Erasmus+ | AGENZIA NAZIONALE INDIRE

PRINTSTEM

Pedagogical Resources IN Teaching Science, Technology, Engineering, Mathematics

TEACHER-LED EDUCATIONAL EXPERIMENTATIONS FOR DEVELOPMENT OF MATHEMATICAL LITERACY COMPETENCES

Intellectual Output N. 4

Release of final validated Intellectual Output: February 2016

(The project is funded by ERASMUS+ Programme through INDIRE Italian National Agency. The content of this material does not reflect the official opinion of the European Union, the European Commission and National Agencies. Responsibility for the information and views expressed in this material lies entirely with the author(s). Project reference N. 2014-1-IT02-KA201-004204)

INDEX

PRINT STEM BRIEF OVERVIEW

Among the causes of early drop-out from upper secondary school by students with a low level of basic competences, there is failure in the learning of mathematical and scientific literacy competences and, more generally, of formal and coded languages. According to the "Strategic Framework for European Cooperation in Education and Training (ET2020) Council Conclusions", the objective is to lower the share of 15-year old European students with insufficient abilities in mathematics and science to less than 15 % by 2020. In 2009, in Europe, the figure for students with insufficient abilities in science-related subjects, according to the PISA standard, was 17%, the share of European students who did not reach a sufficient score in mathematics was 21%.

Mathematics in particular, but other scientific subjects as well, are often perceived by students as something abstract, unrelated to their daily experiences and perceptions. This disconnect leads to lack of interest towards such disciplines and to progressive abandonment of subjects that provide an important asset in the European labour market, which is a market that offers many employment possibilities to people with those skills. For this reason, it is fundamental to develop new teaching methods that promote interest and motivation for mathematics and scientific disciplines. 3D printers are the new frontier in experimental teaching: the possibility of realizing three-dimensional models of objects conceived by the students or of mathematical or scientific concepts or objects, opens new opportunities for motivating and arising the interest of students in these disciplines.

PRINT STEM project is developing programmes and associated devices for replicable use of 3D printers, by also transferring and adapting good practices of partner countries who have already tested their effectiveness in their respective schooling/training systems. As regards the learning difficulties observed in abstract contextualization and reflective observation, the technology will help to overcome them, making it possible to focus primarily on the active experimentation and concrete experience of shapes and object that imply a deeper knowledge of formal languages.

PRINT STEM expected results:

1) analysis-study of the potential application of 3D print technology to experimental teaching of mathematics and science, dealing with the main problems of "low achievers", in terms of lack of attention and low interest (Intellectual Output 1);

2) guidelines for the setting up of an interdisciplinary team of teachers for experimental teaching with 3D printer. This way teachers will be guided towards new teaching approaches and will be invited to plan different possible applications for 3D printer technology in the teaching of their subjects (Intellectual Output 2);

3) conduction of 5 extracurricular project work programmes (independent learning and pupil-led experimentation) and accessible as OER, in the field of design and of product engineering technology, to discover the beauty of "making" using an interdisciplinary approach (Intellectual Output 3);

4) conduction of 5 experimentations aimed at the mediation of abstract concepts in mathematics teaching (teach-led experimentation), accessible as OER (Intellectual Output 4);

5) conduction of 5 experimentations aimed at the mediation of abstract concepts in the teaching of physical and natural sciences (teach-led experimentation), accessible as OER (Intellectual Output 5).

For further information and contacts, please visit http://www.printstemproject.eu/

Partner responsible for the Intellectual Output: Sabanci Kiz Teknik ve Meslek Lisesi

LIST OF PARTNERS

PARTNERSHIP	COUNTRY
Project Coordinator: Istituto d'Istruzione Secondaria Superiore "A.Berenini"	Italy
Cisita Parma Srl	Italy
Istituto Istruzione Superiore “C. E. Gadda”	Italy
Forma Futuro Scarl	Italy
Kirkby Stephen Grammar School	UK
Danmar Computers Malgorzata Miklosz	Poland
Asociacion De Investigacion De La Industria Del Juguete, Conexas y Afines	Spain
Sabanci Kiz Teknik ve Meslek Lisesi	Turkey
1epalchanion	Greece
Evropská rozvojová agentura, s.r.o.	Checz Republic

Chapter 1. Teacher-led training programme for development of mathematic literacy competences through the use of 3d printing - Guidelines for school teachers

1.1 INTRODUCTION

The present Didactic/pedagogical Programme is a set of instructions describing the disciplinary approach and guidelines with which to perform teaching experimentations which teachers can make use, on the initiative of an individual teacher or of a small group, of 3D printing technology to support students' curricular learning (especially for students with difficulties in learning formal and coded languages associated with mathematics) towards the achievement of objectives related to key ideas and/or mathematical processes.

Through application of this methodological approach, abstract conceptualization of mathematical formulas and geometrical shapes can be used to promote learning through concrete experiences and activate a sequence of phases including observation, abstract conceptualization and, finally, active experimentation, which concludes the learn-by-doing cycle.

The proceeding suggested is in line with the recommendations of the "COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS - Rethinking Education: Investing in skills for better socio-economic outcomes" according to which the demand for science, technology, engineering and mathematics (STEM) related skills remains at a high level. The demand for a qualified workforce in technology and research intensive sectors is and will remain at a high level, with an impact on the demand for abilities in the STEM area. Greater efforts should be made to highlight STEM as a priority area of education, and increase engagement at all levels, also in order to make STEM more attractive for students.

1.2 HOW THE EDUCATIONAL PROGRAMME HAS BEEN VALIDATED

The Didactic Programme here presented has been conceived to represent a sound methodology that can significantly increase the level of attention and ability to learn mathematical rules and associated procedures. The approach used affects the way in which students approach mathematics, their motivation, their ability to enjoy learning, significantly improving the quality of learning. In fact, according to the document "Mathematics Education in Europe: common Challenges a National Policy", one of the teaching methodologies most widely used in Europe is problem-based learning, which makes it possible to acquire knowledge and abilities through the application of newly acquired concepts for the solution of a problem, with active learning and discussion stimulated by working in small groups.

Mathematical competences are related to the ability to reason "mathematically", to the ability to solve mathematical problems and to apply mathematical reasoning to real life situations. On that basis of, teachers of the project partnership who participated in experimentations, first evaluated the areas of mathematical literacy where their pupils had greater difficulties and for which the experimentation and programme modelling would have been activated.

The form of experimentation conceived, included a support intended to promote, as part of the ordinary curriculum, a style of learning based on practice, with the effect of demonstrating the relevance of mathematics for practical purposes and raising motivation, thanks also to the use of active teaching methodologies.

The pedagogical approach combined:

1) Clear definition of objectives

2) Motivation boosting activities

3) Stimulating thinking and reasoning as a personal and group challenge

4) Opportunity to diversify the learning progression through different levels of structuring of the experiences.

The partner organisations, secondary schools and technology/business oriented companies who developed the experimentations here described, acted in the following way:

- ⇒ 1st proposal of how to organise the setting and carrying out of experimentations. The schools were given some prescriptive indications in the form of a Protocol, with the minimum requirements/phases and methods for learning evaluation, then had the possibility to customize contents to own internal environment, type of schools, type of curricula, characteristics of students and specific learning needs;
- ⇒ Experimentations in-house concretely carried out by 5 Secondary Schools in Europe (2 from Italy, 1 from Greece, 2 from UK, 1 Turkey), with technological support of the technology/business oriented companies. Experimentations, which can be used as ideas and

suggestions of possible Learning Objects and objects to be printed, are listed in the present document and open files for 3D printers are uploaded for re-use on Thingiverse.com;

⇒ Evaluation and observation of all the results: critical analysis of strength and weak points of the practical organization of activities, collection of students self-evaluation of the experiences, collection of lessons learnt and recommendations from Teachers Team involved;

⇒ On the basis of all the results and observations arose, the final review, fine tuning and modelling of the Protocol has been carefully implemented

⇒ **Final result: tested, revised and validated Didactic Programme ready for re-use throughout Europe**

Note that the present Programme has been first experienced with students aged 15 but has finally been revised and validated in a way that is applicable on mathematic skills to any students' age, level of education, type of school and type of curriculum.

1.3 LICENCE CONDITIONS FOR RE-USE OF THE EDUCATIONAL PROGRAMME

The present Didactic Programme is available for re-use of the reader and of any person interested in introducing, within scholar activities with students, teacher-led experimentations on mathematic skills by support of 3D printers.

Any re-use, transfer, customization of the present Programme will run under the following binding **Creative Commons** Conditions that the PRINT STEM partners decided to apply (also in accordance to Erasmus+ Programme rules):

Attribution	All CC licenses require that others who use your work in any way must give you credit the way you request, but not in a way that suggests you endorse them or their use. If they want to use your work without giving you credit or for endorsement purposes, they must get your permission first.
ShareAlike	You let others copy, distribute, display, perform, and modify your work, as long as they distribute any modified work on the same terms. If they want to distribute modified works under other terms, they must get your permission first.
NonCommercial	You let others copy, distribute, display, perform, modify and use your work for any purpose other than commercially unless they get your permission first

The same Conditions apply to the files of objects printed throughout PRINT STEM Project that you can find in Thingiverse.com for download and re-use at the following reference usernames:

PRINTSTEMPROJECT_BERENINI
PRINTSTEMPROJECT_GADDA
PRINTSTEM_SABANCI
PRINTSTEMPROJECT_KSGS
PRINTSTEMPROJEC

1.4 VALIDATED PROTOCOL OF DIDACTIC PROGRAMME TO CARRY OUT TEACHER-LED EXPERIMENTATIONS WITH USE OF 3D PRINTERS, IN ORDER TO DEVELOP STUDENTS' MATHEMATIC LITERACY COMPETENCES

Specific aim: to introduce the use of 3D printing in the ordinary scholar/didactic curriculum, as method of learning based on practice and active teaching, with the effect of demonstrating students the relevance of mathematic disciplines for practical purposes and raising motivation

The following indications has to be taken as minimum conditions for planning and carrying out experimentations.

Note: for further and fundamental references to the present Programme, see also the following Intellectual Outputs developed in the PRINT STEM project:

⇒ Intellectual Output 1 - Prediction of the impact of 3D printing technology: possibility, frequency and intensity of use as support in the teaching of mathematical and scientific skills,
⇒ Intellectual Output 2 - Methodology and guidelines for the introduction of 3D printers as a tool in teaching experimentations in secondary schools.

