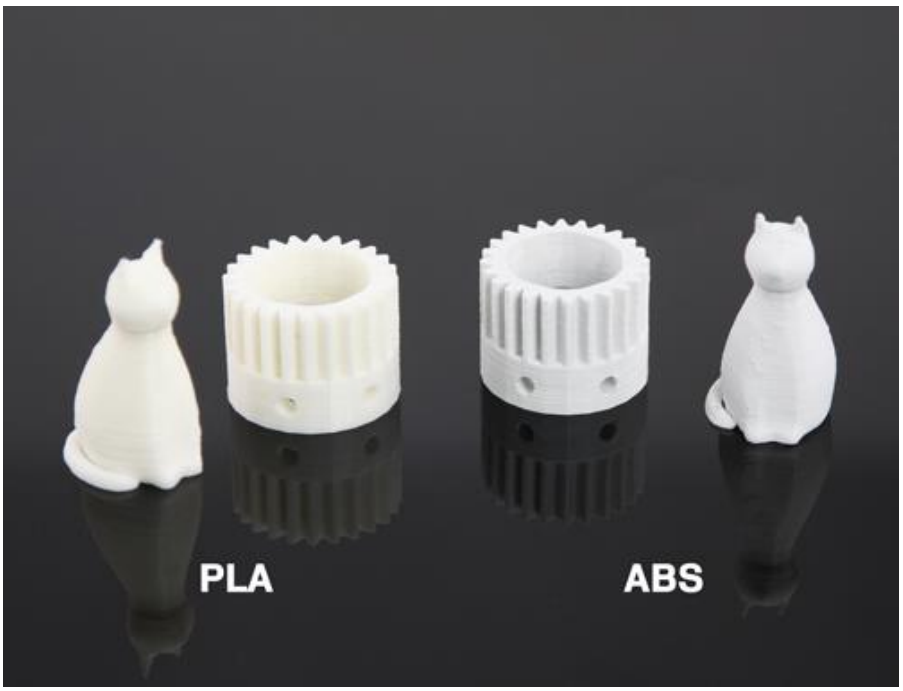


Figure 42 - Comparison of ABS to PLA. Source: 3DHubs.com

Other interesting and gaining popularity materials include:

- Nylon (PA);
- PC (Polycarbonate);
- PETG;
- HIPS;
- Titant HT;
- Flex Filament.

In the vast majority of cases, the producer of each of the filaments gives the specifics of use (temperature selection, etc.).

Safety features

Although 3D printing is relatively safe, as with any of the tools, it can cause damage if it is not used correctly. In this chapter we will list several types of risks for 3D printer users that you need to know in order to use these devices consciously and safely. We will also focus here on the dangers of using amateur and not industrial 3D printers.

The first of these risks are mechanical injuries. The specific, open design of cheaper models of 3D printers has the specific feature that we can reach with our hand to almost any part. However, the dangers resulting from this are rather small (a snap, minor cuts). Nevertheless, we should not put our hands into moving parts during printing. But it may turn out be more dangerous to

pull the finished printout. This is because it is usually done with a spatula because the first layer sticks quite firmly to the build area. Here you can get an injury during tearing off when you press too hard with the spatula and hit the other hand[23].
Tip during class: Consider the damage and don't let the children put their hands in a working 3D printer, good practice may be that you're the only one who will pull the finished product.

Burns are another danger that can occur when working with 3D printers. The two main elements that can be most dangerous in a printer are the print head and the build area[24].
Tip during class: Make sure that pupils do not touch these parts while working.

Equipment failure
One of the most dangerous damage can be equipment failure. Apart from the aspect of extra expenses to repair and lost lesson time, some failures can have quite serious consequences that may even end up setting the printer on fire.
Tip during class: Remember to have the equipment to extinguish a possible fire. Remember to monitor the printer work.

Quite a significant risk, especially when working with a printer in a classroom, are particles and fumes generated during printing. They are formed mainly during the use of FDM technology. Studies show that using several 3DPs in the office can increase UFP (ultra-fine particles) from ~2500 to ~25000, which can affect the deterioration of the breathing system[25].
Tip during class: Analyse the placement of your printer(s) and select a suitable low emission filament. Remember to keep a safe distance during printing and use the printers only in well-ventilated rooms.[26].

[23] https://www.safetyandhealthmagazine.com/articles/18295-d-printing-and-worker-safety
[24] Ibidem
[25] Patryk Szyndler, Selected aspects of 3D print technology, Zeszyty Naukowe WSP nr 3/2017 Technologie. Procesy. Bezpieczeństwo. (Red. tomu) M. Chrząścik, Wyższa Szkoła Promocji, Mediów i Show Businessu, Warszawa 2018
[26] https://www.concordia.ca/content/dam/concordia/services/safety/docs/EHS-DOC-148_3DPrinterSafety.pdf

Additional software resources

Some additional resources for you to prepare your 3D products.

