

# 3D Printing Practical Handbook

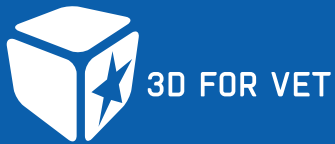


3D FOR VET



Co-funded by the  
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of the European Union

# 3D Printing Practical Handbook



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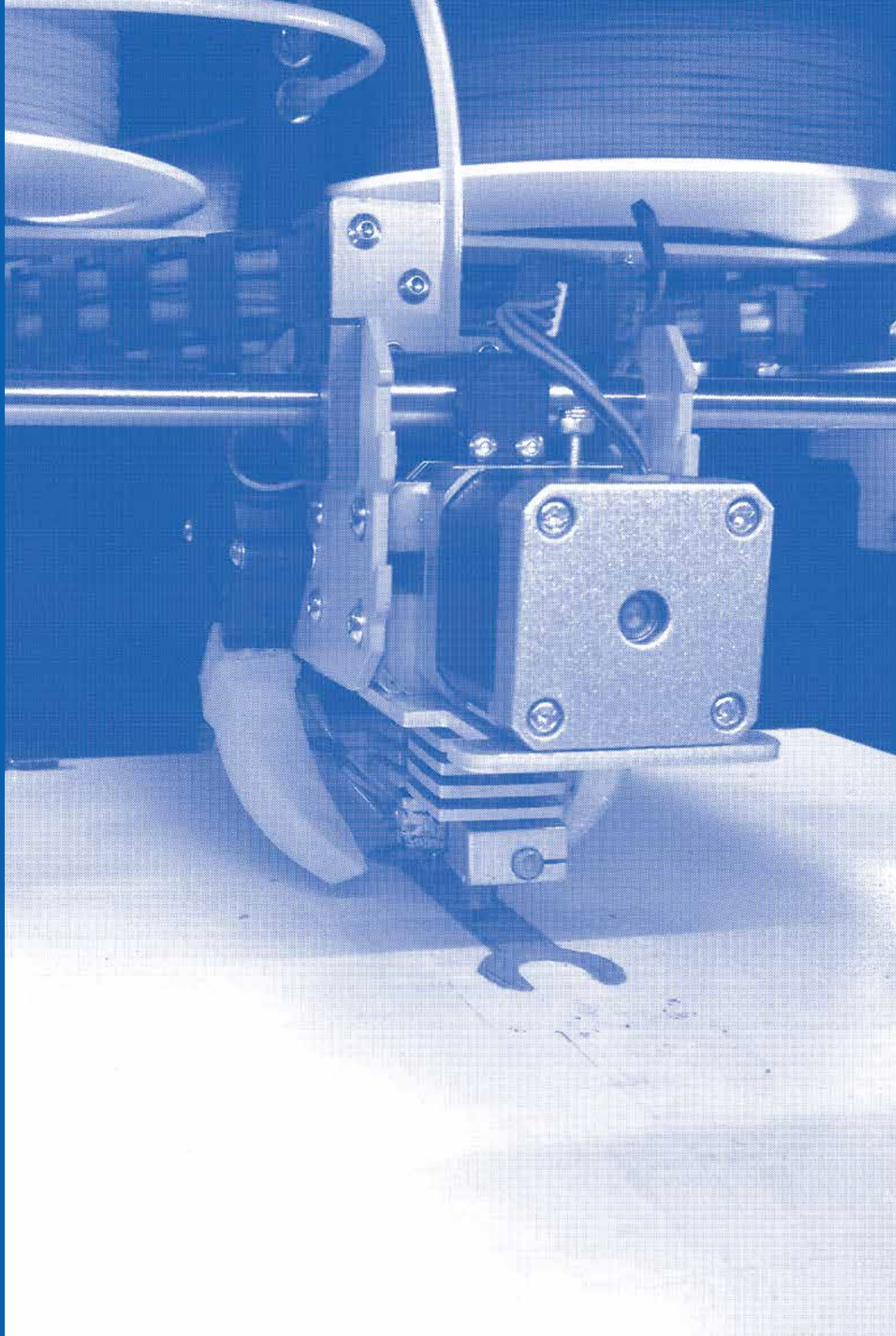
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- Pula Technical School, Croatia
- Metris Research Centre, Croatia
- Malopolska Voivodship, Poland
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# 1 General project and handbook information

## 1.1.

### *How the initiative was launched*

In all European countries, fast-changing technical development and global competition are creating the ever growing demand for well-qualified workers.

Industries and enterprises seek workers who are highly specialized in modern technologies and ready to tackle digital demands as soon as they finish their education.

To keep up with the labour market demands, Vocational Education and Training institutions need to stay current with modern technologies and educate their students to be able to meet the employer's requirements. In this context, investing in education is important in order to make VET an attractive option for young people so they can acquire professional qualifications and update them throughout their working life.

Keeping in mind the new trends in the global and labour market and its large international experience within different EU programmes and initiatives, the Region of Istria created an international partnership gathering other European regions within its bilateral collaboration, including the Austrian Carinthia and Malopolska Region. The partners included their VET schools and educational institutions, prepared the **3D FOR VET - Strategic Partnership for the Development of 3D Competences project** and successfully applied it for funding. Evaluated as the best project proposal, it has been approved for funding within the **ERASMUS+ Programme, under Key Action 2 - Cooperation for Innovation and the Exchange of Good Practices**. The total budget of the project amounts to EUR 250,585.00 EUR. It started in September 2017 and should end in August 2020.

## 1.2.

### **About the project**

The aim of 3D FOR VET - Strategic Partnership for the Development of 3D Competences is to put students from technical vocational schools in a better position in the labour market by introducing 3D technologies into their formal education, applying their knowledge in practice and working together with peers from other EU countries. The target groups that are expected to benefit the most from the project are the students and teachers from the VET schools participating in the project and 2 partner regional authorities.

The project involves partners from 4 European countries: Croatia, Lithuania, Austria and Poland. The partners involved in the project activities are as follows: Pula Technical School, METRIS Research Centre, Panevezio profesinio rengimo centras, Carinthia University of Applied Sciences, Malopolska Voivodship and Zespół Szkół nr 2 im. Jana Pawła II w Miechowie, while the lead partner is the Regional Coordinator for European Programmes and Funds of the Region of Istria.

Throughout the project, different activities have been implemented in order to improve the educational capacities of the involved schools, increase the competitiveness of students by providing them with knowledge on 3D technologies and promote the introduction of modern technologies in high school education in general. The main project activities are described below.

## 1.3.

### **Objectives and structure of the handbook**

One of the key project activities is the preparation of the handbook for conducting practical workshops on 3D printing. The handbook is meant to guide VET teachers and providers through the educational process and provide them with guidelines and practical exercises to perform during their lessons.

With this handbook, the project partners hope to provide VET teachers and trainers with a useful tool for conducting 3D technology workshops based on practical examples and experiences of all the partner institutions gathered during various workshops conducted within the project activities.

The added value of the handbook is that it gives, through case studies, a systematic overview of VET education in the participating countries. The case studies point out the differences and common features of the educational systems in the four countries, which makes the handbook applicable to all VET schools in the countries involved as well as all high- school-aged youth. Furthermore, the handbook is based on the workshops and methodologies that have been already tried and tested.

- The handbook consists of 6 chapters, each opening with a short description and an introduction to its objectives.



## 2 Short-term Joint Staff Training Events

Three (3) short-term training events have been realized within the project: two (2) by the Carinthia University of Applied Sciences, Villach, due to its wide expertise in modern technologies, while the third was held in METRIS, Pula, R&D centre of the Region of Istria.

The main objective of the short-term training events (3D VET teacher workshops) is to help teachers keep up with modern technologies and be able to transfer their knowledge to students. Education of VET teachers is one of the main preconditions for the modernization of VET schools. This goal will be achieved through cooperation between education and training institutions, which will result in considerable improvements in the promotion of vocational programmes, networking and comparison with other institutions, information sharing and exchange of experience.

Modern teaching methods, innovative topics related to the use of modern technologies in the learning process, as well as teaching plans and upcoming activities were discussed at the trainings held in Austria and Pula (Croatia). The teachers were provided with general information and practical examples on how to programme and operate a 3D printer, encouraging them to introduce and implement available technologies as an integral part of their lessons.

The workshops improved the teachers' abilities and teaching competences, which is essential in transferring their knowledge to their students within the workshops organized in their schools.

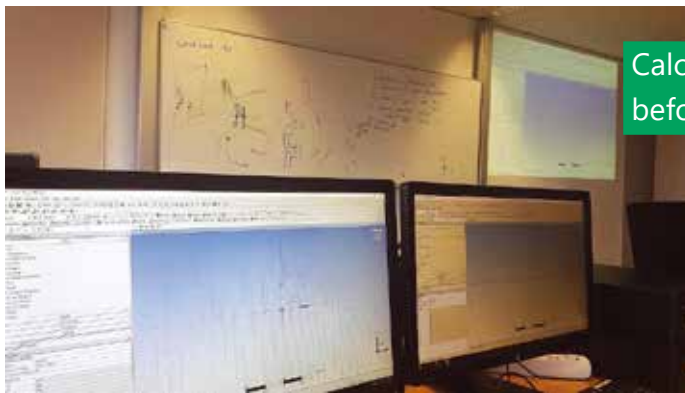
First teacher training, Villach



## 2.1.

### **1<sup>st</sup> Short-term Joint Staff Training Event**

The first Short-term Joint Staff Training Event - VET Teachers 3D Workshop was organized at the Carinthia University of Applied Sciences in Villach in October 2017 and was attended by the teachers from the partner schools. The participants were introduced to 3D printing technologies, basics of construction and 3D printing design rules, as well as the simulation and optimization techniques in 3D technologies. Furthermore, methods and tools to develop customized 3D printing techniques were presented. Different methods, types and applications for 3D prints were analysed and discussed. Several 2D and 3D drawing tools, application modelling software and material testing software were applied during the practical activities. All the participants drew and printed their own 3D models.