PHASE 1
SET UP OF THE TEACHERS TEAM AND TRAINING REQUIREMENTS

Before starting any kind of experimentation, the preliminary step is to set up a team of teachers who will be directly involved in the work of planning and carrying out the activities with the students.

The Teachers Team should include at least:

⇒ 1 teacher from each STEM subjects

⇒ 1 teacher of technical 3D drawings and 3D software

⇒ 1 IT teacher with competences on how to use the 3D printer and related software to convert 3D drawing

One of the most important actions to be taken is to raise awareness and engagement of other teachers within the school. No good results out of experimentations will be possible to achieve unless you have colleagues who proactively cooperate with you and support the work in any phase. It is suggested therefore that you organise an overall meeting with all school teachers and managers so as to share the present document and survey the personal interest of each one to join the Teachers Team, by first explaining what are the aims of the present Didactic Programme in terms of goals towards better learning of students of STEM related contents of the scholar curriculum.

The following Tool can guide you in the choice of the most adequate members of your Teachers Team

<table>
<tr><th colspan="2">TEACHER-LED DIDACTIC EXPERIMENTATIONS FOR DEVELOPMENT OF MATHEMATICAL LITERACY COMPETENCES
Teachers-Team Members Tool</th></tr>
<tr><td>Teachers Team identified: which teachers will be involved to carry out activities</td><td><u>Teacher 1</u>
Name:
Teacher Subject:
Knowledge of 3D printer functioning: YES □ NO □
Knowledge of software for 3D printer use: YES □ NO □
Capabilities to use 3D printer and software: (specify)………
Knowledge and capabilities of software for technical drawing: YES □ NO □

<u>Teacher 2</u>
Name:
Teacher Subject:
Knowledge of 3D printer functioning: YES □ NO □
Knowledge of Softwares for 3D printer use: YES □ NO □
Capabilities to use 3D printer and softwares: (specify)………
Knowledge and capabilities of software for technical drawing: YES □ NO □

<u>Teacher 3</u>
Name:
Teacher Subject:
Knowledge of 3D printer functioning: YES □ NO □
Knowledge of Softwares for 3D printer use: YES □ NO □
Capabilities to use 3D printer and softwares: (specify)………
Knowledge and capabilities of software for technical drawing: YES □ NO □

<u>Teacher n</u>
Name:
Teacher Subject:
Knowledge of 3D printer functioning: YES □ NO □
Knowledge of Softwares for 3D printer use: YES □ NO □</td></tr>
</table>

	Capabilities to use 3D printer and softwares: (specify)……… Knowledge and capabilities of software for technical drawing: YES □ NO □
Why you did choose the above teachers	Take note of the rationale of choosing the above teachers within your Team *It will be of help for future in case:* *- any of them should have to be replaced* *- set-up of other Teachers Team in relation to other subjects of experimentation* *- set-up of other Teachers Team in relation to the same STEM subjects in different classes and students ages*
How did you involve the teachers already?	Take note of what you have done to collect Teachers Team members and overall results of the raising-engagement activities you have carried out. *It will be of help for future in case:* *- any of them should have to be replaced* *- set-up of other Teachers Team in relation to other subjects of experimentation* *- set-up of other Teachers Team in relation to the same STEM subjects in different classes and students ages*
What necessary training for the Teachers Team have you planned or you have to plan?	Take note of necessary trainings to be supplied to any or all Teachers Team in order to fully accomplish the activities of experimentations. Take note of type of learning method, duration and goals.

As clear from last question of the above *Teachers-Team Members Tool*, the second fundamental action to be carried out before starting concretely working with students with the 3D printer technology is to enable Teachers Team members to work practically with the printer and related software.

Specific training to this purpose should be supplied.

Training should cover 3 fundamental areas of the operational setting for experimentations:

1- Technical 3D drawing and related software, either commercial or free-of-charge (open source),
2- 3D printer technicalities: how it functions, how to assemble it, consumable materials to be used for printing objects (mainly plastic), technical problems and to solve them,
3- Software dedicated to convert drawings in technical instructions to the 3D printer to create the objects, either open-source ones or specific software directly connected to the type of 3D printer purchased.

To this aim, specific training should be delivered to teachers and this can take different forms:

⇒ Teachers who already have skills related to 3D printer and software deliver the training to colleagues

- ⇒ Self-learning via tutorials, video-courses, e-book (there are numerous types on the web, example http://www.architectionary.com/SketchupTutorials, https://www.youtube.com/watch?v=biCWssfil2A
  and you can also find the in the Moodle Platform of PRINT STEM partner from Spain, AIJU, to whom it is possible to ask for free access printstem@aiju.info)
- ⇒ Free-of-charge training requested to the company providing the 3D printer
- ⇒ Courses delivered by training companies/organizations

The level and duration of training will be based on teacher's initial competences, level of skills to be achieved in order to conduct the experimentations, possibility to refer to external technicians who could cover the teachers' technical gap. In case of the latter, be aware that any technical problem with the 3D printer may occur at any time during the work with the students and external technicians will for sure do not guarantee every time the promptness of intervention you may need. For this reason, each **Teachers Team should develop its own technical skill-set to lead experimentations at the highest possible independent level, by means of both basic and advanced training**

The training, besides being essential for the operational success of experimentation, is a concrete way to raise, step-by-step, commitment from all members of your Teachers Team. Training

PHASE 2
OPERATIONAL DEFINITION OF THE LEARNING OBJECTIVES IN RELATION TO MATHEMATICAL SKILLS

A Learning Objective is an explicit statement that clearly expresses what the student will be able to do after experimenting the 3D printer associated to mathematic literacy contents. It is an observable and measurable student outcome statement. Learning Objective identify what behavior(s) a student must demonstrate in order for the teacher to know that the planned learning took place. Learning Objectives also benefit students by helping them clarify their personal goals on the activity and give them a framework against which to measure their own success. Learning Objectives should be concise and concrete so they are open to limited interpretation.

Well settled Learning Objectives:

- ⇒ Make both teachers and students involved know what it is expected to achieve and increase their chances to end up with the foreseen results,

⇒ Guide teachers on the planning of instructions, delivery of instructions and evaluation of student achievement,
⇒ Guide students, help them and set priorities,
⇒ Allow for analysis in terms of the levels of teaching and learning.

How to proceed in identifying Learning Objectives in relation to mathematical skills:

Evaluate the areas of mathematic literacy with highest priority in terms of greater difficulties for students and for which the experimentations can be activated within the curricular activities. The focus of the experimentation has to be to understand how concepts apply to processes and situations.

Mathematical competences are related to the ability to reason "mathematically", to the ability to solve mathematical problems and apply mathematical reasoning to real life situations. Bear in mind that according to the PISA standard, mathematical literacy is assessed in relation to:

⇒ Mathematical content, defined with reference to 4 key ideas (quantity, space and shape, change and relations, uncertainty),

⇒ Mathematical processes, defined through general mathematical competences,

⇒ Situations where mathematics is used.

Requirements about Learning Objectives:

⇒ The mathematical skills to be taken into consideration has to be related to:
  - Content areas - use of numbers and calculations, representation of shapes in space, representation of mathematical relations in different ways, production and analysis of data, relationships within & among geometrical objects in 2 and 3 dimensions, theorems,
  - Processes - formulation and solution of problems and connecting problems that belong to different curricular themes, measurement,
  - Application of mathematics in daily life.

⇒ Learning Objectives should refer to the scholar curriculum of students according to the class attended, since the aim of experimentation is to improve students' skills in the STEM subjects/contents directly related to their curriculum,

⇒ Write the objectives dividing them into **General** and **Specific Learning Objectives,**

⇒ *Specific examples of Learning Objective to apply can be found on Chapter 2.*

Examples of verbs to duly describe the Learning Objectives, whether General and Specific:

Knowledge Verbs (1st level)

- Define
- Memorize
- List
- Recall
- Repeat
- Relate
- Name
- Repeat

Comprehension Verbs (2nd level)

- Restate
- Discuss
- Describe
- Identify
- Locate
- Report
- Explain
- Express
- Recognize
- Review

Application Verbs (3rd level)

- Translate
- Interpret
- Apply
- Practice
- Illustrate
- Operate
- Demonstrate
- Dramatize
- Sketch
- Employ
- Schedule
- Use

PHASE 3
SELECTION OF THE DIDACTIC SETTING AND TECHNOLOGIES REQUIRED

For in-depth technical information and hints on printers, materials, etc. see also PRINT STEM Intellectual Output n.2 "Methodology and guidelines for the introduction of 3D printers as a tool in teaching experimentations in secondary schools".

What is 3D printing and how it works – The Basics

3D Printing is an additive manufacturing process that creates a physical object from a digital design. There are different 3D printing technologies and materials you can print with, but all are based on the same principle: a digital model is turned into a solid three-dimensional physical object by adding material layer by layer.

Every 3D print starts as a digital 3D design file – like a blueprint – for a physical object. Trying to print without a design file is like trying to print a document on a sheet of paper without a text file. This design file is sliced into thin layers which is then sent to the 3D printer. From here on, the printing process varies by **technology**, the ones that best fit for the school domain are **desktop printers that melt a plastic material and lay it down onto a print platform**. The printing can take hours to complete depending on the size, and the printed objects. All 3D printing technologies create physical objects from digital designs layer by layer. Available **materials** also vary by printer type, ranging from plastics to rubber, sandstone, metals and alloys - with more and more materials appearing on the market every year. The best materials for didactic purpose is **plastic**, because of its lower cost.

Best technologies for the school domain

Fused Filament Fabrication FFF is the most common technology for **desktop 3D printing** and the one that PRINT STEM partnership identified as the best for didactic purposes in schools with students. The FFF printing process starts with a string of solid material called the filament. This line of filament is guided from a reel attached to the 3D printer to a heated nozzle inside of the 3D printer that melts the material. Once in a melted state, the material can be extruded on a specific and predetermined path created by the software on the computer. As the material is extruded as a layer of the object on this path, it instantly cools down and solidifies – providing the foundation for the next layer of material until the entire object is manufactured.

As the **cheapest 3D printing technology on the market**, FFF also offers a wide variety of **plastic-based materials in a rainbow of colours** including **ABS, PLA** that are those used by the partnership in their experimentations within the project.

FFF is therefore the best choice for quick and low-cost prototyping and can be used for a wide variety of applications. More recent innovations in FDM 3D printing include also the ability to manufacture functional end products with embedded electronics and mechanical parts such as drones. For this reason, it applies also to most advanced technical schools and Teachers Team who would improve the level of experimentations, starting from the baseline carried out within PRONT STEM project. Bear in mind, when you are choosing the printer to be purchased for your school, that due to some design and material limitations, FFF 3D printing is not recommended for more intricate designs, apart from the above mentioned.