Software for create 3D Models

FreeCAD https://www.freecadweb.org/
SketchUp https://www.sketchup.com/
TinkerCAD https://www.tinkercad.com/
Meshmixer http://www.meshmixer.com/

Software for slice 3D Models

Cura https://ultimaker.com/software/ultimaker-cura
Slic3r https://slic3r.org/
Z-Suite https://support.zortrax.com/downloads/
IceSL https://icesl.loria.fr/

Free 3D models

Thingiverse https://www.thingiverse.com/
CGTrader https://www.cgtrader.com/
PrusaPrinters https://www.prusaprinters.org/prints
Zortrax library https://library.zortrax.com/
Repables https://repables.com/
NASA https://nasa3d.arc.nasa.gov/models/printable

Good source of knowledge about 3D printing

https://3dprinting.com/
https://3dinsider.com/
https://all3dp.com/

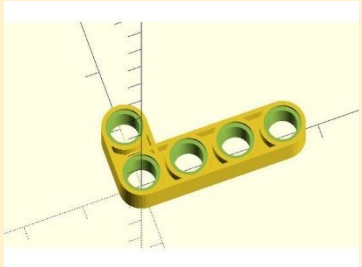
Collection of Case studies

Case study #1

Case study title	Teaching Technology with D3 printing
Lesson's subject	Pawn modeling for board games.
Educational aims	Recognizes and uses composite materials, plastic. Developing technological thinking and skills.
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	A Technology teacher uses 3D printing to create pawn models that can be used in board games. - Jan Twardowski Primary school, Nowa Wieś - 2020 - The 3D model is created based on a mathematical equation using Wolfram Mathematica software, then exported as .STL file. Next, the .STL file is prepared with a slicing software and sent to a 3D printer. - Students understand much better and easier the concept of D3 printing, they can create their own pawn models.
Modelling software used	TinkerCAD - https://www.tinkercad.com
Innovation of the approach	Students can freely expand the basic block base. They develop their imagination by implementing their own projects.
Students' opinions	Possibility of printing new geometrical forms.
Pictures, useful links (if available)	

Case study #2

Case study title	Compatible Lego blocks – development of resources.
Lesson's subject	Designing and printing compatible Lego blocks.
Educational aims	Developing technological thinking and skills. Unlimited development of imagination by implementing your own projects.

Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	An IT teacher uses 3D printing to create compatible blocks that will be used to expand existing resources. We will print the missing part of our construction. - Jan Twardowski Primary school, Nowa Wieś - 2020 - The 3D model is created based on a mathematical equation using Wolfram Mathematica software, then exported as STL file. Next, the.STL file is prepared with a slicing software and sent to a 3D printer. - Students understand much better and easier the concept of D3 printing.
Modelling software used	- TinkerCAD - https://www.tinkercad.com
Innovation of the approach	Students can freely expand the basic block base. They develop their imagination by implementing their own projects.
Students' opinions	Possibility of printing non-existing blocks, e.g. very large wheels or specific gears.
Pictures, useful links (if available)	http://www.swiatdruku3d.pl/wydrukuj-wlasne-klocki-mybuild-pasujace-do-lego/ https://www.thingiverse.com/thing:2503065  Picture source: http://www.swiatdruku3d.pl  Picture source: https://www.thingiverse.com/

Case study #3

Case study title	Understanding of the link between abstraction and concretization
Lesson's subject	Philosophy Support to high functioning autistic students
Educational aims	Facilitate understanding of the link between abstract thought and object. Help to understand the link between project and realization
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Multidisciplinary activity (modeling-art-drawing) and philosophy **Place** Artistic high school - scientific high school - classical high school **Methods** Guided lesson that highlights how the 3D model can be translated into a physical object. **Expected effects** increase abstract thinking and problem solving skills **Difficulties** - few 3D printers available in schools - insufficient technical training of teachers on the use of 3D printers
Modelling software used	not relevant a set of templates ready to be printed might be useful
Innovation of the approach	Students with difficulties in understanding abstract thinking risk being deconcentrated if they are asked to build scale models, the use of 3D printing eliminates the manual construction phase of the object and highlights the direct link between model and object
Students' opinions	Not registered
Pictures, useful links (if available)	

Case study #4

Case study title	Knowledge of the functioning of 3d printers as a basic required professional competence
Lesson's subject	Modeling and Technical drawing
Educational aims	Acquisition of professional competence
Description	Technical workshop **Place**

- **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	scientific high school – technical high school **Methods** workshop **Expected effects** Acquisition of professional competence, team building experience **Difficulties** - few 3D printers available in schools - - insufficient technical training of teachers for 3D printers
Modelling software used	not relevant
Innovation of the approach	3d printer competence is not included in the official school program. The competence will be a competitive vantage for the student after the degree searching for a job
Students' opinions	Not registered
Pictures, useful links (if available)	

Case study #5

Case study title	From the map to the city
Lesson's subject	Support to high functioning autistic students Support to disadvantaged students
Educational aims	increase the comprehension ability of a map favoring the student's autonomy
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Starting from the city map, creation of the 3D model and print. Analysis of the symbols traced in the map and their meaning in physical world. **Place** school **Methods** workshop **Expected effects** increase students' ability to orientate in space and their autonomy in cities **Difficulties** - few 3D printers available in schools - insufficient technical training of teachers for 3D printers
Modelling software used	not relevant
Innovation of the approach	experiential learning
Students' opinions	Not registered
Pictures, useful links (if available)	