Calculations and preparations before printing, Villach

## 2.2.

### **2<sup>nd</sup> Short-term Joint Staff Training Event**

The Carinthia University of Applied Sciences also hosted the second Short-term Joint Staff Training Event - VET Teachers 3D Workshop, which was held from 3 to 6 December 2018. The main topics covered during this activity were the following: possibilities and benefits of integrating 3D printing into education, examples of practical application of 3D printing in different school subjects, practical generative design method & FEM, role of 3D printing in industry 4.0, structural robustness of 3D printing objects and application of 3D prints in mechanical engineering. Special attention was paid to the results from the first training held in Villach.



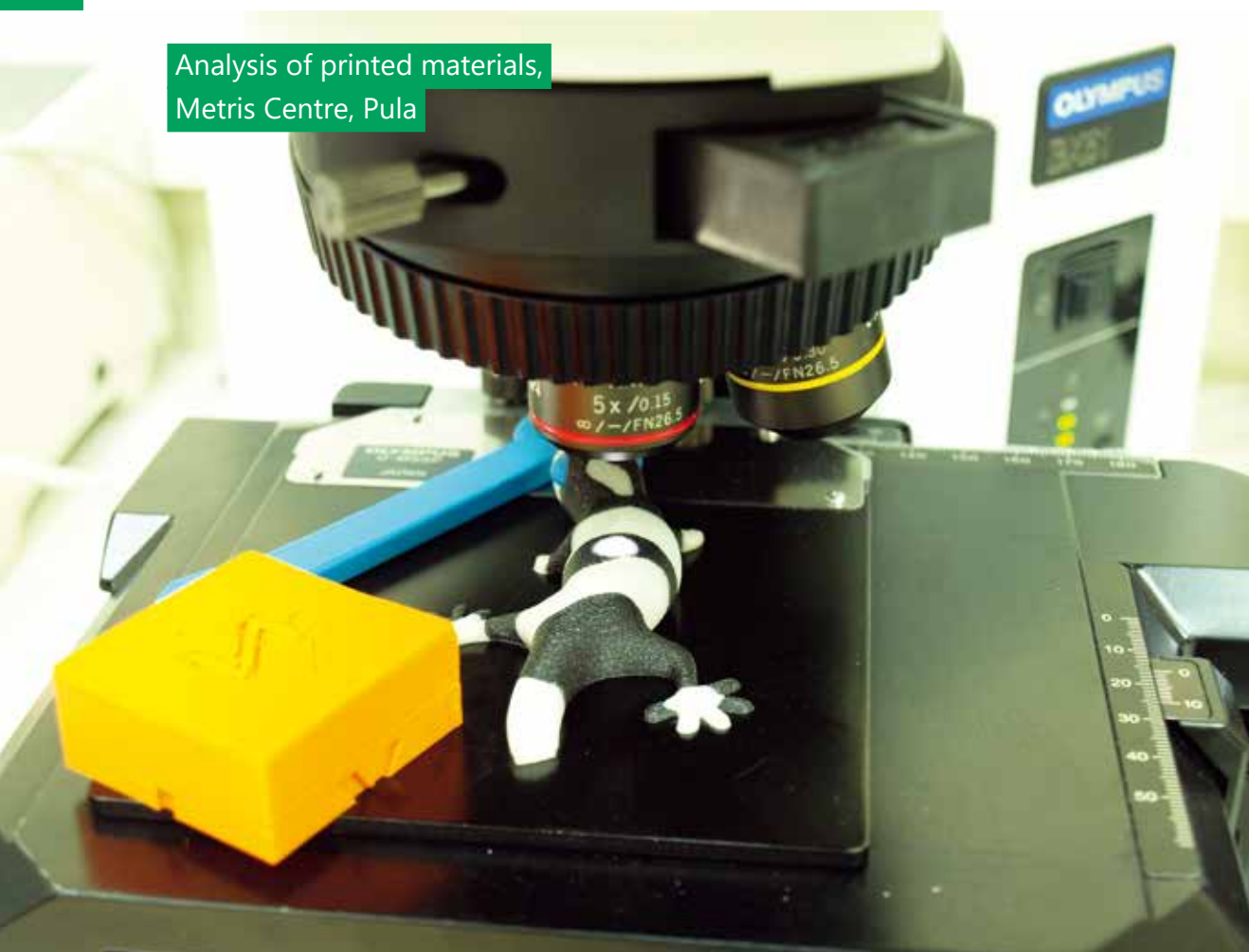
Representatives of the participating schools, Villach

### 2.3.

#### 3<sup>rd</sup> Short-term Joint Staff Training Event

In October 2019, the third Short-term Joint Staff Training Event (C3) of the 3D FOR VET project was held in METRIS and included the visit to the Technological Incubator and the Centre for the Popularization of Science in the Region of Istria. The participants of the workshop were the teachers of the schools involved and the students of the Technical School who presented their work on 3D printers and scanners. Various institutions that operate in the territory of the Region of Istria and use 3D technologies in their work were presented. Thus, the Archaeological Museum of Istria demonstrated the objects and artefact replicas they had produced by applying modern technologies. The CIMOS Group also presented 3D printers, moulds and 3D scanning techniques they use in the production process. During the exercises performed at the Metris Centre, different 3D printed products were analysed, with an emphasis on their chemical and mechanical components and the analyses of their structures and comparison with non-printed materials in general. Various aspects of the printed material were combined in order to create and programme the experiments suitable for students in different subjects.

Analysis of printed materials,  
Metris Centre, Pula





VET teachers using  
Metris Centre equipment, Pula



# 3 Blended mobility of VET learners

During the implementation of the project, 2 blended mobilities were organized for students from 2 partner schools participating in the project. The main objective of the blended mobilities was for students to acquire international experience and exchange the knowledge and practice they gained during the workshops conducted by teachers in their schools. Special attention was paid to the collaboration and networking between the educational institutions in order to create synergy and strengthen the relationships between VET teachers and students in the international context.

The mobilities were particularly useful for young people who had the opportunity to learn new skills and improve their employability, acquire life skills and develop confidence. This way they had the opportunity to improve their education and acquire international competences.

## 3.1.

### *1<sup>st</sup> Blended mobility of VET learners, Panevezio profesinio rengimo centras, Lithuania, 23 – 27 April 2018*

The mobility was attended by teachers and 30 students from Croatia and Poland selected by their teachers. It included the visit to the Centre for Technological Innovation in Vilnius, visit to the partner school and institutions, student

work in mixed international groups. The activities conducted provided the participants with opportunities to learn and improve their knowledge in 3D technologies, as well as to develop language skills and intercultural competences.

Mobility participants, Lithuania



Students and teachers trying to create a 3D model of a dice, Lithuania



**3.2.**  
***2nd Blended mobility of vet learners, Pula Technical School, Croatia, 8 – 12 April 2019***

Students and teachers had the opportunity to get acquainted with the Technical School and its equipment comprising 3D printers and scanners. This way they had the opportunity to apply their theoretical knowledge to concrete and practical examples. The students also visited the Centre for the Popularization of Science and Innovation of the Region of Istria, Metris and the Cimos factory in Buzet. They also got acquainted with the school facilities and the students they were visiting, they exchanged experiences and visited the most important institutions the school cooperates with.

Use of the 3D scanner, Tehnical School Pula





Students experimenting at the Metris Centre, Pula



Students visiting the Cimos factory, Buzet



# 4 Case study

## 4.1.

### *About the case study*

The regional case studies represent the central part of the handbook. Their main purpose is to provide a systematic comparison of the educational systems of the partner countries, define common problems in the VET field and methodologies for solving them. The use of modern technologies in vocational schools in 4 countries has been illustrated through the analysis of the case studies, which was essential in order for the partners to recognize the problems, find the good practice examples from other partner countries and apply them in their VET system, providing a contextual framework for developing the activities and methodologies to be used while conducting the 3D technology workshops in the participating countries.

In addition, the analysis of the case studies has identified the advantages and disadvantages of VET systems in each country, the problems of current technologies and devices used in the 3D technology lessons in VET schools in each partner region, as well as common features and possibilities for collaboration and experience exchange.

## 4.2.

### *Case study - overview*

All the partners have completed the questionnaire describing the VET systems in their regions, based on their experience, national VET curricula and available national VET development programmes and strategies.

In the first part of the case study, the educational institutions participating in the project were presented. Through 10 questions they had to present the region and the country they are coming from, the institution they work for, the educational system of their institution, the status of the students who graduated from the programmes offered by their school. An overview of their answers is provided below.

# Case study on the use of modern technologies

- 4 countries
- 40 interviews
- 4 regional case studies
- 40 main stakeholders

## *Vocational education system*

- age of students: 14 - 18 years old
- 3 types of vocational education systems
- practical trainings

## *Status of vocational graduates*

- over 70% of students entered the labour market
- 20% of students continue with education
- 5% unemployed
- 5% other

## *New equipment and technologies*

- national funds
- international funds - EU projects
- private donations

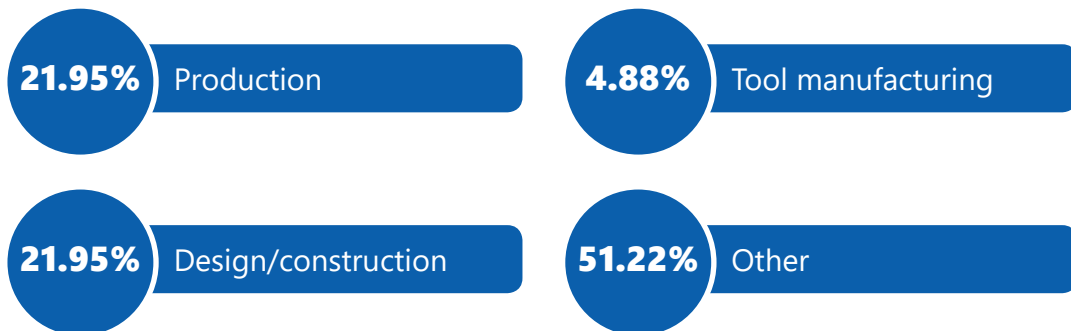
## *Knowledge about 3D technologies*

- teacher courses and seminars
- different activities and EU projects
- innovative teaching and learning methods

**4.3. Interviews with main stakeholders**

The main purpose of the interviews is to engage the relevant stakeholders in order to improve the quality of VET by gathering information on the requirements and use of 3D technologies in their work. The interviews were conducted in all the participating countries and they included small and large companies that are currently using or intend to use 3D technologies in their work in the near future. Expectations: to find out for which the purposes 3D technologies are being used and in which sectors, level of demand for 3D innovations and the companies' interest in hiring 3D experts.