Minimum conditions of logistic accessibility to equipment

Following are specifications of the technologies and IT software required to carry out an experimentation.

EQUIPMENT:

Most used **3D PRINTERS** are summarised here below. They are all adequate for the intended use of the present Didactic Programme. Nevertheless, each school has own specific needs on the basis of core curricula, this means that the **Teachers Team must be clear in explaining their needs** to the person within the school in charge to buy the printer, so as to address to the best provider who can **explain in details technical pros and cons of each available printer, on the basis of the specific requirement for didactic application**.

Manufacturer	Printer	Build Volume	Price (approximately)	Overall performance
Makergear	Makergear M2	203x254x203	Euro1300	Outstanding
Flashforge	Creator Pro	145x225x150	Euro 1200	Excellent
Builder	Builder Dual Feed	220x210x164	Euro 1700	Excellent
Wasp	Delta Wasp	200x200x200	Euro 2500	Excellent
Ultimaker	Ultimaker 2	225x230x205	Euro 2200	Excellent
BQ	Witbox	210x297x200	Euro 1500	Excellent
Type A Machines	Type A Machines 1	305x305x305	Euro 2400	Very Good
Aleph Objects	Lulzbot Taz 4	275x298x250	Euro 2000	Very Good
Wasp	Power Wasp	195x260x190	Euro 1500	Good
Airwolf	Airwolf HD2x	200x280x300	Euro 3500	Good

One important suggestion to guide your choice of the 3D printer: if possible, **avoid printers that do not allow general plastic materials to be used. Some printers work exclusively with use of plastic filament supplied by the printer Manufacturer.** Such "branded" filament can be very expensive (while the printer can attract buyers thanks to a low price) and only restricted thickness or colours type of plastic can be available.

Summary of the most important indications to choose your 3Dprinters:

⇒ Do not buy a printer only on the basis of its cost, but make a qualitative choice. Take your necessary time to investigate the offers on the market.

⇒ Choose a printer that can work with any brand and type of plastic material. If you are not allowed to use different type of plastics, thickness or colours, Teachers Team and students work will be affected, because they are not enabled to reach a satisfying variety of objects throughout time, in particular when they got familiar with the technicalities and want to reach higher quality level of printed objects.

⇒ Choose the provider who can guarantee you fast technical intervention in case the printer blocks or you encounter problems with filament during printing. The time for technical intervention in case of damages affect enormously on experimentation completion and students' motivation.

Requirements about logistic accessibility:

⇒ It is not possible to carry out significant and valuable experimentation if the 3D printer is not in the school premises; students must have access to it because it is one of the motivating and raising-engagement part of the didactic work, since it leverages on students' interest in the digital domain and devices,

⇒ Put the printer in a place where the Teachers Team can monitor its usage, printers are in some ways delicate and supervision to students must be always guaranteed,

⇒ Put the printer in a place where it does not affect with its noise when functioning the didactic work of other people or lessons

⇒ Deliver proper training to the Teachers Team in order to be able to use the printer, monitor it and make simple technical interventions whether necessary when in use with students during the experimentation.

MATERIALS:

Best material (consumable) to be used for didactic experimentations is polymeric plastic: **PLA** and **ABS**. These are both Thermoplastics, which means that they can be heated and moulded, continually, i.e. over and over again. Both are available in a wide variety of colours, which can improve the quality of the overall object you can print.

	Advantages	Disadvantages
PLA	Cheap affordable cost per Kg Can give a smooth shiny surface finish Bio-degradable Gives off very little fumes Low toxicity Low UFP's Reduced distortion compared to ABS	A little more brittle than ABS Melts at a lower temperature Softens at 50°, lower than ABS Slow to cool More difficult to glue than ABS
ABS	Tougher and stronger than PLA Able to be used in higher stressed models Doesn't need a cooling fan Filament tolerances are tighter Can be bonded using solvents or adhesives Higher heat resistance Can be painted and sanded	Must use a heated print bed Prone to curling, cracking and delaminating Petroleum based plastic making it less environmental friendly Can degrade in sunlight

Requirements about logistic accessibility:

⇒ Calculate in advance how much material and which colours you need and have it in-house enough to bring to the end the printing of all the objects related to the experimentation you are going to carry out. Do not underestimate this element, in fact:

- Object printing is fundamental to the experimental didactic since it is exactly the learning phase which requires critical analysis and observation by students on printing results who will have to resonate on possible mistakes in their application to drawings of mathematic formulas and measurements, or theorems, etc. in case the object does not match the set requirements,
- Be aware that one of the most demotivating element of the experience for students is to carry out all the didactic preliminary study and drawings preparation (in accordance to teachers' expectation) and then not to have the possibility to see "their own creations" to take physical shape: you will not reach the same level of engagement the next time you propose the experience to them,

⇒ Material is not expensive on its kind, but throughout several experimentations you may use a lot, on the basis of the complexity of types of objects, their shape, size and/or number of samples to be printed. Try to find ways to cooperate with IT companies or other local companies interested in students' skills on 3D printing so as to obtain from them some free material to feed the school stock,

⇒ Deliver proper training to the Teachers Team in order to be able to fill the material in the 3D printer, to change filament when necessary as for colours or when it finishes, to monitor it and make simple technical interventions whether necessary when in use with students during the experimentation.

3D MODELLING PROGRAMMES:

Creating a printable design is a crucial step in the 3D printing process of the experimentation. There are a vast range of 3D Programmes for use in schools. There are commercial and free ones. Some modelling software can be very expensive, with annual renewal fees. This sort of cost makes it difficult for schools to afford, unless a school is specialised in engineering or other type of curricula that makes it already available of such Programme.

Free software perfectly match scholar requirements for experimentation foreseen in this Didactic Programme. Examples are: Autodesk 123D, SketchUP, TinkerCAD, 3DTin, Cube, Design Spark, FreeCAD,.

In case your school is available to afford the cost of commercial Programme, the most adequate for didactic purposes are: Cubify Invent, Geomagic Design, Autodesk Inventor, Solid Works.

As a whole, beginner-friendly free software - such as SkethUP and TinkerCAD - offer the most important basic design tools and make 3D modelling as easy as it gets. Just be aware that, after a first set of experimentations carried out, the Teachers Team and students themselves will be quite likely to advance to other, more professional programmes - such as Autodesk or SolidWorks - which enable the printing of more sophisticated objects. The degree of velocity with which you pass from an easy free software to a commercial more advanced one, will much depend on the Teachers Team ambition to heighten the degree of complexity of printed objects and the Learning Objects in STEM subjects to be achieved.

Requirements about logistic accessibility:

⇒ Choose the 3D modelling software that best matches achievement of the Learning Objectives the Teachers Team have settled, according to the object(s) they have chosen to print as final result,

⇒ Choose the 3D modelling software easier for students to learn how to use it, on the basis of their age and type of scholar curriculum,

⇒ If available, choose the software already in use in your school, in this way the Teachers Team and students themselves will more easily master the experimentation,

⇒ The software must be compatible with 3D printing,

⇒ The software must be installed on the computer laboratory of the school where students will work. ensure that computer devices of your school support the run of the software

⇒ Prepare IT laboratory to enable maximum 3 students working on the same computer,

⇒ Deliver proper training to the Teachers Team in order to be able to use the software and train students as well during experimentation

PROGRAMMES FOR FILE CONVERSION:

STL is the standard file type used by most additive manufacturing processes. This is the file type which will be saved from the 3D design/modelling software/programme.

Requirements about logistic accessibility:

⇒ Choose the programme that best matches achievement of the Learning Objectives the Teachers Team have settled, according to the object(s) they have chosen to print as final result,

⇒ Choose the programme easier for students to learn how to use it, on the basis of their age and type of scholar curriculum,

⇒ If available, choose the programmes already in use in your school, in this way the Teachers Team and students themselves will more easily master the experimentation,

⇒ The programme must be compatible with 3D printing,

⇒ The programme must be installed on the computer laboratory of the school where students will work. ensure that computer devices of your school support the run of the software

⇒ Prepare IT laboratory to enable maximum 3 students working on the same computer,

⇒ possible Learning Objects and objects to be printed, are listed in the present document and open files for 3D printers are uploaded for re-use on Thingiverse.com under the following Usernames: PRINTSTEMPROJECT_BERENINI, PRINTSTEMPROJECT_GADDA, PRINTSTEM_SABANCI, PRINTSTEMPROJECT_KSGS, PRINTSTEMPROJECT

⇒ Deliver proper training to the Teachers Team in order to be able to use the programme and train students as well during experimentation

PHASE 4
SETTING UP THE PEDAGOGICAL ORGANIZATION AND IMPLEMENTING AN EXPERIMENTATION

Minimum requirements for the carrying out and educational success of experimentation:

1° - Definition of Learning Objectives and object to be printed

Number of hours dedicated: 3

People involved: Teachers Team all together

2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved

Number of hours dedicated: 5

People involved: Teachers of each subject involved and School coordinator

3° - Communicating the project to students (the class)

Number of hours dedicated: 1

People involved: Teachers Team

Teachers introduce to students the educational project of using the 3D technology to enhance STEM subjects learning. The action is necessary raise interest and engagement of students towards the activities, boosting the next learning success.