Case study #6

Case study title	The physical form of the mathematical equation
Lesson's subject	Support students to understand the meaning of mathematical equation.
Educational aims	Involve and interest students in a subject that is considered abstract and distant from real life
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Starting from the mathematical equation, creation of the 3D model and print. **Place** All type of schools **Methods** workshop **Expected effects** Enforce mathematical approach effects in students **Difficulties** - few 3D printers available in schools - insufficient technical training of teachers for 3D printers
Modelling software used	not relevant
Innovation of the approach	experiential learning
Students' opinions	Not registered
Pictures, useful links (if available)	

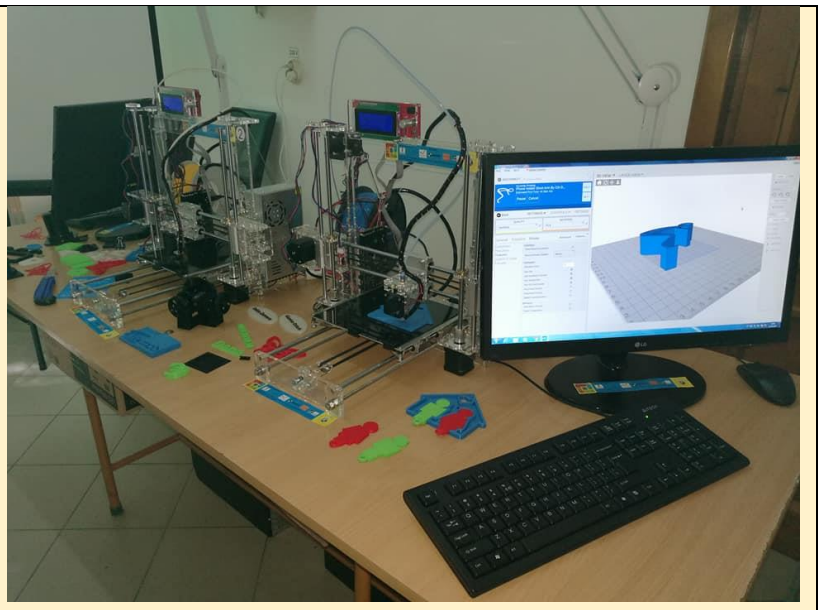
Case study #7

Case study title	Tactile Math – teaching mathematics with 3D printing
Lesson's subject	Advanced math
Educational aims	To explain advanced math concepts using visual and tactile teaching materials
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	A math teacher uses 3D printing to create complex surfaces that acts as visual aids for a better understanding of abstract math concepts. - Torrey Pines High School, San Diego, USA - 2019 - The 3D model is created based on a mathematical equation using Wolfram Mathematica software, then exported as .STL file. Next, the .STL file is prepared with a slicing software and sent to a 3D printer. - Students understand much better and easier the math concepts - Some 3D modelling work may be needed to make the mathematical model printable; 3D modelling and 3D printing skills are necessary (however, they can be outsourced).
Modelling software used	Wolfram Mathematica
Innovation of the approach	It is a new way to allow students to interact with advanced math problems. With the conventional way (writing equations) the students connect with the problems theoretically while 3D printing allows incorporating of visual and tactile learning in the lesson plan.
Students' opinions	Students have a whole new tactile understanding of the presented math concepts.
Pictures, useful links (if available)	https://www.simplify3d.com/tactile-math-teaching-advanced-mathematics-with-3d-printing/

Picture source: www.simplify3d.com

Case study #8

Case study title	Technology workshop
Lesson's subject	3D Printing
Educational aims	To familiarize students with 3D printing technology
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	A technology workshop was set up in a Romanian school. It helps students to experiment a complete technological process, starting from raw material (filament) to the final product, including recycling of failed prints. - Technical College of Communications "Nicolae Vasilescu Karpen", Bacău, Romania - 2019 - A 3D printing technology workshop was created in the school. It includes several 3D printers, computers, a filament extruder. - Students will learn about 3D printing technology and its applications. In addition, they make connections between various knowledge fields and understand better why they need to learn, becoming more motivated in their education and professional development. - The equipment was quite expensive for the school. The problems was solved by applying for and winning a contest offered by "Științescu", a Romanian fund for boosting STEM education.
Modelling software used	AutoCAD
Innovation of the approach	A technology laboratory that aims not only to 3D printing technology teaching but also to increase STEM study motivation, to inspire future careers and entrepreneurship.
Students' opinions	Students have been fascinated by 3D printing technology
Pictures, useful links (if available)	https://stiintescu.ro/mentori/dana-andronic-atelierul-de-tehnologii/