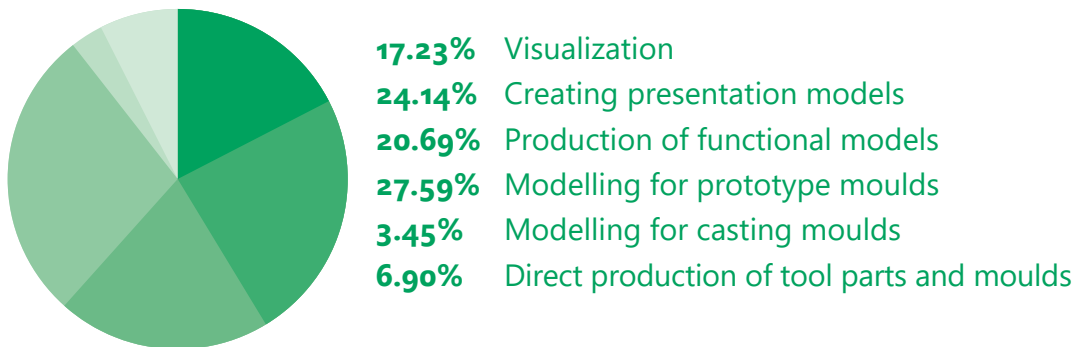
**Companies' main activities**



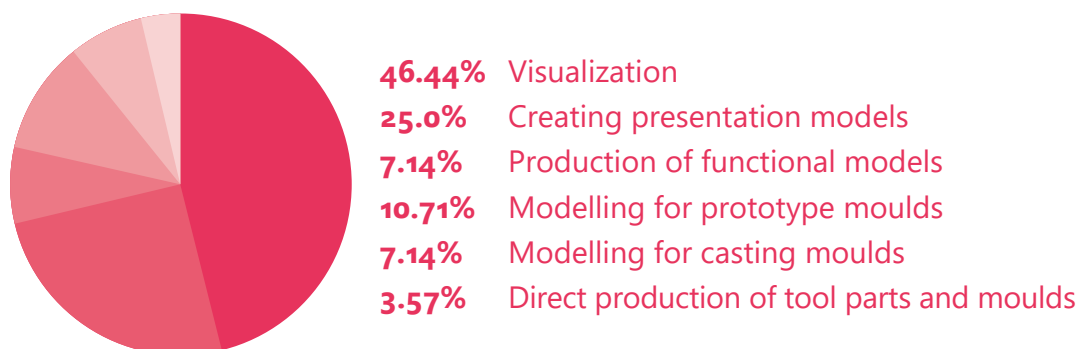
**Use of 3D printed products**



**If yes, which technologies?**



**If no, possible use of 3D models**



### *Investments in 3D technologies (next year)*



### *Lack of 3D specialists*



### *Need for employing 3D specialists*



#### **4.4.**

#### **Case study - summary**

The results gathered within the case studies showed that 3D technology, as one of the biggest technology trends at the moment, is being increasingly adopted in various sectors, including architecture, construction, electrical engineering, automotive and health-care industry.

The survey revealed that more than 50% of the companies interviewed have implemented 3D technologies in their work so far. The use of 3D printers and scanners significantly speeds up the production process, which until recently was a very time-consuming and expensive process.

Moreover, about 40% of the companies stated that they have the intention to invest in 3D innovations and equipment in the following year and, what is even more important for the purpose of this case study, 43.59% of them are struggling with an increasing lack of 3D specialists.

Therefore, a continuing growing demand for the 3D technologies experts is expected in the labour market. This is why educational institutions need to adapt and further develop their offer, which must be tailor-made to fit the labour market needs. By participating in various project teachers are increasing their competences, which results in a higher quality teaching process. It is very important to have innovative technologies at educational institutions and possibilities to provide students with the latest knowledge.

This project aims to implement 3D technologies in schools in order to prepare future generations for the competitive market and further higher education.

# 5 Examples of practical exercises to perform on 3D printer

This section provides the description of examples of the exercises performed during the workshops conducted by different partners. The aim of the section is to make the practical examples available to teachers and other educational stakeholders of the VET schools in all partner regions involved in the project, in order to facilitate their preparation and contribute to the improvement and promotion of VET education in general.

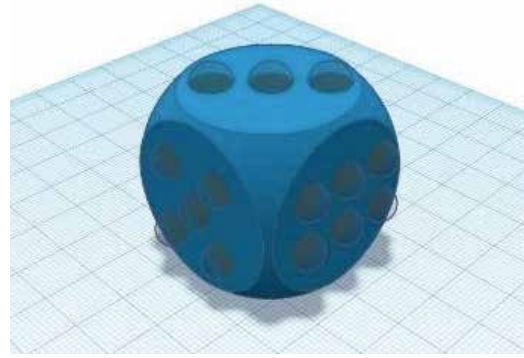
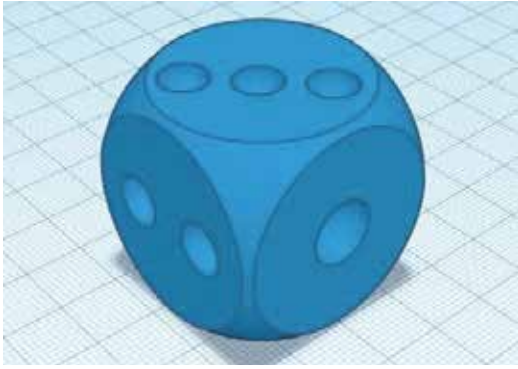
- The following exercises were carried out during the educational courses:

## 5.1. EXERCISE "DICE"

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<b>Subjects/field:</b>	science, math
<b>Class size:</b>	12 to 14 students/2 to 3 students per group
<b>Duration:</b>	one day
<b>Required tools:</b>	In addition to a computer and a fused deposition 3D printer with the associated software, the following materials are required for the workshop: <ul style="list-style-type: none"><li>• FreeCAD (free and open-source CAD modeller or a similar programme)</li><li>• scale</li><li>• open space to launch</li><li>• 3D printer</li></ul>
<b>Goals/learning objectives:</b>	The students learn about the basics of 3D printing, how the printing process works and the differences between the printing processes. They learn to operate the printer and the associated software independently in order to print out the dice models.

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## Lesson plan and activities

### 1. Teacher preparation

Every student has to have a computer and the software.

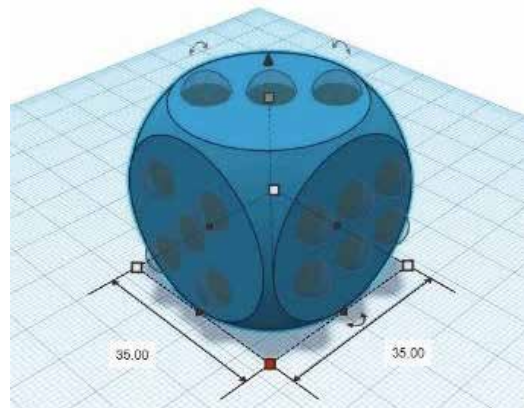
**TIP:** Print the entire dice from the same material and filler. In terms of print time, print 2-3 units at one time.

### Print settings

Raft	No
Support	Yes
Resolution	0.4 mm
Fill	35%

### 2. 3d printing basics

The teacher explained to the students how a 3D printer works, which types of printers they have and how to operate them. Some keywords the teacher should mention/explain: printing process, in-fill/infill pattern, shell/layer, support, raft, layer height, file format, design rules, errors.



### 3. Modify the original printing settings and test the new parts

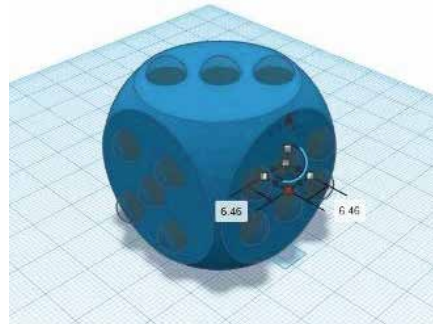
The modified parts were printed out and tested by the students. To modify printing settings means, for example, to reduce the layer height from 0.4 mm to 0.2 mm to get a smoother surface finish. Note that the printing time will increase. The infill is another parameter that the students can modify. They can change it from the recommended 30% to 10% or 50%. Use a scale to measure the weight difference of the new parts.

**TIP:** Modify printing settings one at a time to see the effect. Keep in mind that a lower infill and fewer shells will reduce the weight but also reduce the stability.

#### 4. Advanced part

In the next part of the workshop the students design and build their dice. They have two possible options.

The first one is to modify the existing design. The second option is to create a completely new design. The groups can decide which option they want to choose and begin planning their design.



If the students prefer option one, they have to do a surface reconstruction. The .stl File has to be converted into a solid body. The .stl File is not editable with a normal CAD programme. After the .stl File from the dice is converted into a solid body, the model can be exported and edited with the CAD software or it can be modified directly in FreeCAD.

**TIP:** In the CAD software, you can assemble a model dice, see where its centre of mass is and how it changes.

#### 5. Evaluate and review the designed and built dice

The students print their self-made designs and test them.

#### 6. Reflection

What's the most important thing you've learned today? Why?