4° - Entry level assessment

Number of hours dedicated: 5

People involved: STEM teachers and students

2 hours: STEM teachers develop together an entry-level written test to be delivered to students so as to check their current STEM knowledge and skills on those required in order to access properly the experimentations;
1 hour: students undergo the test;
2 hours: the Teachers Team evaluate the tests and, accordingly, may revise the experimentations Learning Objectives (at point 1°) in case, for example, the students' entry level is higher or lower the expected: if the level is higher, the Learning Objectives will be raised up and made more ambitious, on the contrary, they will be downsized

5° - Training Unit on Maths Subject

Number of hours dedicated: (*on the basis of the topics that the experimentation will cover*)
People involved: Maths teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work. The teacher delivers the theoretical lesson, with ordinary teaching method

6° - Training Unit on other related Subject(s)

Number of hours dedicated: (*on the basis of the topics that the experimentation will cover*)
People involved: Subject teacher(s)
Didactic methodology used to teach the contents: front lesson, laboratory work and group work. The teacher delivers the theoretical lesson, with ordinary teaching method

7° - Assessment of the knowledge and skills acquired with "ordinary" teaching method

Number of hours dedicated: 5
People involved: Subject teacher(s) and students
Didactic methodology used to teach the contents: written test made up of at least 10 close questions and 5 open questions on the topics/contents taught (at Point 5° and 6°)

2 hours: on the basis of the defined Learning Objectives (at point 1°), subject teacher(s) develop the test, bearing in mind that the same test will be delivered to students after 3D printing application to learning, for comparing purposes;
1 hour: students undergo the test;
2 hours: subject teacher(s) evaluate the tests

The results will be used afterwards to compare learning before and after the use of 3D printing for educational purposes. In this way it will be possible to appraise concretely the impact of the technology on STEM learning of students

8° - Training Unit on Technical Design

Number of hours dedicated: 12

People involved: Technical drawing Teacher

Didactic methodology used to teach the contents: front lesson group and IT laboratory work. Students learn functionalities and concrete usage of the Software that will be used next to design in 3D the object chosen

9° - Design of the object

Number of hours dedicated: from 1 to 4 *(depending on the difficulty of the objects, i.e if it is one-piece object or made up of several components)*

People involved: Technical drawing Teacher and students

Didactic methodology used: laboratory work and group work

10° - Transfer of the object designed to 3D printing programme

Number of hours dedicated: from 1 to 4 *(depending on the difficulty of the object, i.e if it is one-piece object or made up of several components)*

People involved: students and IT Teacher and/or STEM teacher able to use the software

Didactic methodology used: laboratory work, transfer of the object onto .stl file, ready for printing

11° - Object printing

Number of hours dedicated: from 2 to <u>many hours</u> *(depending on the difficulty of the object, i.e if it is one-piece object, big or small, elaborated and/or made up of several components)*

People involved: students and IT Teacher and/or STEM teacher confident with the 3D printer

Didactic methodology used: laboratory work

12° - Fine tuning / redoing

Number of hours dedicated: from 1 to 3 hours

People involved: students (with support of IT Teacher and/or STEM teacher)

Didactic methodology used: laboratory work. In case of printing mistakes, students revise accordingly their object design in order to assess whether it is a "simple" printing error or a mistale in calculating formulas, sizes etc of the object, on the basis of STME contents. Students have to reflect autonomously on mistakes so as to find the source of them. Accordingly, the drawings are revised and the correct object printed.

14° - Final evaluation of Learning Outcomes achievement

Number of hours dedicated: 6

People involved: Subject teacher(s) and students

Didactic methodology used to teach the contents: direct observation from teachers + written test made up of at the same 10 close questions and 5 open questions on the topics/contents taught as delivered at project start (at Point 7°).

1 hour: students undergo the test;

2 hours: subject teacher(s) evaluate the tests and compare the results with the one supplied at project start. The comparison will make objectively clear whether, how and where the 3D technology have concretely supported students' improvement on STEM subjects.

3 hours: the Teachers Team collect for each student the evaluation made through their direct observation during implementation of activities, giving a score from 0 to 5 and adding any useful comments to the following items:

a) levels of engagement,
b) interest shown,
c) active participation,
d) proactivity,
e) quality of self-learning,
f) problem solving ability,
g) technical accuracy using softwares and the printer
h) cooperation with other students

15° - Assessment of students' self-evaluation and motivation

Number of hours dedicated: 1

People involved: students

Didactic methodology used: students are given a final questionnaire where they will anonymously express their own personal evaluation of the experience. The questionnaire can be used to gather also hints and new ideas to be applied on new activities/experimentations with the technology.

The following Tool can be used to assess students' motivation and hints on the experimentations

	STUDENT'S SELF-EVALUATION QUESTIONNAIRE 3D-Printer Experimentation on Mathematical Literacy Competences	YES, VERY MUCH	YES	ONLY IN PART	NO
1	Did you have good expectations from your future experience with the 3D printer before the start of the exercises with your teachers?				
2	Did you understand clearly the objectives of in-class learning before the start of the 3D printing exercises?				
3	Are you satisfied with the experience with the 3D printer in terms of learning mathematic-related contents?				
4	Were the exercise with use of the 3D printer useful to improve your knowledge and understanding of mathematical rules/concepts related to the object that you designed and printed?				
5	Did you appreciate the use of the 3D printer in learning theoretical rules and math contents instead of a „classic" lesson/didactic methodology?				
6	Do you think that the 3D printer is an effective didactic method to teach theoretical/abstract contents otherwise difficult to understand?				
7	Did you find the software in 3D printing easy to use?				
8	Can you suggest any changes to the software? Please, specify:				
9	Did the use of 3D printer increase your interest and motivation towards learning mathematical subjects? Why? Please write here to explain your answer:				
10	Do you think that the use of 3D printer exercises can improve the practical understanding of links among different STEM subjects?				
11	Was the duration of the exercise teaching through the 3D printer satisfactory to you? Why? Please, specify:				
12	Would you have preferred a longer experimentation in order to improve even more your knowledge/understanding of the mathematical contents?				
13	Would you like to repeat the experience in other subjects and/or with other objects to be printed? Please, write here which ones:				
14	Would you suggest to your school to make a steady use of the 3D printer to teach you mathematical and/or scientific topics?				
15	What would you suggest to your teachers in order to improve new exercises with 3D printer in order to teach your class theoretical subjects, rules, or formulas etc? Write here:				

Chapter 2. Didactical experimentations carried out by 5 Secondary Schools: Learning objectives - Printed objects - Lessons Learnt - Recommendations

2.1 GEOMETRICAL INTERPRETATION OF THE PYTHAGOREAN FORMULA (1Epalchanion - Greece)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) Relations within and between geometric objects in two and three dimensions

2) Measurements

3) Percentages, ratios and proportions

SPECIFIC Learning Objectives

1) Relationship of algebraic equation and the geometrical interpretation of the Pythagorean theorem

2) Inverse of Pythagorean theorem

3) Generalization of the Pythagorean Theorem

4) Determination of the triangle data if it is known sides.

How the Learning Objectives have been identified by teachers and why?

The choice of General and Specific Learning Objectives based on the combination of three factors:

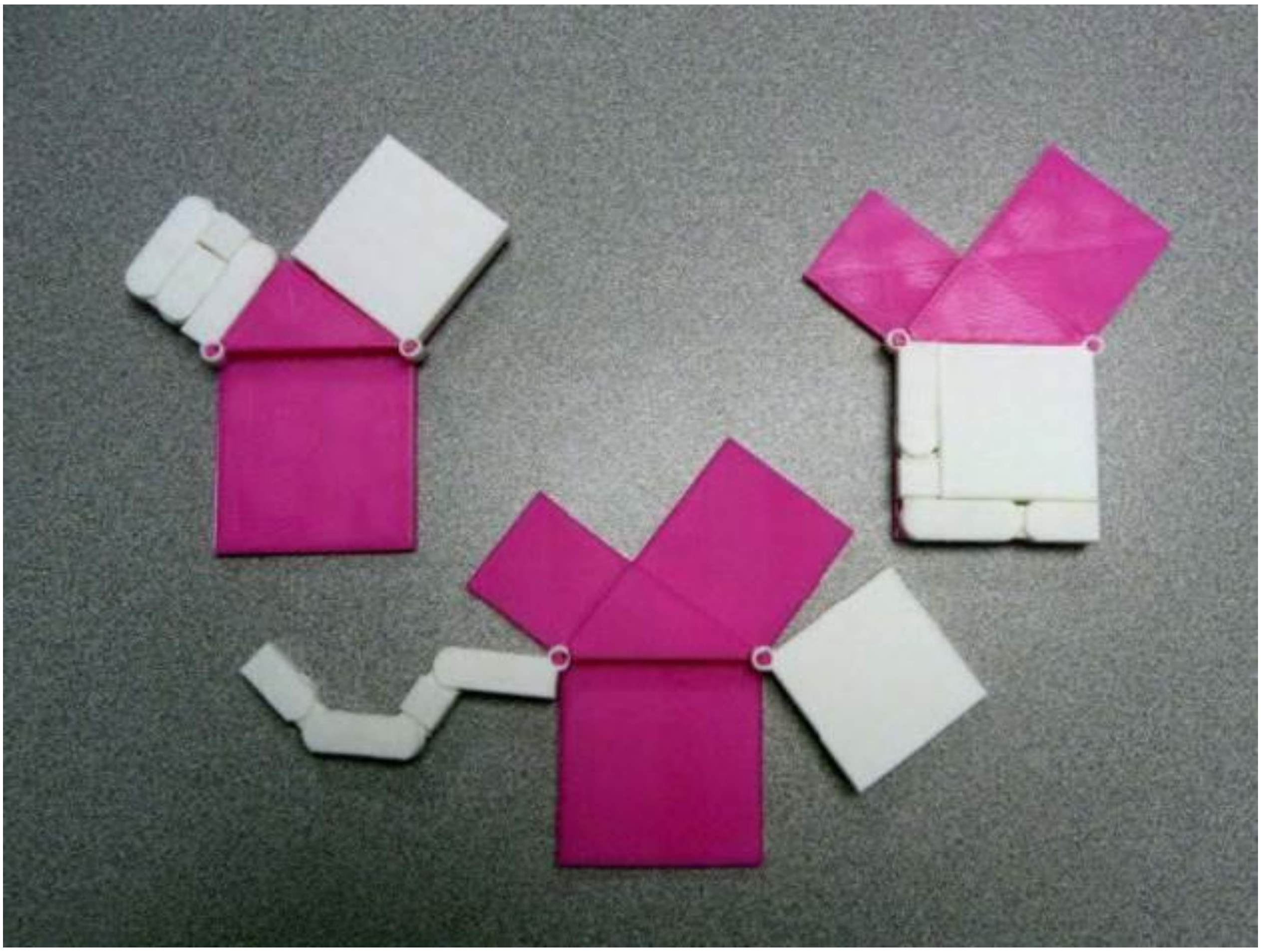
1. The conclusions that came out of the IO1, concerning mathematical literacy items with a higher level of priority
2. The syllabus for Eukleidis's Geometry for the 1st Grade of Technical Vocational Schools and more specifically Chapter 3 (Triangles) and Chapter 9 (Metric measurements and the Pythagorean Theorem).
3. Students' relevant knowledge from the 2nd Grade of Junior High School