	 Picture source: www.stiintescu.ro

Case study #9

Case study title	3D printing / 3D design in primary school
Lesson's subject	3D project printing, 3D design, elaboration of a 3D logo.
Educational aims	Learn to handle 3D software and technological equipment - 3D printer; Create an innovative learning environment, adaptive to the student, dynamic and interactive that stimulates and reinforces the teaching-learning process;
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	This lesson happened in Basic School of Ribeira de Neiva, School Center of Moure, Basic School of Freiriz, School Center of Lage and Basic School of Parada Gatim. The students were from 3rd and 4th grade. The lesson had 2 hours' duration. This lesson showed students 3D printing from shared projects. They understood the functioning and explained the different possibilities. Then the Happy 3D program was presented, where students were challenged to create an identification logo for each work group. At the primary school, a 3D printer was left for students to experiment and present to the other classes. The teachers showed that they recognized the students' appetite for handling 3D drawing tools and pointed out countless ways to enhance this resource.

Modelling software used	Happy 3D
Innovation of the approach	Project based learning
Students' opinions	Students showed great interest in 3D design, showing enormous enthusiasm to answer the challenge of creating a logo.
Pictures, useful links (if available)	Link: https://www.flashforge.com.br/happy-3d 

Case study #10

Case study title	3D printing / 3D design in primary school II
Lesson's subject	3D project printing, 3D design, elaboration of a 3D letter.
Educational aims	Learn to handle 3D software and technological equipment - 3D printer; Create an innovative learning environment, adaptive to the student, dynamic and interactive that stimulates and reinforces the teaching-learning process;
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	This lesson happened in Basic School of Ribeira de Neiva, School Center of Moure, Basic School of Freiriz, School Center of Lage and Basic School of Parada Gatim. The students were from 3rd and 4th grade. The lesson had 2 hours duration. This lesson inspired students to 3D printing with a new online tool. Then the TinkerCAD program was presented, where students were challenged to create their name first letter. The teachers showed that they recognized the students' appetite for handling 3D drawing tools and pointed out countless ways to enhance this resource.
Modelling software used	TinkerCAD
Innovation of the approach	Project based learning

Students' opinions	Students showed great interest in 3D design, showing enormous enthusiasm to answer the challenge of creating / shaping a letter.
Pictures, useful links (if available)	Link: https://www.tinkercad.com/ 

Case study #11

Case study title	Teach Biology through 3D Printing – 3D Bioprinting
Lesson's subject	Biology and Laboratory Practices
Educational aims	Engage and motivate students to be part of practical classes and learn through a dynamic method.
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Bioprinting is used to create super soft biological structures used for medical purposes. However, 3D printing through simple printers can be used to print parts of the human body or animal body, for a proper representation of organs that cannot be easily represented or explained. For instance, create anatomical models to teach pupils about the human body (creating a skeleton). Place All type of schools Methods Classes, workshops, laboratory experiments. Expected effects ~ Students distinguish and learn about human body and living beings bodies' parts. ~ Associate organs with systems of the body. Difficulties ~ Price and affordability of 3D for schools. ~ Insufficient technical training of teachers for 3D printers
Modelling software used	Not relevant
Innovation of the approach	Teaching through collaboration

Students' opinions	Not registered
Pictures, useful links (if available)	Link: https://www.europeanpharmaceuticalreview.com/news/71599/3d-printing-biological-structures/ 

Case study #12

Case study title	3D Printers for Sustainable purposes
Lesson's subject	Sustainable Technology.
Educational aims	Enhance creativity and show practical purposes for which 3D Printing can be used for sustainable development and life improvement.
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Theoretical and problems disclosure to concern for the need of a sustainable development. In addition, bring 3D Printing as the solution for problems and the key for sustainable development and reduce of waste. **Place** High schools and universities. **Methods** Workshops, classes, visits to companies that use 3D Printers. **Expected effects** ~ Discussion and build awareness for global problems. ~ Empathy and build feeling of philanthropy. ~ Enhance creativity and imagination in order to bring solutions to the detected problems. ~ Proper use of 3D Printer. **Difficulties** ~ Price and affordability of 3D Printers. ~ Insufficient technical training.
Modelling software used	Small size 3D Printers and big size printers used by organizations (visit).
Innovation of the approach	Teaching through collaboration and constructions.
Students' opinions	Not registered

Pictures, useful links (if available)	https://www.3dnatives.com/en/3d-printing-sustainability-220420194/ https://www.3dnatives.com/en/3d-printing-sustainable-manufacturing-method-211120185/

Case study #13

Case study title	Teaching Geography Using a 3D Printer.
Lesson's subject	The Economic Activities of Europeans: Agriculture and forestry in Europe.
Educational aims	Engage and motivate students in a subject that is considered indifferent and distant from real life.
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Starting from assigning vegetation zones to the groups of students, relevant information is distributed in order to research and identify the characteristics of the zone assigned to them. Students are expected to print 3D objects in order to create a model of the physical environment. **Place** All type of schools **Methods** workshop **Expected effects** - Students distinguish the main features of agricultural production. - Students associate agricultural products with environmental factors. - Students distinguish the vegetation zones into which the European continent is divided. **Difficulties** - few 3D printers available in schools - insufficient technical training of teachers for 3D printers
Modelling software used	Not relevant
Innovation of the approach	Teaching through collaboration Flipped Classroom
Students' opinions	Not registered
Pictures, useful links (if available)	https://edu.ellak.gr/2019/01/18/axiopiisi-tou-3d-ektipoti-sto-gimnasio-krokou-kozanis-didaskontas-geografia-sto-gimnasio-me-tin-chrisi-trisdiastatou-ektipoti/

Case study #14

Case study title	Using a 3D Printer in the teaching process
Lesson's subject	Teachers of different specialties in a school introduce the use of the 3D Printer to specific sections of their lessons.