Would you use 3D printing in future projects?

What do you want to learn more about and why?

Reflect on your thinking, learning and work today. What were you most proud of?

#### 7. References

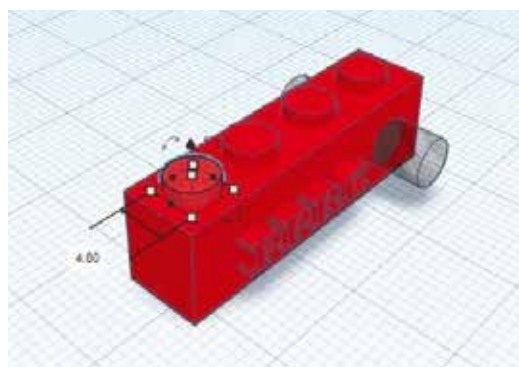
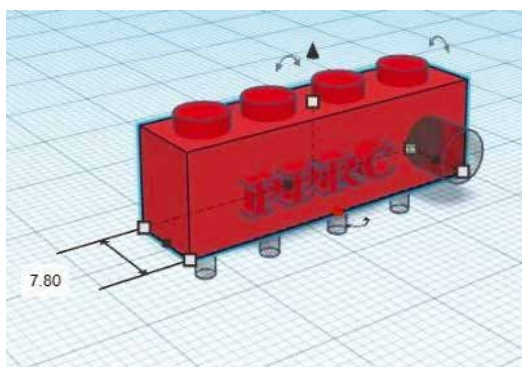
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- [www.bc3dtechnologies.com/en/3d-printer/bc3d-sigma/](http://www.bc3dtechnologies.com/en/3d-printer/bc3d-sigma/)
- [www.bc3dtechnologies.com/en/sigma-getting-started/#break-intro](http://www.bc3dtechnologies.com/en/sigma-getting-started/#break-intro)

## 5.2. EXERCISE “LEGO PENDANT”

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<b>Subjects/field:</b>	science, math
<b>Class size:</b>	12 to 14 students/2 to 3 students per group
<b>Duration:</b>	one day
<b>Required tools:</b>	In addition to a computer and a fused deposition 3D printer with the associated software, the following materials are required for the workshop: <ul style="list-style-type: none"><li>● FreeCAD (free and open-source CAD modeller or a similar programme)</li><li>● scale</li><li>● open space to launch</li><li>● 3D printer</li></ul>
<b>Goals/learning objectives:</b>	The students learn about the basics of 3D printing, how the printing process works and the differences between the printing processes. They learn to operate the printer and the associated software independently in order to print out the Lego pendant models.

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### Lesson plan and activities

#### 1. Teacher preparation

Every student has to have a computer and the software.

**TIP:** Print out the entire Lego pendant from the same material and filler. Print all the Lego pendants made together.

#### Print settings

Raft	Yes
Support	Yes
Resolution	0.4 mm
Fill	100%



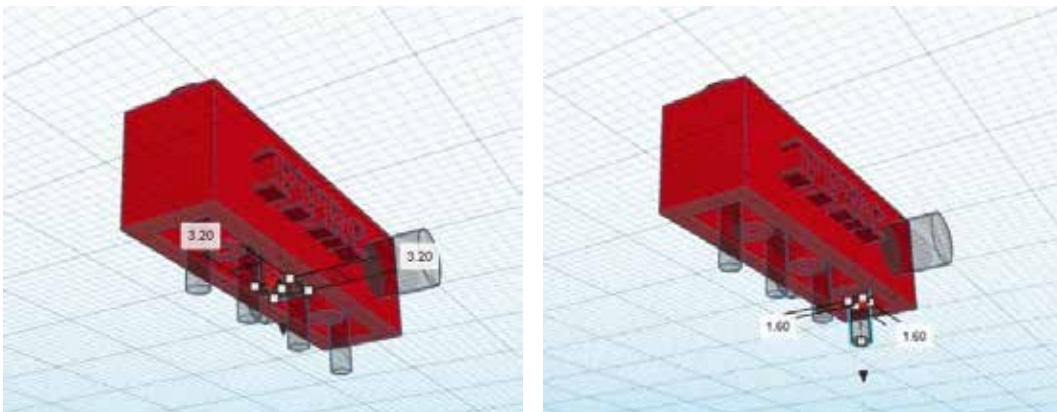
## 2. 3D printing basics

The teacher explained to the students how a 3D printer works, which types of printers they have and how to operate them. Some keywords the teacher should mention/explain: printing process, infill/infill pattern, shell/layer, support, raft, layer height, file format, design rules, slicer, errors.

## 3. Modify the original printing settings and test new parts

The modified parts were printed out and tested by the students. To modify printing settings means, for example, to reduce the layer height from 0.4 mm to 0.2 mm to get a smoother surface finish. Note that the printing time will increase. The infill is another parameter that the students can modify. They can change it from the recommended 30% to 10% or 50%. Use a scale to measure the weight difference of the new parts.

**TIP:** Modify printing settings one at a time to see the effect. Keep in mind that a lower infill and fewer shells will reduce the weight but will also reduce the stability.



## 4. Advanced part

This part of the workshop is to design and build a Lego pendant. The students have two possible options. The first one is to modify the existing design. The second option is to create a completely new design. The groups can decide which options they want to choose and begin planning their design.

If the students prefer option one, they have to do a surface reconstruction. It is necessary to convert the .stl File into a solid body. The .stl File is not editable with a normal CAD programme. After the .stl File from the Lego pendant is converted into a solid body, the model can be exported and edited with another CAD software or it can be modified directly in FreeCAD.

**TIP:** In the CAD software, you can assemble a model Lego pendant, see where its centre of mass is and how it changes.



### 5. Evaluate and review the designed and built lego pendant

The students print their self-made designs and test them.

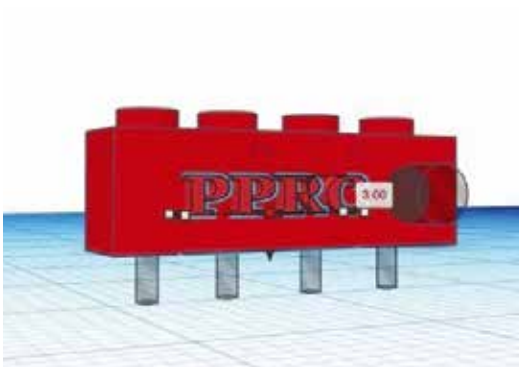
### 6. Reflection

What's the most important thing you've learned today? Why?

Would you use 3D printing in future projects?

What do you want to learn more about and why?

Reflect on your thinking, learning, and work today. What were you most proud of?



### 7. References

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- [www.bcn3dtechnologies.com/en/3d-printer/bcn3d-sigma/](http://www.bcn3dtechnologies.com/en/3d-printer/bcn3d-sigma/)
- [www.bcn3dtechnologies.com/en/sigma-getting-started/#break-intro](http://www.bcn3dtechnologies.com/en/sigma-getting-started/#break-intro)

### 5.3. EXERCISE “DESK ORGANIZER”

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<b>Subjects/field:</b>	engineering, learning, ergonomics
<b>Class size:</b>	12 to 15 students/ 2 to 3 students per group
<b>Duration:</b>	one day
<b>Students’ abilities:</b>	sketching skills, some spatial sense, commitment, ability to cooperate in a group
<b>Required tools:</b>	a computer with a connected 3D printer and installed software and the following materials: <ul style="list-style-type: none"><li>● Autodesk Inventor Professional (free CAD version or similar)</li><li>● tape or glue</li><li>● felt fabric</li><li>● ruler, zipper</li><li>● sketchbook</li><li>● scissors, knife</li></ul>
<b>Goals/learning objectives:</b>	In the workshops the students will learn the basics of ergonomics and organizing workspace. 3D printing technology can help us organize our workspace. We can create various models of containers, shelves, trays, binders for various materials, utensils and tools. After selecting a place to organize (e.g. a desk, student’s table), the students design their own organizers. In groups they choose their shape, size and capacity. They initially make sketches on paper, and then transfer them to a digital platform supporting the computer-aided design.

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#### *Lesson plan and activities*

##### 1. Teacher preparation

Each group of students has containers of different shapes and sizes at their disposal to inspire them and help them configure their models.



**TIP:** Prepare a set of typical containers and organizers of various shapes and sizes.

## 2. Basic ergonomic rules

The teacher introduces the basic principles of ergonomics to the students. Workplace ergonomics means to provide the conditions which are adapted to the psychophysical capabilities of the employee.

1. Tools and position adjustment - keeping our body in a natural position while working prevents degenerative diseases, cramps and other ailments. Our workplace should include:

- a comfortable chair,
- a spacious desk that provides proper support for the wrists,
- footrest that protects the knees,
- adequate lighting to reduce eye strain,
- correct arrangement of tools and utensils.

2. Analysing and adapting working conditions (creating workspace adapted to the employee's psychophysical capabilities, carrying out professional tasks with the least effort, minimising fatigue, reducing stress, taking regular breaks).



## 3. Performing methods

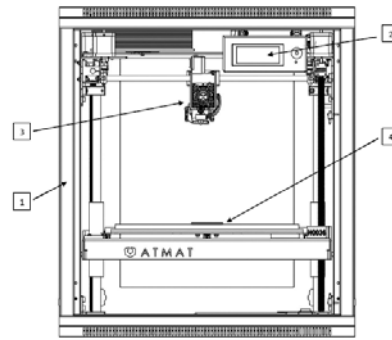
The teacher demonstrates how to make a desk organizer to store things such as: pencils, pens, ball pens. Another type of organizer is the one for keeping drawing instruments, such as a ruler drawing triangles, etc.

## 4. Group work

After the teacher's demonstration, the students try to build their organizer versions from the available materials. The task is to organize accessories, materials and tools depending on the professional activity. The organizer has to contain 2 to 4 assortments.