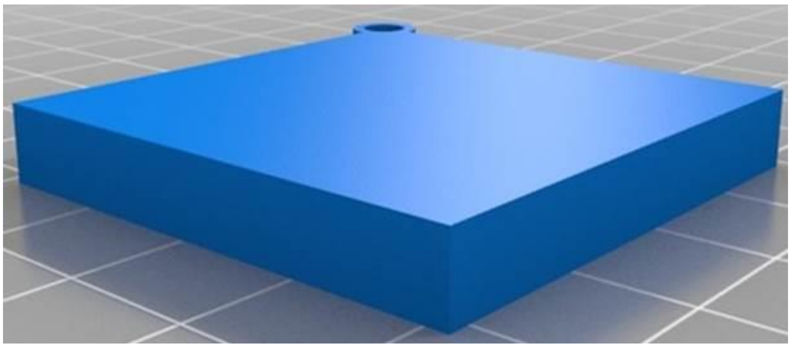
PRINTED OBJECT

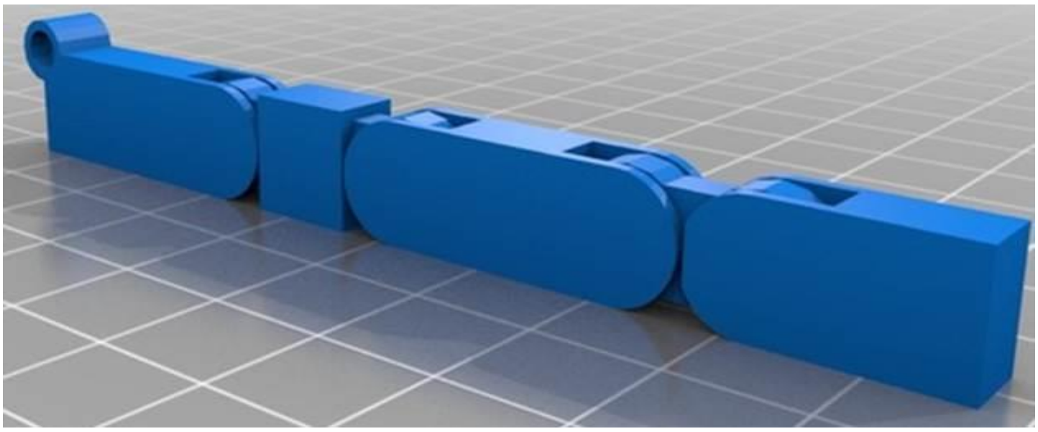
In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing the shape of the geometrical interpretation of the Pythagorean formula.

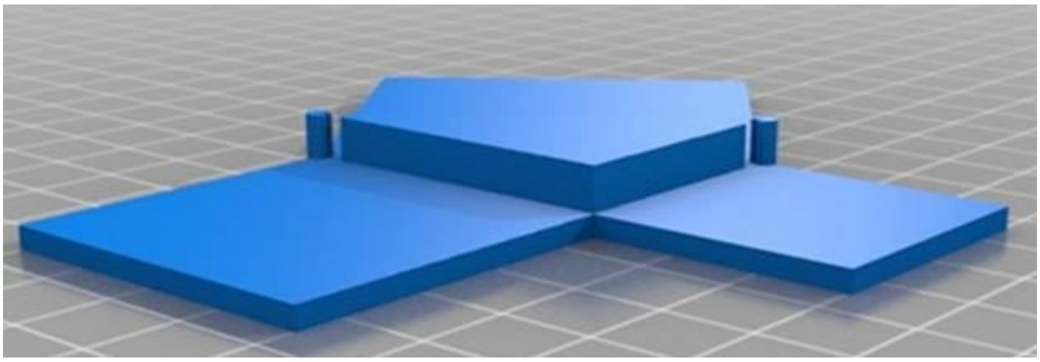
Why this object?

- According to survey, students have great difficulty in associating the algebra type of the Pythagorean formula to its geometrical interpretation, which is considered to be a necessary step in order for them to understand it better.
- The object would enable pupils in associating the algebra type of the Pythagorean formula to its geometrical interpretation, which is considered to be a necessary step in order for them to understand it better. Moreover, a great number of students in our school lack really significant knowledge in Mathematics, such as multiplying and dividing, shape recognition and drawing, the notion of volume, area calculation, etc.









PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ basic computer knowledge and competences
- ✓ basic knowledge and competences in technical drawing
- ✓ basic mathematics knowledge

THE TEACHERS TEAM INVOLVED

One (1) teacher has been involved in the experimentation:

List each teacher' subject/domaine:

1 teacher of Mathematics

Rationale of the Teachers Team

The teacher involved in the team was chosen because he combined knowledge of two scientific subjects, that of Mathematics and that of Computer Science. Thus, he was the ideal teacher needed to carry out successfully the experimentation, include specific references to the skills required to lead properly the students on each experimentation phase.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:

Number of pupils: 34

Type of group: Two inter-classes groups A1 , A2

Number of classes: Two(2)

Scholar curriculum specialisation of the class(es) involved: General Education classes, with the vocational orientations of: Financial studies – Accounting, Maritime studies, Agriculture studies

"Special needs" students: -

Entry level assessment: Students had no drawing knowledge and skills before attending the project. Neither were they aware of 3D drawing software. Their knowledge of the Pythagorean theorem was poor, as they were taught this theory for the first time in the 2nd Grade of Junior High School. The percentage of students who answered the evaluation test before the beginning of the experimentations was 6%.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	Pythagorean formula / associating the algebra type to its geometrical interpretation
Topics related to the Learning Objectives of experimentation	• Know the Pythagorean theorem and the inverse of • Solve problems using the Pythagorean theorem • To check if a triangle with known sides is rectangular • Relationship of the Pythagorean theorem to irrational numbers. Apply to geometric problems and real measurement problems
Total number of hours dedicated to completion of the experimentation	20

OTHER RELATED SUBJECT	TECHNICAL 3D DRAWING

Didactic Topics related to the Learning Objectives of experimentation	Teaching basic commands of the 3D Drawing software in order to be able to complete the experimentation.
Total number of hours dedicated to completion of the experimentation	4

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** a) 123D_Design-Autodesk, b) tinkercad. Both of them are freeware, and have great gallery. Tinkercad is for entry level users and 123D more specific.
- **SOFTWARE(S) for object PRINTING:** Cube Print 4.0 . This is the software that came with 3d printer we bought. It is not an open source software.

links to useful tutorials available on the web:
http://www.3dsystems.com/shop/support/cube/videos

3D PRINTER:
CUBE 3D PRINTER TECH SPECS
WEIGHT & DIMENSIONS
Cube dimensions:
(with cartridge)
13.2(w) x 13.5(h) x 9.5(d) inches / 33.5(w) x 34.3(h) x 24.1(d) cm

Operating Envelope:

28.9(w) x 20.6(h) x 15.8(d) inches / 73.4(w) x 52.3(h) x 40.1(d) cm

Cube weight:
(with cartridge)
17 lbs / 7.7 kg

Box dimensions:

26.3(w) x 20(h) x 14.5(d) inches / 66.8(w) x 50.8(h) x 36.8(d) cm

Box weight:

22 lbs / 10 kg

CONNECTIVITY
Wireless:

Print over WiFi with the Cube Print App for Mac OS X and Windows

Wired:

Transfer print files with the USB stick (supplied with the Cube)

Mobile devices:

Print direct with the Cube Print App for iOS and Android (available soon for free download)

PRINT PROPERTIES
Technology:

Plastic Jet Printing (PJP)

Print jets:

Dual jets

Maximum design size:

6 x 6 x 6 inches / 15.25 x 15.25 x 15.25 cm

Material:

Tough recyclable ABS plastic or compostable PLA plastic

Layer thickness:

70 microns, fast mode: 200 microns

Supports:

Fully Automated, easy to peel off

Dual cartridges:

Each cartridge prints 13 to 14 mid-sized creations

OPERATING ENVIRONMENT
Room temperature:

16–29°C (60–85°F)

Non-condensing relative humidity:

30–60%

SOFTWARE
Description:

Comes with software to create cube readable files

Print jets:

Dual jets

Windows requirements:

Cube software runs on 32 and 64-bit Operating Systems on Windows 7 and above
Minimum screen resolution: 1024 x 768
Minimum IE version: 10 and above
Mac OSX requirements:

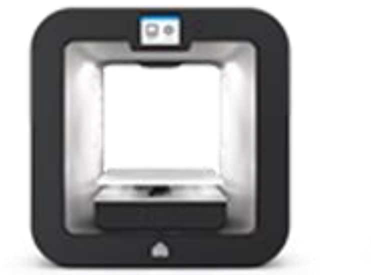
Cube software runs on Mac OSX 10.9 and above
Minimum screen resolution: 1400 x 900
Android Phone/tablets requirements:

Cube Print App is available in the Play Store for your Android phones/tablets running Android 4.0 (Ice Cream Sandwich) and above
iOS requirements:

Cube Print App is available in the App Store for your iPhone running iOS 8 and above
Minimum hardware requirements:

Processor: Multi-core processor - 2GHz or faster per core SystemSystem RAM: 2 GBOpen GL for mobile platforms:Open GL ES 2.0 and aboveOpen GL for desktops:OpenGL 3.0 and above

- **Cost 1350 euro**



IMPORTANT: Time necessary to print 1 object of the experimentation with this 3D printer is 1 hour at fast mode: 200 microns.

- **PLASTIC MATERIAL:** Tough recyclable ABS plastic or compostable PLA plastic

Its average cost 50 euros

IMPORTANT: Quantity of this material necessary to print 1 set of three squares, a chain and a triangle is: 5%

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

1st - Definition of Learning Objectives and object to be printed

Number of hours dedicated: 2

People involved: 1

2nd - Identification of Subjects related to experimentation and planning of the working hours for each subject involved

Number of hours dedicated: 2

People involved: 1

3rd - Entry level assessment – introduction in 3D DRAWING software

Number of hours dedicated: 4

People involved: 1 + 34

Description:

- Video tutorials for basic menu and commands of 123D Design software
- Drawing in scale, making measurements in centimeters and millimeters, adding and subtracting dimensions
- Basic two – dimensional shapes drawing – analysing the basic methods of 2D data visualisation
- Transformations in space – introduction to structures and descriptive methods of 2D data
- Presentation of 3D visualisation basic commands – Geometry on surface
- Object sequence – projections
- 3D drawing of polygons, triangles, parallelograms

4th - Training Unit on Pythagorean formula / associating the algebra type to its geometrical interpretation Subject:

Number of hours dedicated: 4

People involved: 1+34

Didactic methodology used to teach the contents:

- teaching by using real-life objects and calculations - deduction

- group work

- arousing critical thinking and problem solving techniques

5th - Training Unit on Relationship of the Pythagorean theorem to irrational numbers Subject:

Number of hours dedicated: 1

People involved: 1+34

Didactic methodology used to teach the contents:

Teaching by using real-life objects and calculations - deduction

- group work

- arousing critical thinking and problem solving techniques

6th - 123D Design of the object:

Number of hours dedicated: 6

People involved: 1+34

Didactic methodology used:

- front lesson,
- pupils self-study,
- laboratory work,
- group work

The students drew the three objects on the 123D.