Educational aims	Active involvement of students through the construction of 3D objects.
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Secondary school teachers are informed about the function and capabilities of 3D priding, then each teacher designs and organizes a project in order to utilize 3dP in his teaching. **Place** High school **Methods** workshop **Expected effects** - Students discuss and build historic monuments - Students make sundial - Students construct a model of the periodic table of chemicals - Students discuss and create models and construction components. - Students make everyday objects as well as puzzle games **Difficulties** - few 3D printers available in schools - insufficient technical training of teachers for 3D printers
Modelling software used	TinkerCAD
Innovation of the approach	Teaching through collaboration and constructions
Students' opinions	Not registered
Pictures, useful links (if available)	https://edu.ellak.gr/wp-content/uploads/sites/11/2017/06/3d_gymnasio-geraki-lakonias.pdf

Case study #15

Case study title	I Produce 3D Printer
Lesson's subject	3 Boyutlu Yazıcı Tasarım ve Üretimi
Educational aims	To produce a new printer with its own designs from 3D printers used in many fields, to take part in the production process and to create a new printer with its own designs.
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	3D printer production Sivas Science and Art Center 2019-2020 Research, Cooperative Work, Project Based Learning Involving in the production process as a creator to create a new product.
Modelling software used	CURA, Repetier and other Software Supporting Open Source Firmware
Innovation of the approach	This design was created by themselves

Students' opinions	In the 3D printer production process, I gained a lot of skills such as design skills, modeling skills, making production, turning the product into a material gain in the market.
Pictures, useful links (if available)	https://www.eba.gov.tr/videoizle/67074c8cc1e2cd3d8415e8343411074b3b12243204001

Case study #16

Case study title	National 3D Game Move (Designed by Bilsem-Since and At Centers)
Lesson's subject	Developing Fun Gamified Educational Materials
Educational aims	Use of 3D Game Engine and 3D Modeling Tools
Description - **Place** - **Time** - **Methods** - **Expected effects** - **Difficulties**	Mersin Silifke Yıldırım Beyazit GSB Youth Camp 02.06.2020-06.06.2020 Training on Game Design, 3d modeling, and Game coding were attended by visual arts, Technology Design and IT teachers around Turkey. The teachers participating in the training have gained basic level skills and have been given the level of teaching their students at their schools of duty. Lack of time.
Modelling software used	Unreal Engine 4.0, Blender 2.8, Adobe Fuse, Mixamo
Innovation of the approach	Cognitive diversity of the target group and interactive study
Students' opinions	It was emphasized that they were able to receive the necessary basic level training in a short time and declared that they would give lectures at their schools, and the software used was easy, functional, and enjoyable.

Pictures, useful links (if available)	

Lesson plans and recommendations for future implementations

Lesson plan #1

Title	***The school of the future in 3D***

Summary	***Students will learn the basic functions of the TinkerCAD program and design any simple 3D model.***

Table of Summary	
Subject	*Information technology*
Topic	*Learning the basic functions of the TinkerCAD program.*
Age of students	9-12
Preparation time	*120 minutes*
Teaching time	*90 minutes*
Online / offline teaching material	*www.tinkercad.com*

Integration into the curriculum

Students:

- use computers and computer applications developing the ability to express their thoughts and present them individually or in groups

Aim of the lesson

Understanding the principles of using the 3D modeling program - TinkerCAD.

Activities

Name of activity	Procedure	Time
1. Providing the purpose and topic of the lesson.	Students write down the topic of the lesson	5 min
2.Registration for the TinkerCAD program.	Students create an account and then log in	10min
3. Learning how to move on the work surface.	Students watch the teacher showing how to move on the working surface TinkerCAD program using a cube and the mouse, and then practice this skill	10 min
4. Learning how to add objects to the work surface, add color, dimension and change the shape.	Students observe how to complete these tasks, a then they practice these skills	20min
5. Learning how to turn, lift, move, copy and remove blocks.	Students watch the teacher showing these skills and then practice it themselves	20min
6.Creating models	Students create their own 3D models.	20 min
7.Homework assignment.	Students write down the content of their homework: Design a 4-element model	5 min

Assessment

Hang three flipcharts with unfinished sentences on the board and ask students to finish them on post-it notes and then stick them on a suitable poster:

1. From today's lesson I will remember .....
2. I liked..... the most.
3. The most difficult was ....

Recommendations / teachers' opinions on possibilities of implementation, benefits, ideas on how to use 3DP in various subjects

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Lesson Plan #2

Title: *The school of the future in 3D*

Summary

To make students interested in computer science and 3D design using the https://www.tinkercad.com application. The teacher and the students will conduct lessons in printing blocks compatible with Lego Mindstorms. Under the guidance of the teacher, students

will search for appropriate block designs, then we will prepare for its printing and check its compatibility with the blocks owned by the school.