## 5. Evaluation and review

Each group of students presents their organizer (toolbox) and its purpose, arrangement of containers, arrangement on the table, optimal setting. The students also give their opinions and decide whether to add some finishing touches to their organizers in terms of geometry, attachment and shape. How can you make your organizer more attractive?



- 1 - printer frame
- 2 - control panel
- 3 - printer head
- 4 - print bed

## 6. Printing on a 3D printer - Basic information

The students are familiarised with the 3D printer. They learn about the structure of the printer they will work on. Its elements, placement, commissioning, controlling, operation.

The teacher explains the issues of using the printer, in particular: rules of safe 3D printer operation, assembly of the printer, transport, installation, use and maintenance.

After that, the students are introduced to the parameters and possibilities of the printer by configuring it via the control panel as well as the 3D printing programme (e.g. 1999 Ultimaker Cura).

These settings are important for the quality of 3D prints, which in case of desk organizers should look elegant.

The basic parameters of the printer are:

- dimensions
- weight
- printing technology
- type of extruder
- materials
- number of nozzles
- nozzle diameter
- filament diameter
- max. head temperature
- max. print speed
- work field
- supported file formats

## 7. Advanced designing part

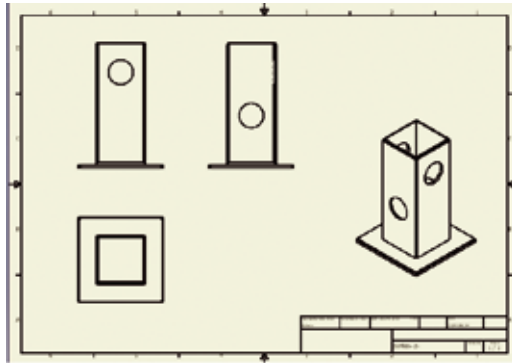
In this part of the workshop the students work in groups on advanced assignments. The task is to design a desk organizer in several versions (e.g. 3 versions) in the form of sketches representing different designs of the organizer. After making the sketches, the group chooses the best design to implement. They should consider accepting the teacher's help in order to achieve the best results in terms of quality. The quality of the model depends on the accuracy, which is also related to layer thickness and printing time. Upon seeing the surfaces of different quality, you can make a compromise between the time of printing and the quality of the model.

The students in groups begin computer-aided 3D design in a CAD programme (e.g. Autodesk Inventor, FreeCAD, OpenSCAD and others).

The students save the completed design in the required file formats, one of which is the ".stl" format recognized by the printer software.

Some printers require the file to be converted into ".gcode" format, which is implemented by "Ultimaker Cura". When designing, the students can use ready-made designs available on the website for hints or inspiration.

The prepared file is sent to the printer and they start printing.



### 8. Evaluation and review

The students present and evaluate completed works. It is possible to organize a contest for the most successful project. The students share their opinions and indicate the most useful and efficient solutions.

### 9. Reflection

What important things did you learn during the workshop?

Will you use 3D printing in other projects?

What were your thoughts and why?

Consider whether 3D technology today affects your work, study, entertainment.

### 10. Useful websites

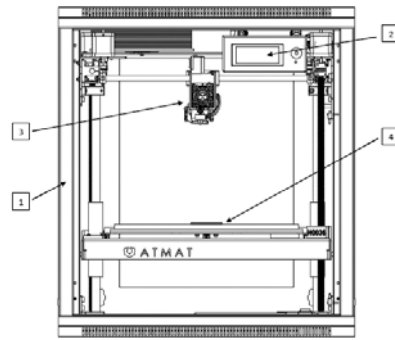
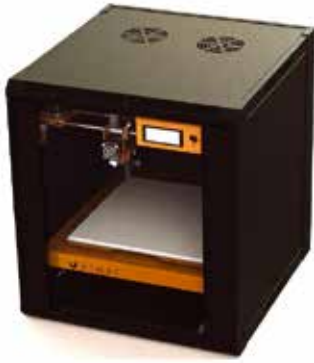
- [www.thingiverse.com/education](http://www.thingiverse.com/education)
- [www.atmat.pl/](http://www.atmat.pl/)
- [www.makerbot.com/education/3d-printing-guidebook/](http://www.makerbot.com/education/3d-printing-guidebook/)
- [www.autodesk.com/education/free-software/inventor-professional](http://www.autodesk.com/education/free-software/inventor-professional)



#### 5.4. EXERCISE “WRENCH MODEL”

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<b>Subjects/field:</b>	engineering, learning, mechanics
<b>Class size:</b>	12 to 15 students 2 to 3 students per group
<b>Duration:</b>	one day
<b>Students’ abilities:</b>	sketching skills, some spatial sense, commitment, ability to cooperate in a group
<b>Required tools:</b>	A computer with a connected 3D printer with installed software for workshop implementation and the following materials: <ul style="list-style-type: none"><li>● Autodesk Inventor Professional (free educational version of CAD or similar)</li><li>● tape or glue</li><li>● felt fabric</li><li>● ruler, caliper</li><li>● sketchbook</li><li>● scissors, knife</li></ul>
<b>Goals/learning objectives:</b>	Exercises “Workshop Tools” are designed to familiarize the students with the possibilities of designing workshop spanners, taking into account their shape, appearance, proportion as well as the need to take care of details when designing solid objects. An important aspect of designing is to minimize the consumption of printing material (filament). The main goal of the exercise is to encourage young people to use 3D technology in designing even the simplest objects.



- 1 - printer frame
- 2 - control panel
- 3 - printer head
- 4 - print bed

## Lesson plan and activities

### 1. Teacher preparation

Each group of students has to design wrenches that will resemble the real ones in shape and proportion, starting with the simplest version to more complex ones.

### 2. Tools basic information

Spanner - non-adjustable tool used for tightening and loosening nuts and bolts, usually with a hexagonal head. There are two most common classifications of wrenches: metric or inch size wrenches. In the metric system, the size of the wrench corresponds to the distance between the jaws in millimetres, in the inch system this distance is given in inches.

### 3. Performing methods

The teacher demonstrates an example of a wrench. He/she shows the students what it looks like in reality and how to construct the given object (a combination wrench) from the available solids.



### 4. Group work

After the teacher's demonstration, the students try to build their wrench versions based on their own ideas.



## 5. Evaluation and review

Each group of students presents their model of the tool, presenting their own concept, its shape, amount of details, the way of setting the 3D printer on the table, optimal setting. The students also decide whether to add some finishing touches to the designed models. The aim is to change the shape of the wrench and increase the amount of details.

## 6. Printing on a 3D printer- basic information

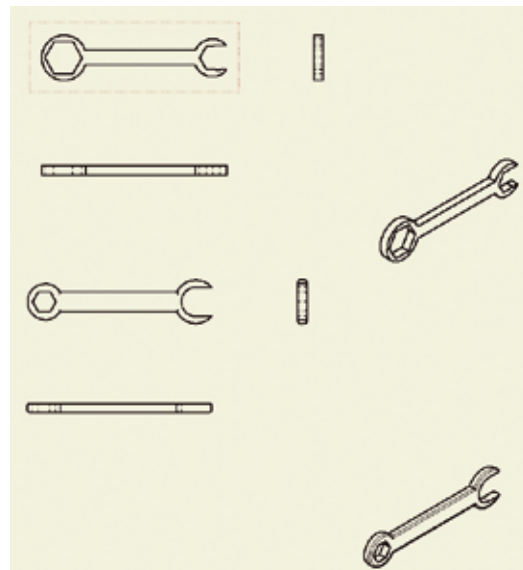
The students are familiarized with the 3D printer. They learn about the structure of the printer they will work on. Its elements, placement, commissioning, controlling, operation.

The teacher explains how to use the printer, in particular: rules of safe 3D printer operation, assembly of the printer, transport, installation, use and maintenance.

After that, the students are introduced to the parameters and possibilities of the printer by configuring it via the control panel as well as the 3D printing programme (e.g. 1999 Ultimaker Cura).

The basic parameters of the printer are:

- dimensions
- weight
- printing technology
- type of extruder
- materials
- number of nozzles
- nozzle diameter
- filament's diameter
- max. head temperature
- max. print speed
- work field
- supported file formats



## 7. Advanced designing part

In this part of the workshop the students work in groups on advanced assignments. The task is to design a wrench model (e.g. 2 versions) in the form of sketches presenting different designs of the wrench. After making the sketches, the group chooses the best design to implement.

They should consider accepting the teacher's help regarding the printing process in order to achieve the best results possible in terms of quality. The quality of the model depends on the accuracy, which is also related to layer thickness and printing time. Upon seeing the surfaces of different quality, they can make a compromise between the time of printing and the quality of the model.

The students in groups begin computer-aided 3D design in CAD programmes (e.g. Autodesk Inventor, FreeCAD, OpenSCAD, other).

The students save the completed project in the required file formats, one of which is the ".stl" format recognised by the printer software. Some printers require the file to be converted into ".gcode" format, which is implemented by "Ultimaker Cura".

When designing, the students can use ready-made designs available on the website for hints or inspiration.

The prepared file is sent to the printer and they start printing.



## 8. Evaluation and review

The students present and evaluate completed works. It is possible to organize a contest for the most successful project. The students share their opinions and indicate the most useful and efficient solutions.

## 9. Reflection

What important things did you learn during this workshop?

Will you use 3D printing in other projects?

What were your thoughts and why?

Consider whether 3D technology today affects your work, study, entertainment.