- The base, which is the right – angled triangle with sides 3,4,5 and the 3 squares which are formed from each side of the triangle.
- The square of one vertical side.
- The square of the other vertical side in the form of a chain. Because the drawing of the chain demanded special skill in drawing, we decided to download the specific .stl file from its open source gallery http://www.thingiverse.com/ in the Internet.


E=α²
E=γ²
E=β²

7th - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 2

People involved: 1+34

Didactic methodology used:

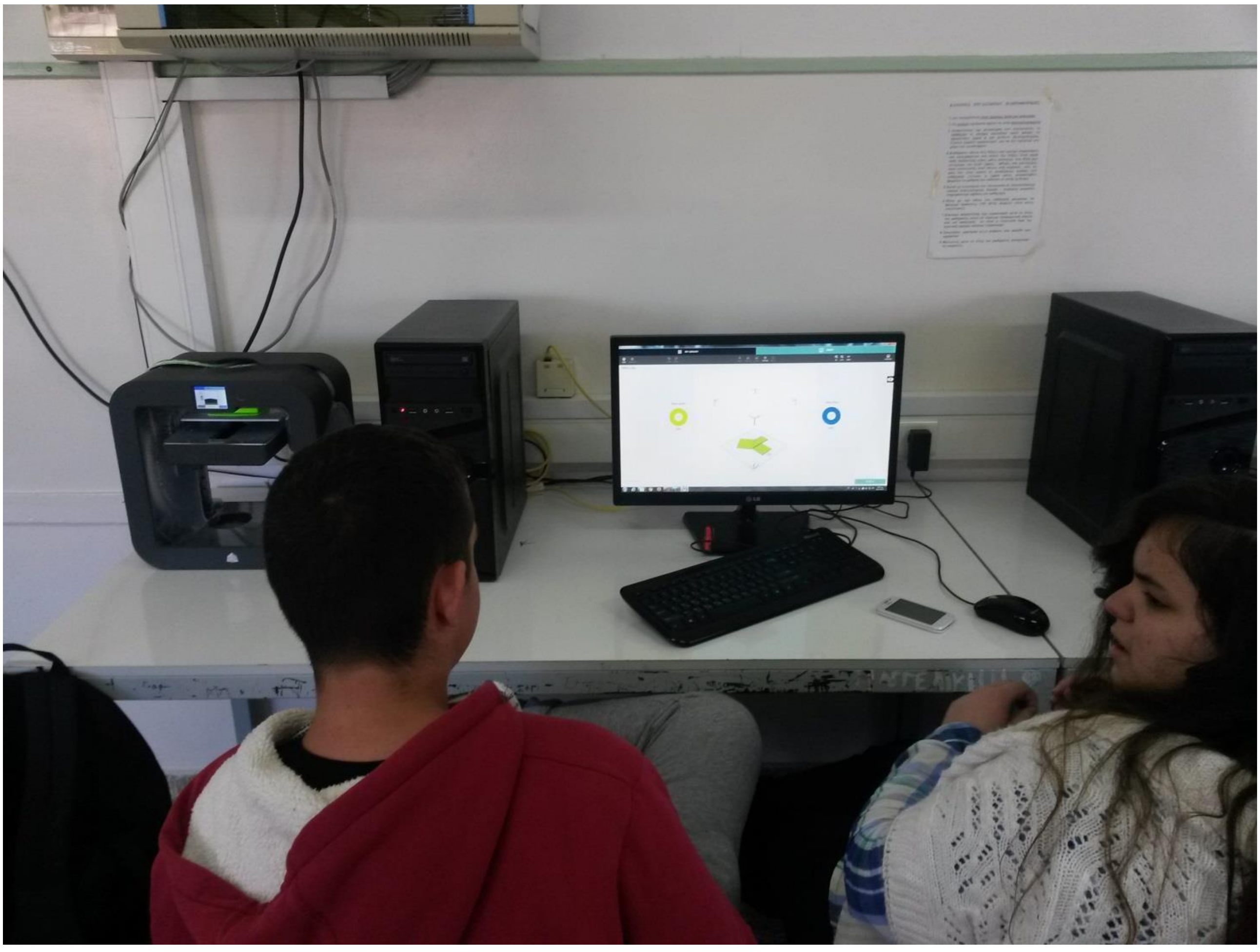
- front lesson,
- pupils self-study,
- laboratory work

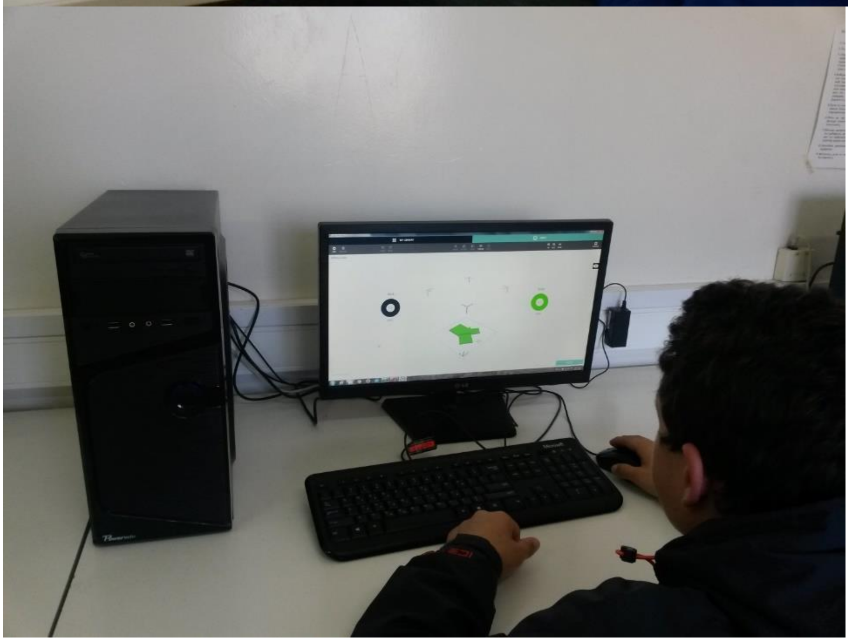
In the beginning, we presented the process and the parameters we could set for the final object to be printed. Then, the students applied these features to the objects they had designed. More specifically, they experimented on:

Move, Rotate, Scale, center the printing object

Select material (ABS, PLA) and color for each printing head

To decide on the print quality (Draft, Standard, Premium, Custom) , the layer resolution (70, or 200 microns) and finally if they have to use support material or not.





8th - Object printing:

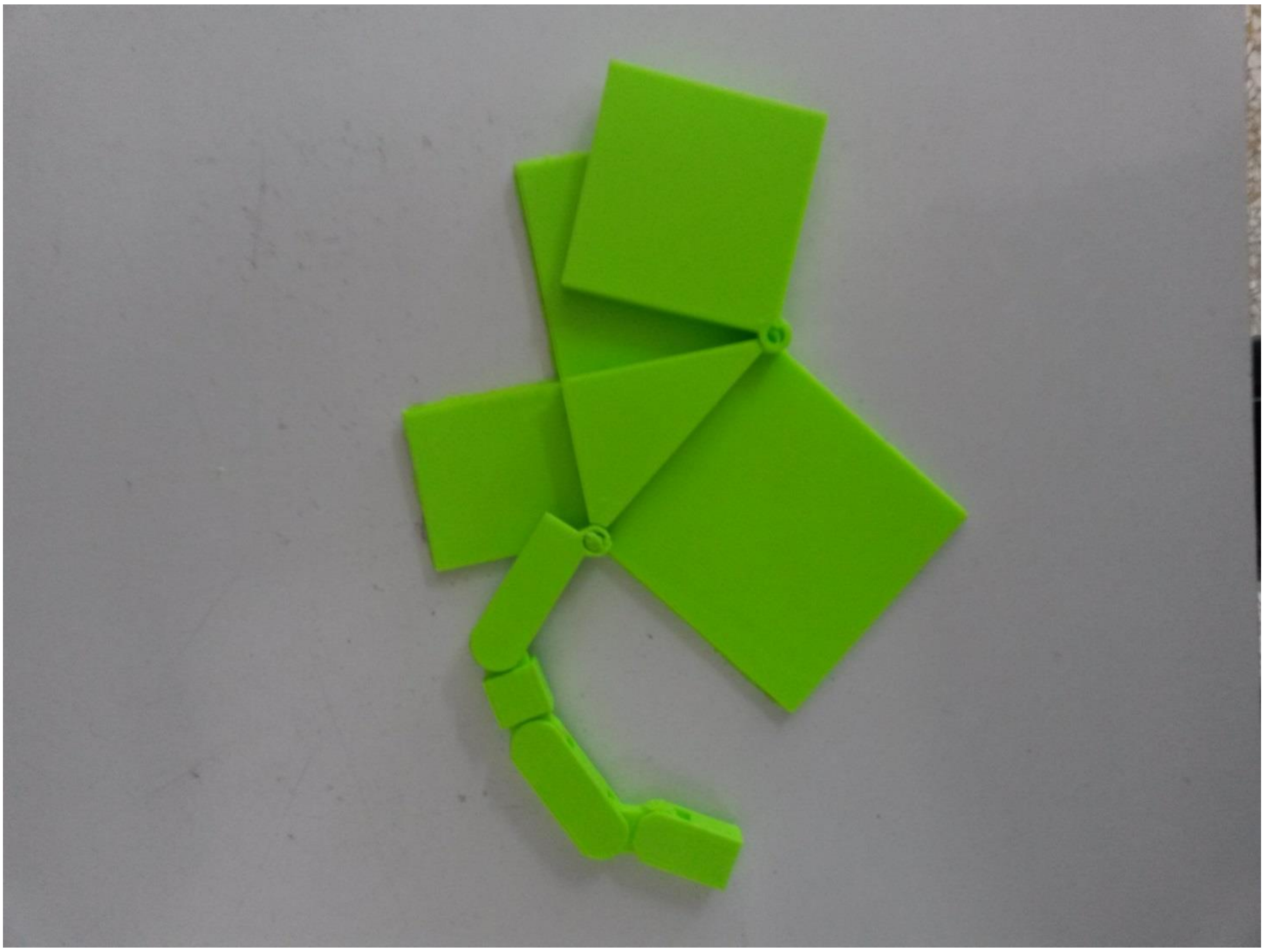
Number of hours dedicated: 10 (6 with the school closed)