Table of summary	
Subject	*Information technology*
Topic	*Our first Lego brick.*
Age of students	*9-14*
Preparation time	*90 minutes*
Teaching time	*140 minutes*
Online / offline teaching material	*Application: https://www.tinkercad.com* *3D printer .* *A Lego block that we will print or a photo of it .* *Caliper - Needed to compare the printed brick with the original.*

Integration into the curriculum

E2-PODST-INF-2.0-KLVIIVIII-II.4 - saves the results of his work in various formats and prepares printouts;

E2-PODST-INF-2.0-KLIVVI-II.2 - tests his programs on the computer in terms of compliance with the adopted assumptions and, if necessary, corrects them, explains the course of the programs;

E2-PODST-INF-2.0-KLIVVI-II.4 - collects, organizes and selects the effects of his work and the necessary resources in a computer or other devices, as well as in virtual environments (in the cloud).

E2-PODST-INF-2.0-KLIVVI-V.1 - uses technology in accordance with the adopted rules and law; follow the rules of occupational health and safety;

E2-PODST-INF-2.0-KLVIIVIII-IV.1 - to find the information and learning resources

E2-PODST-INF-2.0-KLIVVI-IV.2 - identifies and appreciates the benefits of working together to solve problems together;

E2-PODST-INF-2.0-KLVIIVIII-III.3 - correctly uses terminology related to IT and technology.

E2-PODST-INF-2.0-KLIVVI-III.2.a - participates in various forms of cooperation, such as: programming in pairs or in a team, project implementation, participation in an organized group of learners, designs, creates and presents the effects of joint work.

Aim of the lesson

The student is able to use a tablet, laptop to gain knowledge.

The student knows the application https://www.tinkercad.com and can use it for purposes related to acquiring knowledge and developing skills.

The student is able to solve tasks individually and in a team.

The student knows the terms: 3D printing, 3D printer, .stl file, print design.

The student can search for a project at https://www.tinkercad.com and download it.

The student knows what the .stl file is for.

The student can export a .stl file to an external printer.

The student knows how to use a caliper.

The student is able to work in a team on a joint project.

Print a compatible brick from Lego Mindstorms using the https://www.tinkercad.com program.

Activities

Name of activity	Procedure	Time
Reminder of the basic safety rules when using a 3D printer	The students are listening.	10 minutes
Introduce students to the topic of the classes	The teacher informs the students that in today's class they will print a compatible brick for the Lego Mindstorms set at https://www.tinkercad.com	10 minutes

Launching the application on the website https://www.tinkercad.com	Students on tablets or laptops run the application https://www.tinkercad.com The teacher uses the projector to display it and reminds of its basic functions. Students follow the teacher's instructions.	10 minutes
Searching for printing bricks compatible with the Lego Minsdstorms set.	The teacher divides the class into groups and recommends everyone to find a suitable block design compatible with the Lego Mindstorms set at https://www.tinkercad.com Students follow the teacher's instructions.	20 minutes
Choosing the best design.	Students present the searched projects and explain why they chose them - then, together with the teacher, they will choose the best project.	20 minutes
Importing the project into the editor.	The teacher asks the students to import the selected project into the TinkerCAD editor. Students follow the teacher's instructions and then edit the project.	10 minutes
Checking the dimensions of the block - comparison with the original one with the use of electronic caliper.	Using a caliper, the students measure the original block and write down all the dimensions, then in the TinkerCAD editor they use a ruler to see if all the dimensions are correct. The teacher controls the work of the students - provides help with measurements if necessary.	20 minutes
Saving the finished .stl file and sending it to the 3D printer.	Students save project .stl and then send it to print. The teacher supervises their actions.	5 minutes
Printout of the project in a 3D printer	The teacher starts the printer. Students observe the initial printing phase. After printing, students check the compatibility of the block with the set.	80 minutes
Summary of the lesson	The teacher and the students will summarize the result of the work and evaluate the printout.	20 minutes

Assessment

Knowledge test : https://quizizz.com/admin/quiz/5f1d56106ed34c001b9e725e/wydruk-d

Recommendations / teachers' opinions on possibilities of implementation, benefits, ideas on how to use 3DP in various subjects

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Lesson plan #3

Title

BİLSEMs ARE DESIGNING

Author(s)

Summary

The basic training is given to teachers working in science and art centers on Information technologies, visual design and technology design, 3D game design, 3D museum design, and educational material development. Unreal Engine 4.0 and Blender 2.8 training are provided in this training. Programs are introduced at basic levels to the participants and then passes to the practical training.