## 10. Useful websites

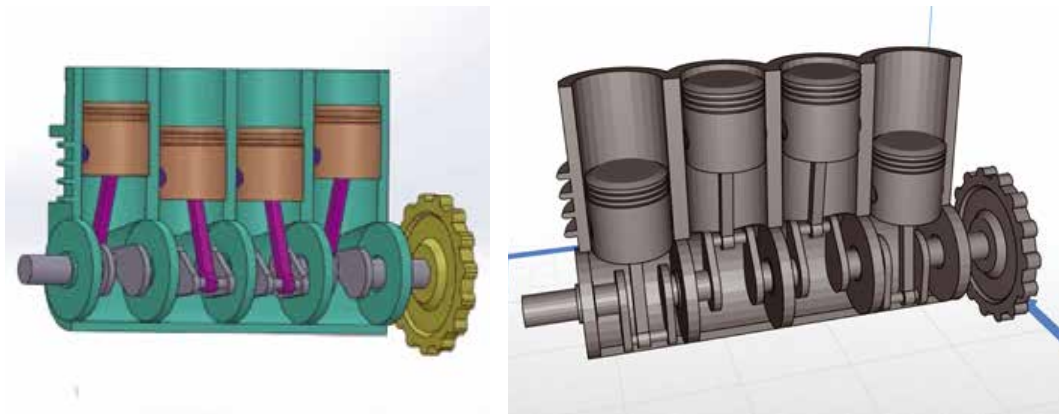
- [www.thingiverse.com/education](http://www.thingiverse.com/education)
- [www.atmat.pl/](http://www.atmat.pl/)
- [www.autodesk.com/education/free-software/inventor-professional](http://www.autodesk.com/education/free-software/inventor-professional)
- [www.tinkercad.com/](http://www.tinkercad.com/)
- [www.ultimaker.com/en/products/ultimaker-cura-software](http://www.ultimaker.com/en/products/ultimaker-cura-software)
- [www.google.com/search?q=kluze+3d&ie=utf-8&oe=utf-8&client=firefox-b](http://www.google.com/search?q=kluze+3d&ie=utf-8&oe=utf-8&client=firefox-b)

## 5.5. EXERCISE "FOUR-CYLINDER ENGINE"

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<b>Subjects/field:</b>	engineering
<b>Class size:</b>	10 to 16 students/3 to 4 students per group
<b>Duration:</b>	1 day intro into 3D printing, 2 days of workshop
<b>Required tools:</b>	In addition to a computer and a fused deposition 3D printer with the associated software, the following materials are required for the workshop: <ul style="list-style-type: none"><li>● FreecAD (free and open-source CAD modeller or a similar programme)</li><li>● available models</li></ul>
<b>References and models:</b>	<a href="http://www.thingiverse.com/thing:2881472">www.thingiverse.com/thing:2881472</a>
<b>Goals/learning objectives:</b>	The engine can be made on a 3D printer. The students are introduced to the basics of 3D printing, how the printing process works and the difference between the printing processes. They learn how to work independently with the printer and the engine model printing software.

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### *Lesson plan and activities*

#### 1. Teacher preparation

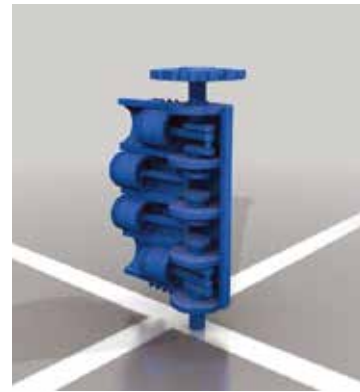
Each group of students should have a basic 3D model of the basic elements of a 4-cylinder engine before they begin the process of selecting the necessary parameters for 3D printing.

**TIP:** Print individual movable elements of the mechanism in one colour (e.g. black) and the other parts in different colours and, if necessary, without the supporting material, lying flat on the work platform.

### Printing settings:

Raft	Yes
Support	Yes
Nozzle diameter	0.4 mm
Layer	0.19 mm
Infill	10%

### Model examples:

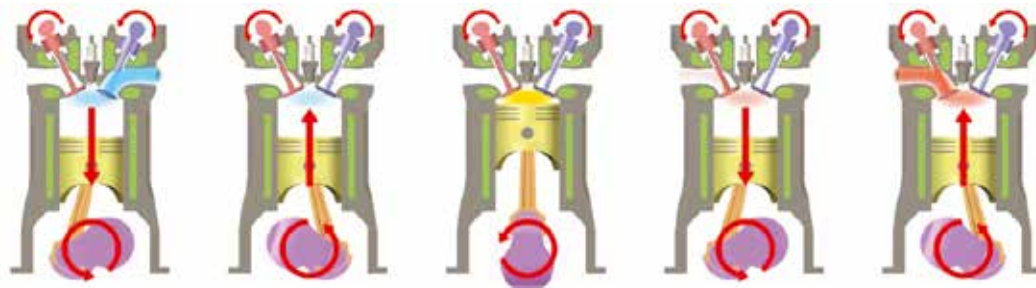


## 2. 3D printing basics (introductory lesson unit)

The teacher explains to the students how a 3D printer works, which type of printers they have, and how to operate them. Some keywords the teacher should mention/explain: printing process, infill/infill pattern, shell/layer, support, raft, layer height, file format, design rules, slicer, errors

## 3. Basic structure of internal combustion engines

The teacher explains to the students the basic structure and functioning of individual parts of a four-stroke internal combustion engine.



## 4. Demonstration and description

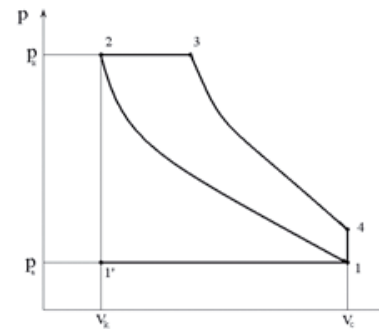
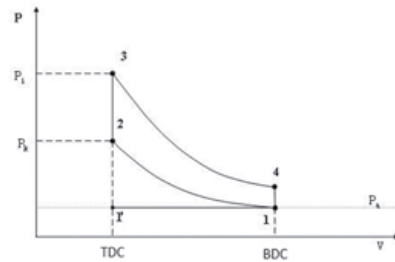
See below a description of the theoretical operation of a four-stroke engine:

- Otto process

The Otto process starts by injecting a mixture of fuel and air into the cylinder and then compression begins. The mixture increases pressure and temperature and its volume decreases. Then the spark plug creates a spark and ignites the mixture. The mixture is currently combusted by increasing the pressure and temperature in the cylinder at constant volume. After the combustion of the mixture is completed, the expansion phase is followed by the exhaust phase, where the pressure and temperature in the cylinder drop to their values from the beginning of the process. With the completion of the above steps a new cycle begins.

- Diesel process

The diesel process is the combustion process of an internal combustion piston engine. In it, the fuel is ignited by compressed air in the combustion cylinder into which the fuel is injected. The process begins with the compression of the air in the cylinder. This is followed by the initial isobaric heating which is continued by the expansion of the mixture. Theoretically, the pressure is constant in the first part of the combustion phase. In practice, there is an increase in pressure at this stage but it is less pronounced than in the Otto process. The last stage of the process is the exhaust, when the exhaust gases are vented out of the cylinder.



### 5. Assembly design test

The students must assemble the basic unit of a four-cylinder engine into a functional unit.

### 6. Evaluate and review

Each group presents an elaborate example of the engine. Discuss other engineering items that could be crafted this way. What factors affect how an engine is modelled? How can we improve, change or create our own engine model design?

### 7. Modify the original printing settings and test new parts

In groups, they discuss which printing settings they want to change and what impact this will have on the printed object. The modified parts were printed out and tested by the students. To modify the printing settings you can, for example, increase layer height from 0.19 mm to 0.29 mm to get a rougher surface. Note that this will decrease the printing time. The infill is another parameter that the students can modify. They can change it from the recommended 10% to 20% or 30%. Use a scale to measure the weight difference of the new parts.

**TIP:** Modify printing settings one by one to see the effect. Keep in mind that a lower infill and fewer shells will reduce the weight but also reduce the stability.

## 8. Evaluate and review the modified parts and the whole engine

Each group calculates and evaluates the main printing parameters such as: layer thickness, printing time, infill, layer height and other printing process features. Discuss which of them have a major impact on achieving the stability of the object. Have the expected results been achieved?

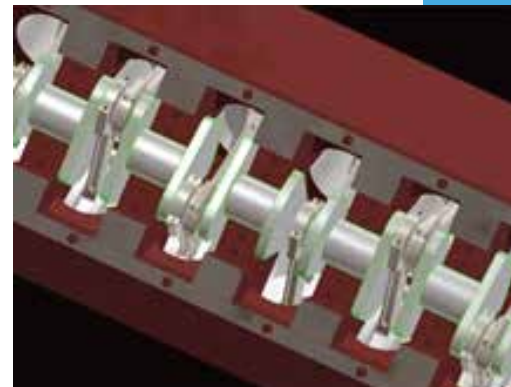
## 9. Advanced part - Design and build new modified parts of engine or the whole unit

In this part of the workshop the students design and build their own designs of the engine and different engine unit parts. To do that, the students model their own designs



by using the knowledge they acquired during the workshop, the discussions and test of the engine parts and shapes. They have two possible options. The first one is to modify the existing design. The second option is to create a completely new design. The groups can decide which option they want and begin planning their design.

- Different examples:



## 10. Evaluate and review the modified design

The students print their self-made designs and test them. Do the changes/improvements help as expected?

### 10. Reflection

Which engine designs were the most efficient and what common design features do they have?

What's the most important thing you've learned today? Why?

Would you use 3D printing in future projects?

What do you want to learn more about and why?

Reflect on your thinking, learning and work today. What were you most proud of?

## 5.6. EXERCISE “WIND TURBINE”

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<b>Subjects/field:</b>	electrical engineering
<b>Class size:</b>	10 to 16 students/3 to 4 students per group
<b>Duration:</b>	1 day intro into 3D printing, 2 days of workshop
<b>Required tools:</b>	in addition to a computer and a fused deposition 3D printer with the associated software, the following materials are required for the workshop: <ul style="list-style-type: none"><li>● FreeCAD (free and open-source CAD modeller or a similar programme)</li><li>● available models</li></ul>
<b>References and models:</b>	<a href="http://www.thingiverse.com/thing:2822484">www.thingiverse.com/thing:2822484</a>
<b>Goals/learning objectives:</b>	The wind turbine can be made on a 3D printer. The students are introduced to the basics of 3D printing, how the printing process works and the difference between the printing processes. They learn how to work independently with the printer and their wind turbine model printing software.