People involved: 1+34

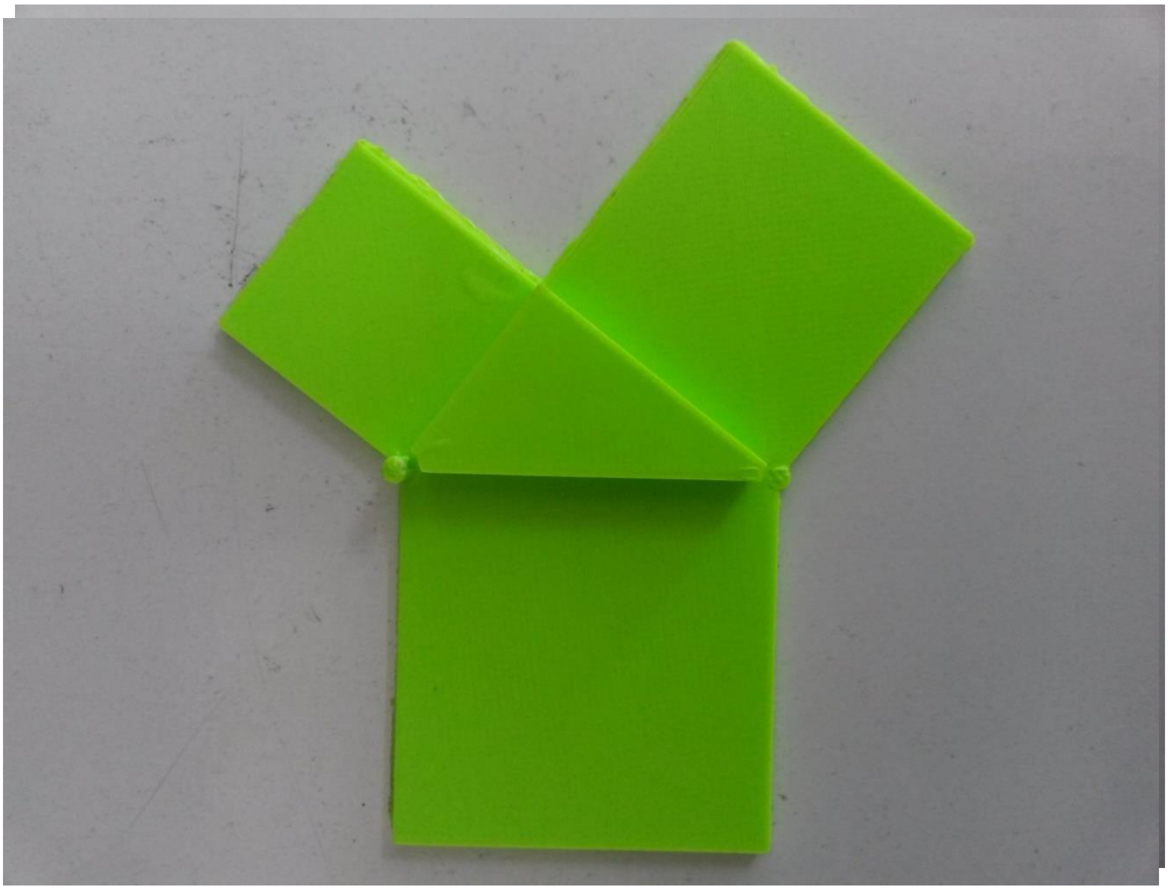
Didactic methodology used:

Not all objects created by students were printed, since they themselves selected which ones would. One object from each team was printed. Sub-groups of 4-5 students printed and completed the process on their own, under the teacher's discreet surveillance. Sometimes the printing process failed due to several reasons.

- Small amount of glue in the printing base of the 3D printer
- Printing out of borders
- Collapse of one of the printer's head, for which we asked replacement.
- Defective printing materials (PLA) stopped printing, although there was still an amount of 60% left.



- The completion of the object printing process was too long and as a result, the students' interest declined. Moreover, certain problems of unsuccessful printing could not be immediately dealt with (by cancelling the printing process), resulting to waste of printing material.



9th - End of experimentation

Number of hours dedicated:2

People involved: 1 teacher + 34 students

Didactic methodology used:

Presentation of items manufactured by the students.

Discussion about the difficulties encountered by several students to design software 3D objects, and attempt to find a solution. We tested for 1 hour alternatively online tinkercad software that is provided free for use in https://www.tinkercad.com/.

In the short time dedicated students reported that they found it easier to use, but we did not have time to use it more to draw reliable conclusions.

Some other students have recommended we take a first look at online libraries for objects (free to use) we have decided to print. If such files do not exist, then we would have to design them on our own.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main mathematical subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of ad hoc written exam within the planned scholar test of the subject including other topics than the experimentation-related ones and recorded the following learning results:

1) Their problem solving ability was improved, regarding problems concerning knowledge of the Pythagorean Theorem. The percentage of students who answered the evaluation test before the beginning of the experimentations was 6%, whereas the percentage of students who answered the test questions with altered rubric, rose to 65%!

2) It is also worth noting that it was not only their ability to solve problems concerning the Pythagorean theorem and its inverse that improved impressively, but also their ability to express it both in oral and written form.

3) We also need to mention the fact that the impressive results described above, may be the combined result of many factors. That means that the time we dedicated to teach the Pythagorean Theorem (together with the 123D Design use) was 24 hours in total, whereas the time predicted by the analytic program of studies for traditional teaching is just 6 hours.

Direct observation on pupils - made by each member of the Teachers Team during the experimentations - enabled to record to the following further learning and/or "transversal" results:

1) Some students faced great difficulty in the 123D Design software and this was proved by their occasional but deliberate absence from the lesson. There is the risk of adding more difficulty to their already-existing bad relationship with Mathematics and 3D drawing or on the best occasion, replace them with others.

2) Students did not seem to enjoy the printing process because it was extremely time-consuming and had to inevitably take place out of the lesson and classroom limitations.

LESSONS LEARNT

What we want to note is that the overall assets of the project was undoubtedly positive.

Our general picture is that both students and teachers gained a lot from this process, since they got in touch with an innovative technology, which will surely play a dramatic role in the near future. Moreover, they obtained new skills and abilities in the specific subject of Mathematics. We refer to the following problems, only with a view to help augment the produced results and under no circumstances should they be considered as appalling factors for the use of 3D printers in teaching.

We will refer to the problems as we encountered them and not in an order based on their significance.

1. The shortage of financial resources of schools resulted in a great delay as far as the purchase of the 3D printer is concerned, but also restricted our options in one of the most economical ones, which inevitably caused great problems regarding its function and handling its printing materials (PLA and ABS).
2. It is crucial to assure beforehand that a satisfactory number of teachers of each specialization are willing to participate in the project and commit themselves to working hard, in order to meet the project's expectations. Due to lack of interest expressed by our colleagues, combined with the zero appointments of new teachers this year, the whole load of work that the project demanded was limited to one teacher – as far as IO4 experimentations are concerned – and this proved really tiresome, not to mention, troubleshooting for the printer and the software which we will refer to later.
3. Another very important point to be taken into consideration are the difficulties faced by teachers and pupils with the use of 3D Drawing software. There is the necessity for a Teachers' training course on the use of 3D Drawing software, before the beginning of experimentations and the choice of Drawing 3D software for beginners. Otherwise, if the STEM subject experimentation is not Engineering, then the solution may be the galleries with preset .stl files.
4. The choice of hardware and software is of great importance. Teachers and technicians responsible for the selection of the needed equipment have to be extremely cautious about their choice. The most important aspect to consider is technical problems that arise with the 3D printer, since technical support by Business partners cannot be guaranteed. We cannot possibly know if all 3D printers of the same cost suffer from the same problems, but based on our negative experience, we would definitely discourage teachers who would like to run experimentations, from buying Cube3 printer, since both the printer itself and the printing material have great defects in their use and function.

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Students gets introduced to a really innovative technology, which will have a determining impact in humanity's evolution, as it has already been characterised as the Third Industrial Revolution.
- ✓ When students get familiar to 3D printing technology, their boldness for design augments, increasing their confidence and imagination.

- ✓ They are able to learn from their mistakes, which will be an invaluable experience going into their futures.
- ✓ They can realise in tangible terms, notions that seemed really abstract or impossible to understand.
- ✓ Students learn indirectly – through working out evidence and proof of mathematical formulas and axioms - all the Domains in which 3D printers have already found application.
- ✓ Students discover a new way of approaching and conquering knowledge.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ The cost of purchase of a 3D printer and printing materials is so high nowadays, that most schools in Greece cannot afford.
- ✓ When 3D models to be printed are too large or of high accuracy, they demand too much time for their printing, making students miss the satisfaction and joy of watching their work completed.
- ✓ Teaching 3D Drawing software can be as noteworthy an obstacle as teaching STEM subjects in the traditional way, with all the well-known side-effects.
- ✓ A lot of preparatory time is needed by teachers, in order for the experimentation to be strictly structured.
- ✓ Appropriate laboratory facilities, accessible by all STEM teachers, are necessary.
- ✓ Constant technical support is vital, because if the 3D printer collapses and no solution is found for a long time, all magic surrounding 3D printing is lost, together with the students' interest.

RECOMMENDATIONS

- ✓ 3D Drawing Software selection should be as simple to use, appropriate for young learners at a beginner's level, as well for teachers who may have never dealt with such software before.
- ✓ Make sure that seminars by Experts are held, on the use of software and hardware chosen, through which the Interdisciplinary Team will be trained. If a teacher does not feel confident about the subject he / she has to teach, he / she is not going to use it.
- ✓ Besides teaching STEM subjects, the use of 3D printers can also be applied and taken advantage of in an Interdisciplinary project studying local history, architecture, etc through printing significant local monuments, in which Language Teachers, Computer Science teachers and Civil Engineering teachers can get involved.
- ✓ Encourage the use of open source, free to use libraries on the Internet, with pre-set .stl files that have already been used for teaching a great number of different subjects. In this way, we can focus only in the process of 3D printing and the use of printed objects in teaching, overcoming the potential obstacle of teaching 3D Drawing.
- ✓ Make sure that constant technical support is available, since it is a vital for the successful completion of all experimentations and the project as a whole.
- ✓ We strongly encourage that students initially deal with pre-set files, working on objects which are of great interest for them, so that the transition to teaching more complex notions, such as these of Mathematics, is smoother.