Table of summary	
Subject	*Unreal Engine ve Blender ile 3 boyutlu tasarım ve eğitim materyali geliştirme*
Topic	*3D game design, 3D museum design and educational materials development with Unreal Engine and Blender*
Age of students	*Up to 22 years old*
Preperation time	*To have basic ICT knowledge and ability*
Teaching time	*30 lesson hour*
Online / offline teaching material	*Unreal Engine 4.0* *Blender 2.8*

Integration into the curriculum

The teaching process will be facilitated by developing 3-dimensional materials suitable for the basic courses and workshops given in science and art centers. In addition, 3-dimensional game designs and games that are suitable for curriculum outcomes will be developed to make teaching

processes more permanent. Museums that are difficult to visit with 3D museum designs will be offered to students.

Aim of the lesson

To ensure that science and art center teachers will able to make 3D material designs, have basic knowledge and skills for 3D game design, and have the competencies to perform 3D museum design.

Activities

Name of Activity	Procedure	Time
About 3D Design	Basic information about 3D design	2 lesson hour
Designs that can be made with programs	Introducing the potential of using the program by showing the designs that can be made with the programs with examples	2 lesson hour
Introducing basic interface designs	Introducing the basic interface design of Blender 2.8 program	2 lesson hour
General commands	Introduction of general commands used in Blender 2.8 program	2 lesson hour
Extra commands	Introduction of extra commands used in Blender 2.8 program	2 lesson hour
Lighting, Scene and Render	Introduction with lighting, scene and rendering in Blender 2.8 program	2 lesson hour
Modifiers	Introducing modifiers in Blender 2.8 program	2 lesson hour
Layers	Practical introducing about layers in Blender 2.8 program	2 lesson hour
Rigging	Practical introducing about Rigging in Blender 2.8 program	2 lesson hour
Introducing Basic Interface Designs	Introducing the basic interface design of Unreal Engine 4.0 program	2 lesson hour
Project Information and Basic Functions	Project information and introduction to basic functions with Unreal Engine 4.0	1 lesson hour
Light, Camera and Sound	Practical demonstration of light, camera and sound with Unreal Engine 4.0	2 lesson hour
Active Blueprint Functions	Practical demonstration of active blueprint functions with Unreal Engine 4.0	2 lesson hour
Animations and Models	Practical demonstration of animations and external models with Unreal Engine 4.0	2 lesson hour
Project consolidation	Project consolidation in Unreal Engine 4.0	1 lesson hour

Project Packaging and Evaluation	Practical demonstration on project packaging and evaluation in Unreal Engine 4.0	2 lesson hour

Assessment

The applied training material will be evaluated in terms of its applicability in education and its suitability to the education level, and guidance will be given to the trainees.

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Lesson plan #4

Title

I PRODUCE 3D PRINTER

Summary

Trainings are organized to produce a new printer with its own designs from 3D printers used in many areas, to take part in the production process and to create a new printer with its own designs.

Table of summary

Subject	*To produce and design it's own a new 3D printer*
Topic	
Age of students	*Up to 14 years old*
Preparation time	*To have a basic level of ICT knowledge* *To have basic level of 3D design knowledge*
Teaching time	*30 lesson hours*
Online / offline teaching material	*3 D Printer*

Integration into the curriculum

3D printers, which are devices that transform the data stored in the computer environment into physical real objects, are used in many areas in the education stage. Understanding the logic of these printers, learning their technical features, designing printers and using them more efficiently in education are among the main objectives of training.

Aim of the lesson The aim of the course is to understand the logic of 3D printers and learn their technical features to design printers and use them more efficiently in education.

Activities

Name of activity	Procedure	Time
The Logic of 3D Printers	Examining the working logic of 3D printers	2 lesson hour
Technical Aspects of 3D Printers	Examination of technical features of 3D printers	2 lesson hour
Parts of 3D Printers	Examination of 3D printers and the parts used in the printer	2 lesson hour
Developability of 3D Printers	Brainstorming on the developability of 3D printers	2 lesson hour
Development of 3D Printer Parts	The development of parts fo the 3D printers developed as a result of printer Brainstorming	2 lesson hour
Development of 3D Printer Parts	Determining the necessary materials and costs for 3D printer production	2 lesson hour
Development of 3D Printer Parts	Practical training on the implementation of the developed parts of the 3D design	4 lesson hour
Development of 3D Printer Parts	Practical training on the implementation of the developed parts of the 3D design	4 lesson hour
Creating a 3D Printer	Practical trainings on the creation and assembly of electronic circuits in 3D printers	2 lesson hour

Creating a 3D Printer	Practical trainings on the creation of developed 3D printers	4 lesson hour
Market Value of 3D Printers	Determining the market value of the generated 3D printer and determine the work required for the production of series	2 lesson hour
Sales of 3D Printers	Determination of the studies required for the sale of 3D printers created	2 lesson hour

Assessment

The applications will be evaluated in terms of their applicability in 3D printer design and production and their suitability to the education level and guidance will be given to the trainees

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Lesson plan #5

Title

3D printing: What I need to know to start?