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### Lesson plan and activities

#### 1. Teacher preparation

Each group of students should have a basic 3D model of the main elements of a wind turbine before they begin the process of selecting the necessary parameters for 3D printing.

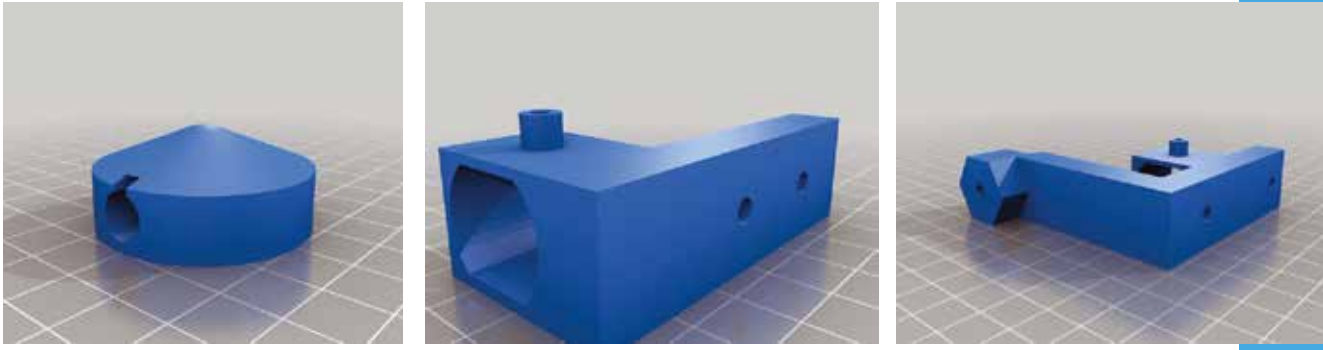
**TIP:** Print individual movable elements of the mechanism in one colour (e.g. black) and the other parts in different colours and, if necessary, without the supporting material, lying flat on the work platform.

#### Printing settings:

Raft	Yes
Support	No
Nozzle diameter	0.4 mm
Layer	0.19 mm
Infill	10%



- Model examples:



## 2. 3D printing basics (introductory lesson unit)

The teacher explains the students how a 3D printer works, which types of printer they have and how to operate them. Some keywords the teacher should mention/explain: printing process, infill/infill pattern, shell/layer, support, raft, layer height, file format, design rules, slicer, errors

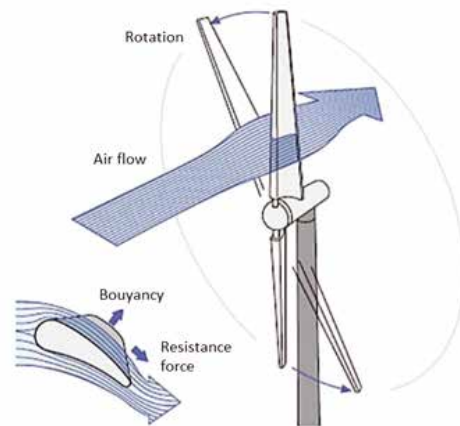
## 3. Basic structure of a wind turbine

The teacher explains to the students the basic elements and function of individual parts of a wind turbine.

## 4. Demonstration and description

A wind turbine is a rotating machine that converts wind's kinetic energy into mechanical power and then, through electric generators, to electricity. The main components of a wind turbine are:

a rotor or wind turbine (consisting of a hub, shaft and blades - usually 3 blades), braking system, slow-running shaft mounting elements, control and monitoring system, electric generator, pivot or swivel equipment, machine or gondola housing, pole, power transmitter (usually a multiplier), foundation, transformer, power system connection and special equipment.



## 5. Assembly design test

The students must assemble the basic unit of the wind turbine into a functional unit.

## 6. Evaluate and review

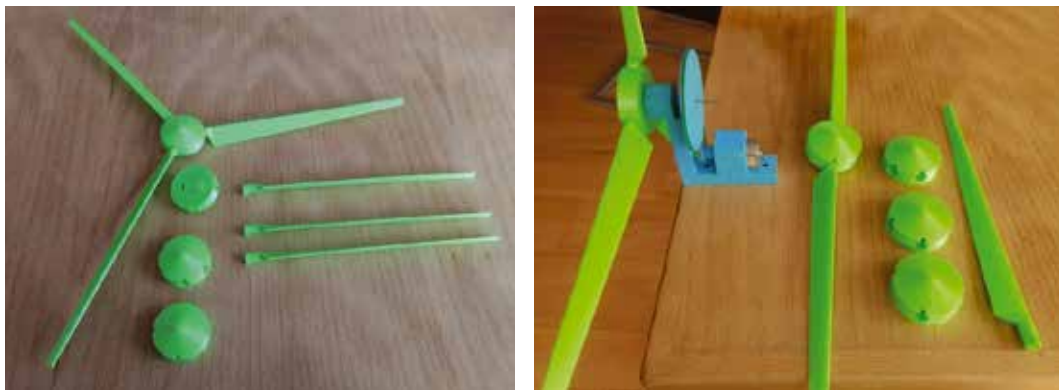
Each group presents an elaborate example of a wind turbine. Discuss other engineering items that could be crafted this way. Which factors affect how a wind turbine is modelled? How can we improve, change or create our own wind turbine model design?



## 7. Modify the original printing settings and test new parts

In groups, they discuss which printing settings they want to change and what impact this will have on the printed object. The modified parts were printed out and tested by the students. You can modify printing settings by, for example, decreasing the layer height from 0.4 mm to 0.29 mm to get a smoother surface. Note that this will decrease the printing time. The infill is another parameter that the students can modify. They can change it from the recommended 10% to 20% or 30%. Use a scale to measure the weight difference of the new parts.

**TIP:** Modify printing settings one by one to see the effect. Keep in mind that a lower infill and fewer shells will reduce the weight but also reduce the stability.



## 8. Evaluate and review the modified parts and the whole wind turbine

Each group calculates and evaluates the main printing parameters such as: layer thickness, printing time, infill, layer height and other printing process features. Discuss which of them have a major impact in achieving the stability of the object. Have the expected results been achieved?

## 9. Advanced part - Design and build new modified parts of wind turbine or the whole unit

In this part of the workshop the students design and build their own designs of the wind turbine and different wind turbine parts. To do that, the students model their own designs by using the knowledge they acquired during the workshop, the discussions and tests of the wind turbine parts and shapes. They have two possible options. The first one is to modify the existing design. The second option is to create a completely new design. The groups can decide which option they want and begin planning their design.

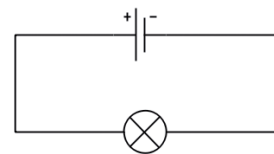
- Different examples:



Also, it is necessary to implement a circuit using a small alternator (dynamo) that generates electricity similar to a bicycle light. It will convert the mechanical energy of turning the wind turbine into electricity by moving a magnet. It works on the principle of electromagnetic induction. The rotating magnet creates a variable magnetic field that induces a current that gives light to a bulb in a fabricated circuit.

#### 10. Evaluate and review the modified design

The students print their self-made designs and test them. Do the changes/improvements help as expected?



**TIP:** Check the ability of the wind turbine blade to rotate in the existing design.

#### 11. Reflection

Which wind turbine designs were the most efficient and what common design features do they have?

What's the most important thing you've learned today? Why?

Would you use 3D printing in future projects?

What do you want to learn more about and why?

Reflect on your thinking, learning and work today. What were you most proud of?

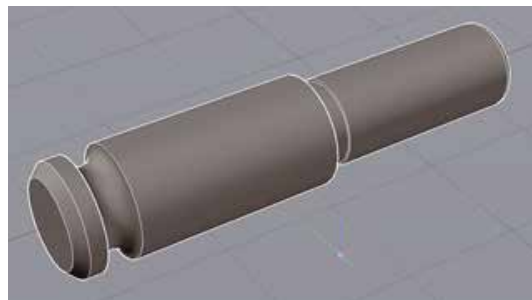
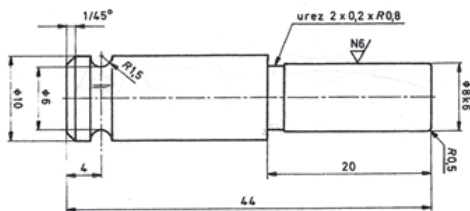


## 5.7. EXERCISE "AXLE CONSTRUCTION"

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Subjects/field:	engineering, science
Class size:	12 students
Duration:	2 days
Required tools:	AutocAD 2018, 6 computers with necessary configurations, 3D printer, printer material (printing filament)
Goals/learning objectives:	The exercise aims to teach the students how to use AutocAD, to see the difference between 3D printing and CNC processing, applications of 3D printing, working with a 3D printer.

---



### Lesson plan and activities

#### 1. Teacher preparation

The required programme is installed on each computer used by a group of students. The teacher's computer also has the programme and is connected to a projector with a shared screen so that the students can follow. The plan for creating the 3D models is shown in detail in the images below.

#### 2. 3D modelling task

It is necessary to model the object according to the attached image and prepare it for 3D printing. Model created in AutocAD 2018.

#### 3. Modelling in AutocAD

The teacher and the students go through the modelling process step by step at different stages so that the students can follow and create their own model using the programme. Each group has different dimensions of the workpiece.