Summary

Types of 3D printing on the markets, materials and programs used for 3D editing

Table of summary

Subject	*Introduction to 3D printing*
Topic	*Learning how to use a 3D printing*
Age of students	*>10*
Preparation time	*10 m*
Teaching time	*60 min*
Online / offline teaching material	*Online:* *Google classroom (or other educative platform)* *YouTube* *Google search* *Search form* *Learning Quiz*

Integration into the curriculum

It is intended to help students do research with criteria on the acquisition or knowledge of a product for 3d printing and using it to creating products for other subjects, such as maths or science, for instance.

Aim of the lesson

Understand the principles of operation of a 3D printer, costs of materials and equipment and criteria for comparison between them

Activities

Name of activity	Procedure	Time
Introduction	Students receive a research guide on 3D printing. The guide should contain questions that motivate students to look for information about 3d printers.	5m
Research	The guide should start from the idea that you want to buy a 3D printer: - 3D printers are distinguished mainly by the form of printing, observe on YouTube a filament print and a digital light print also known as resin printing. - Printers are also distinguished by the printing area. What are the most common? - How to perceive the print quality? - What are the most sold printers, opinions and costs?	15m

Challenge	Students will be given three scenarios imagining that they are printer sellers: 1 - A customer wants to buy a 3d printer for starters. He has no knowledge, he is a person who likes to experiment and can spend up to 500 euros on the purchase of equipment. 2 - A customer wants to buy a printer for the school where he works. He wants a printer for students to use and experiment with and wants to use a lot the equipment in different subjects. It was important that the System had security, network, different programs and he can spend up to 2000 euros. He does not exclude the possibility of buying two printers for the same budget. 3 - A customer wants a printer with the possibility of printing soluble PVA filaments for supports on the parts.	30m
Questionnaire	Students complete an online questionnaire with quick survey questions. 1- Are the most sold printers made of filaments? V 2- Is a larger printer better than a smaller printer? F 3- 3D printers use programs to print? V	10m

Assessment

At the end it will be done an evaluation questionnaire

Recommendations / teachers' opinions on possibilities of implementation, benefits, ideas on how to use 3DP in various subjects

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Lesson plan #6

Title

3D printing: How to draw?

Summary

Programs and drawing editing platforms for 3D printing

Table of summary	
Subject	*Introduction to 3D drawing*
Topic	*Learning how to use 3D drawing*
Age of students	*>10*
Preparation time	*10 m*
Teaching time	*60 m*
Online / offline teaching material	*Online:* *Google classroom (or other educative platform)* *YouTube* *free 3d printing design platforms* *Learning Quiz*

Integration into the curriculum

It is intended to help students to use some 3D drawing tools. They can be useful for Art subjects, for instance.

Aim of the lesson

Understand the principles of operation of a 3D printer and 3D design platforms or programs

Activities

Name of activity	Procedure	Time
Introduction	Students will observe a 3D filament type print and will be challenged to design a simple piece	10m
Research	Through a video prepared for this purpose, students observe the process of drawing in 3D, preparing for printing and printing. https://www.tinkercad.com/learn/designs https://www.youtube.com/watch?time_continue=141&v=Vx0Z6LplaMU&feature=emb_logo	5m
Challenge	Design a key ring with your name - In this task, students receive a step-by-step guide to drawing a piece. They should use the free online drawing tool *www.thinkercad.com* or even any tool they may have on the operating system (eg. paint 3D)	45
Evaluation	Students submit their piece on an online site for simulation of printing time and costs (https://www.omnicalculator.com/other/3d-printing)	10

Assessment

A satisfaction questionnaire will be made at the end of the evaluation questionnaire

Recommendations / teachers' opinions on possibilities of implementation, benefits, ideas on how to use 3DP in various subjects

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Additional resources

1. Thingiverse Education, https://www.thingiverse.com/education
2. “Training in 3D Printing To Foster EU Innovation & Creativity”, Erasmus+ project, https://3d-p.eu/
3. Makerbot Educators Guidebook, https://www.makerbot.com/stories/3d-printing-education/free-ebook-makerbot-educators-guidebook/
4. Ford, S. and Minshall, T., Where and how 3D printing is used in teaching and education, Additive Manufacturing, Volume 25, Pages 131-150, 2019
5. Learn how 3D Printing is useful everywhere, www.sculpteo.com/en/applications/
6. 2020 Types of 3D Printing Technology, https://all3dp.com/1/types-of-3d-printers-3d-printing-technology/
7. 5 Greatest 3D Printing Applications https://all3dp.com/2/greatest-3d-printing-applications/
8. The Future of 3D Printing: Beyond 2020, https://all3dp.com/2/future-of-3d-printing-a-glimpse-at-next-generation-making/
9. 14 3D printing applications & examples, https://builtin.com/hardware/3d-printing-applications-examples
10. 3D Printing Applications: A New Age,www.jabil.com/insights/blog-main/3d-printing-applications.html
11. The top 5 benefits of 3D printing in education, www.makerbot.com/stories/3d-printing-education/5-benefits-of-3d-printing/
12. 10 ways teachers are enhancing STEM learning with 3D printing https://www.makersempire.com/top-10-stem-3dprinting-education/