Create a 2D draft in TOP view.  
Use of the command LINE  
(drawing lines), CIRCLE (drawing  
circles), TRIM (snipping):

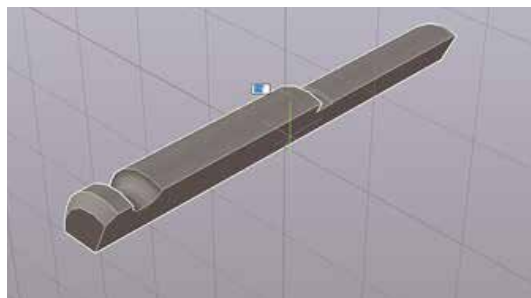
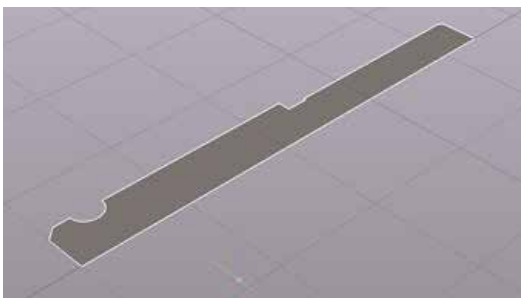


The REGION command will create  
a surface that will rotate and  
from which it will be created.

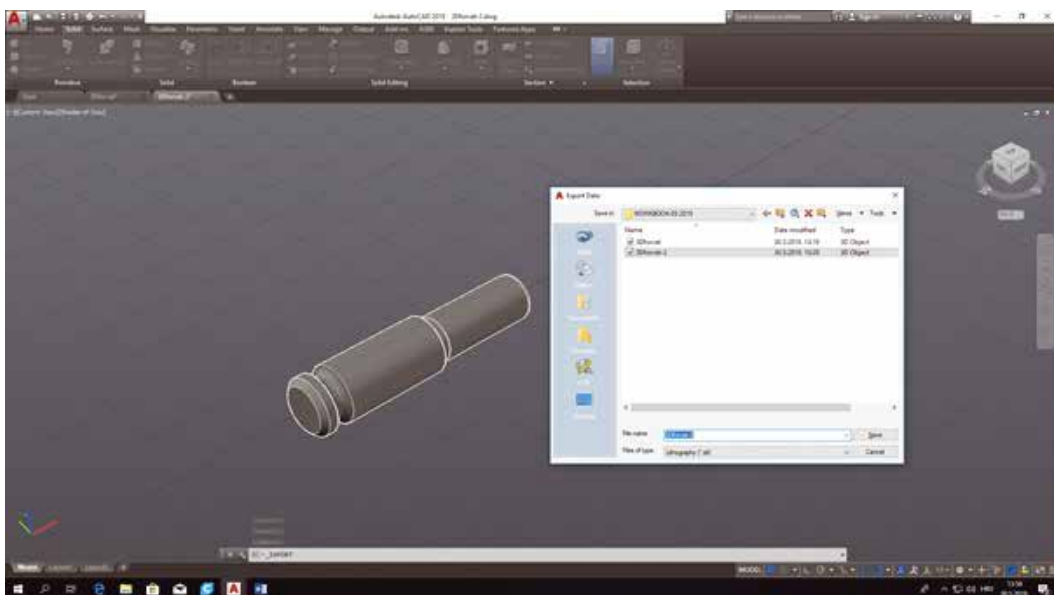


ISOMETRIC SW view:

Using the REVOLVE command the  
surface area rotates around the  
x axis by 360°:



The final appearance of the model:



With the UNION command merge individual objects into one object.  
After that, export the file to .stl format.

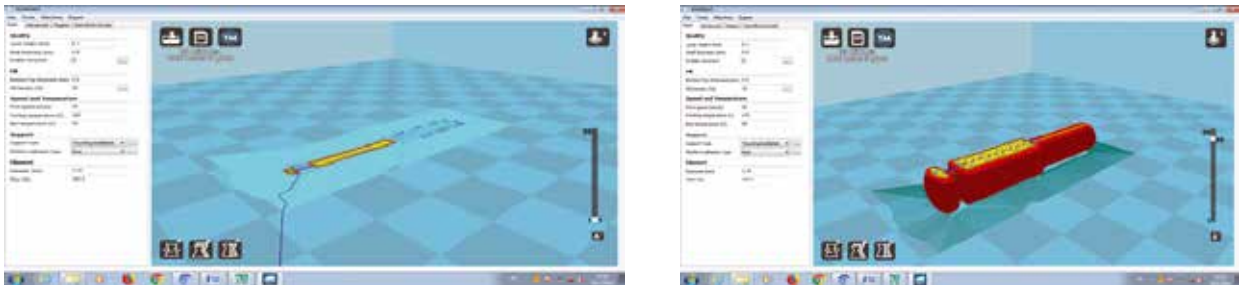
#### 4. Simulation view

The teacher shows the students how to work in the programme that is used to view the simulation and printing settings. In this case it is "Cura", but there are many other programmes that can be easily used for this purpose. In this part the teacher explains to the students the importance of the simulation phase in a 3D printing process. The simulation shows which parameters can still be modified before starting to print.

The following images show the programme interface as well as which sizes can be modified and how.

Open the CURA programme to prepare the settings for 3D printing and reading the model in .stl format:

View of the simulation of printing models by layers at different stages of printing:

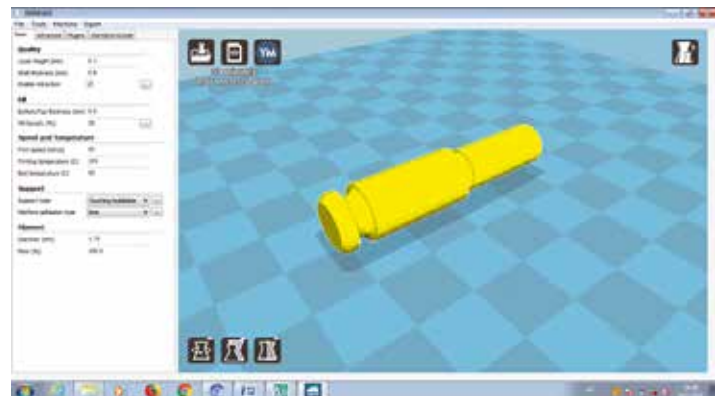


#### 5. 3D printing basics

The teacher explains to the students the properties of the printer: its operation, axis types and movements, axis drive, filament application method, filament temperature and printing bed, printing settings, printer reference and other parameters. Modelling is followed by:

Switching to G-code ("save as g-code") and adjusting the printing parameters on the printer:

- layer height: 0.1 mm
- shell thickness: 0.8 mm
- thickness of the filled layer on the top/bottom: 0.6 mm
- percentage of central part density: 30%
- print speed: 50 mm/s
- filament temperature: 195 °C
- bed temperature: 50°C
- supports: no
- and other parameters



## 6. 3D printing settings modification and testing new parts

The above printing settings can be modified. The teacher shows the students how changing a particular size affects the quality and the speed of printing. The students have the freedom to change the input parameters within acceptable limits (determined by the teacher). This will provide the students with an example of how a specific setting affects 3D printing.

For example:

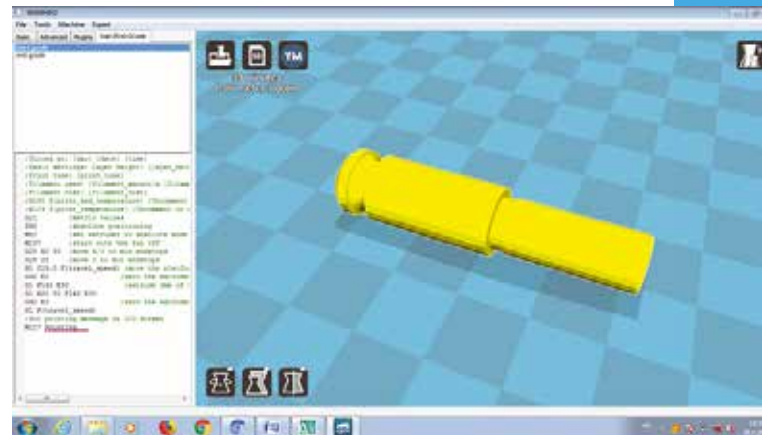
- the percentage of filling affects the strength of the workpiece, print speed, weight of the workpiece, consumption of materials
- the print speed affects the quality of the workpiece surface, print time
- the thickness of each layer affects the print quality, the interconnection of the layers
- the surface temperature affects the quality of the base layer applied to the bed.

**NOTE:** Each group should change only one of the specified parameters to see how it affects the measures. For example, one group changes only the percentage of the filling, the other group changes only the temperature of the bed, etc.

View programme commands in g-code:

## 7. 3D printing process

Individual groups of students print their own models according to the parameters previously agreed with the teacher. After completing the printing, the students estimate the extent to which the modified parameter has affected their object. After all groups finish their prints, the students exchange their objects and explain each other how modifying a single parameter has affected the print quality. This gives the students an insight into all modifications in input sizes by groups and they can discuss their experiences.



## 8. Evaluation

What's the most important thing you've learned today? Why?

Do you want to use 3D printing for future projects?

What do you want to learn more about and why?

How will the 3D technology affect your education?

# 6 Handbook

## – conclusion

This handbook is intended for VET teachers who are involved in the learning process focused on 3D technologies. Along with other activities conducted within the project, it is expected to have a considerable impact on the professional development of VET teachers and on the improvement of the quality of education. The focus of the handbook is to provide the teachers with methods and practical examples they can work with within their educational institutions. Its main purpose is closely connected to the project's main objective, which is to create the VET education system that is linked with the business world and the constantly changing demand for new skills and competences in the labour market. In order to achieve this goal, it is essential for VET providers to continually improve their education, as well as the education they offer and thus contribute to the modernization and improvement of the quality of vocational education. Thanks to the exercises and practical examples it contains, the handbook should enable the teachers to develop and introduce innovative programmes and skills based on the methods and tools derived from the analysis of the practices that are being used in the partner educational institutions, which is one of VET priorities in all the partner countries.

Achieving any of these targets would be a great accomplishment for the project partners and authors of this handbook.

## *References*

- Regional case studies (4)
- Interviews with main stakeholders (40)
- Joint staff training reports (3)
- Blended mobility reports (2)
- Workshops with students







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