2.2 SMALL ROCKET REALLY FUNCTIONING AND LAUNCHED (Kirby Stephen Grammar School -UK)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) Understanding Newtons Laws of motion
2) Understanding velocity
3) Understanding acceleration
4) Understanding Thrust
5) Predicting rocket trajectory

SPECIFIC Learning Objectives

1) How to use the equation SUVAT
2) How to apply the equation.
3) Working through examples.

How the Learning Objectives have been identified by teachers and why?

Learning objectives were mainly based around applying mathematical content to a fun project. A number of projects were considered but the rocket project had a number of advantages. To start with the project would be one which created a great deal of interest. Pupils would be inspired by setting off a real live rocket. This would then lead into the mathematical content of the project.

The mathematical aspects of the rocket project are far ranging and were seen as being very adaptable ie the maths content could be tailored specifically to the groups ability and gave a large scope for differentiation. Another aspect of this flexibility would be the ability to adapt the maths content to suit the maths curriculum schools, depending on the topic or project being taught.

Other reasons include the current international interest in space exploration, the first Britain to live in the international space station and the travel and possible colonization of Mars. The film the Martian is also a good film to get pupils enthused.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a simple single stage rocket. This included the Nose Cone, Rocket Motor Housing and Fins.

Why this object?

The object would enable pupils to manufacture and test the rocket actually experiencing this in real life. As the project had been pre-designed pupils were simply required to follow basic design and manufacturing skills within a framework which would ensure success, something seen as being quite important.

PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ Use of 3D Software.
- ✓ Use and access of the 3D Printer.
- ✓ Basic ability to manipulate equations.
- ✓ Basic understanding of the laws of motion.

THE TEACHERS TEAM INVOLVED

Teachers have been involved in the experimentation:

1 teacher of Design & Technology for 3D Software support and tutorials

1 teacher of Chemistry to support with chemical reactions teaching

1 teacher of Physics to support with the Physics and Mathmatical content.

Rationale of the Teachers Team

The teachers involved in the team were chosen because they had the necessary skills and more importantly enthusiasm for the project. They were also chosen because they had the necessary ability to get the job done and see the project through. Reliability in getting the project completed is essential to the success of the project.

Organisational skills and the ability to get the project up and runningare very important if the project is to succeed.

Understanding the level at which to pitch the project and assessing the level at which pupils are at, so that the content can be suited to the group, is also important so pupils are learning new skills as well as applying previously taught skills.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:

Number of pupils: 40

Type of group: 1 mixed group trending towards more able pupils, but not all.

One group with special interest in Technical subject. Of these, 3 pupils had statements for learning issues. 1 had behavioral issues and 2 were considered to be Gifted and Talented.

Number of classes: 2

Scholar curriculum specialisation of the class(es) involved: All pupils are following a Science and Maths subject. 60% of pupils had opted for a Technology / Engineering GCSE course.

"Special needs" students: 4 of the students had been categorized as being Gifted and Talented. 2 students had dyslexia**.**

Entry level assessment: Use of current and projected grades using Key Stage 2 data and assessments in maths and science.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	Manipulation of algebraic expressions
Topics related to the Learning Objectives of experimentation	Use of SUVAT equations.
Total number of hours dedicated to completion of the experimentation	9 Hours

OTHER RELATED SUBJECT	Physics

Didactic Topics related to the Learning Objectives of experimentation	Velocity, time and acceleration.
Total number of hours dedicated to completion of the experimentation	9 Hours

OTHER RELATED SUBJECT	Chemistry
Didactic Topics related to the Learning Objectives of experimentation	Redox reactions
Total number of hours dedicated to completion of the experimentation	1

OTHER RELATED SUBJECT	Use of 3D Printer
Didactic Topics related to the Learning Objectives of experimentation	3
Total number of hours dedicated to completion of the experimentation	3

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** Trimble / Google Sketchup V8. Later versions are now available. This is a quick and easy 3D Software package to learn and is a free down load. There is a vast library of components for down loading and a large support network. There are also a great number of down loads and U-Tube clips for self help.

- **SOFTWARE(S) for object PRINTING:** Cura software was used as it has been specifically designed for Ultimaker. It is also a free download and open source. There is a support community for it.

- **3D PRINTER:** Ultimaker 2

  IMPORTANT: Time necessary to print 1 (object of the experimentation) with this 3D printer is 3/4 of an hour

- **PLASTIC MATERIAL:** PLA was used for most of the printing as it was seen as being more reliable with less distortion than ABS.

  IMPORTANT: Quantity of this material necessary to print 1 (Rocket Nose Cone and Rocket Motor Housing) is: approx one 20mm cube.

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

1° - Definition of Learning Objectives and object to be printed

Number of hours dedicated: ¾ hour max.

People involved: 2

2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved

Number of hours dedicated: 1/2hour to discuss what each teacher would prepare.

People involved: 3

3° - Entry level assessment

Number of hours dedicated: 1hour to gather previous assessments

People involved: 2

4° - Training Unit on Maths Subject:

Number of hours dedicated: 5 and currently on going.

People involved: 1

Didactic methodology used to teach the contents: front lesson.

5° - Training Unit on Chemistry Subject:

Number of hours dedicated: 1hour

People involved: 2

Didactic methodology used to teach the contents: laboratory work,

6° - CAD Design of the object:

Number of hours dedicated: 5 hours to prepare tutorial 4 hours for pupils to follow.

People involved: 1

Didactic methodology used: Self guided tutorial

7° - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 1 hour

People involved: Pupils did this as a group.

8° - Object printing:

Number of hours dedicated: 40 mins for Nose cone and Rocket Motor Housing. 40mins for the Fins. However a number of pupils rockets could be printed off at once. With the printer left on over night time issues were irrelevant.

People involved: Each pupil was encouraged to print their own. However faults with design and manufacturing meant that the teacher had to re-print or modify the designs

Didactic methodology used: Pupils were encouraged at all stages to Design, file convert and print their Rockets. However inevitably problems did occur. Either designs were incorrect; sizes were wrong; print meshes were wrong or the print filament became fouled. This required the teacher or technician to intervene and correct. The teacher involved has a number of pre-printed models which could be quickly swapped for incorrect prints. The Fins as they could only be printed 3 at a time were pre-printed ready for use by the pupils.

9° - End of experimentation

Number of hours dedicated: 2hours

People involved: 1 teacher

Pupils set rockets off and concluded with a basic design evaluation.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main mathematical subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of discussion and simple maths, physics and chemistry exercises and recorded the following learning results:

1) Pupils gained a greater understanding of what 3D Printing is.

2) Some of the mathematical concepts was a little too rigourous and needed to be simplified. Maybe just one of the mathematical concepts should be taught.

Direct observation on pupils - made by each member of the Teachers Team during the experimentations - enabled to record to the following further learning and/or “transversal” results:

1) Some pupils took to the project really well and actually started to help other pupils. The cooperation between groups was very encouraging. The design aspect of the project was particularly good as there was a spirit of cooperation , support and competition. This could perhaps be applied more to the Maths / Science aspect of the project.

LESSONS LEARNT

The type of project and how you go about teaching it will depend very much on the type of institution you work in. The time you have available for the teaching of the project will be a limiting factor too. It is important to consider the ratio between Printing and Theory work.

A 3D Print of a working model may just be a way of introducing a concept or project and provide pupils with an initial interest in the project. However it may provide the framework around which you base the whole project, for example once you have explained one mathematical principle and pupils have done a few calculations the teacher could return to the 3D Print and look at another concept and provide a number of exercises for pupils to learn / do and so on.

As a design / engineering teacher I will use the Rocket project as a way to excite pupils; get them to learn how to use 3D Design Software (Sketchup); use as a basis to talk about materials and properties of materials and production processes.

Pilot projects first and gradually build up on them. So for example start by getting pupils to use a 3D Software package. If successful move on to printing . See if pupils respond then set them a homework to explore properties of materials required for Rocket flight. Test the Rockets etc. By starting off with simple and basic projects with different groups it will allow the teacher to assess the feasibility of projects that they would like to teach.

By far the biggest problems will be with the printing out. The main issues are; the time it takes to print out an object and the print going wrong. These have to be managed in such a way so that the prints are not being waited for. By printing over night prints can be completed for the following day. However depending on timetabling there may actually much more time. It’s important to have work held in reserve!

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Good fun
- ✓ Exciting for teacher and pupils alike
- ✓ Covers a wide range of skills.
- ✓ Covers a wide range of STEM subjects
- ✓ Enables a variety of concepts to be introduced to pupils.
- ✓ Provides a wide range of teaching opportunities.
- ✓ Pupils may become inspired.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ Can be time consuming to resource.
- ✓ Can take a lot of time to organise .
- ✓ May prevent the teaching of other aspects of an assessed course.
- ✓ Could go wrong.

RECOMMENDATIONS

The next stage for me will be to develop a range of projects linked to the Rocket Project. One such project which I am considering is a Mars project. This will link up a variety of projects relating to a manned mission to colonise Mars. For example pupils in groups will need to develop and make a Rocket, Base, Transportation Device, Robot arm etc.

2.3 HISTORICAL SITES OF ADANA CITY (SABANCI KIZ TEKNIK VE MESLEK LISESI – Turkey)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) To arouse pupils' interest in and motivation for mathematics

2) To enhance pupil's problem-solving skills in real-world situations

3) To give the pupil the opportunity to appreciate the importance and usefulness of unconventional educational methods such as self-help, learning by doing, induction of personal experiences

SPECIFIC Learning Objectives

1) To equip pupils with basic computer skills for 3d design and printing

2) To strengthen the creativity of the pupils

3) To show to the pupils that mathematics is a down-to-earth science which they can use in their daily lives

How the Learning Objectives have been identified by teachers and why?

Our Ministry of Education has a directive for the contents of compulsory curriculum for 9th and 10th grade classes. The contents include rectangular prism, triangular prism, circumference, parabola, functions, symmetry, semicircles, parabolic curves, truncated pyramids and range measurements. In our conventional activities and carrying out the 3d printing experiments, we planned and executed to follow the contents of the above-mentioned compulsory curriculum.

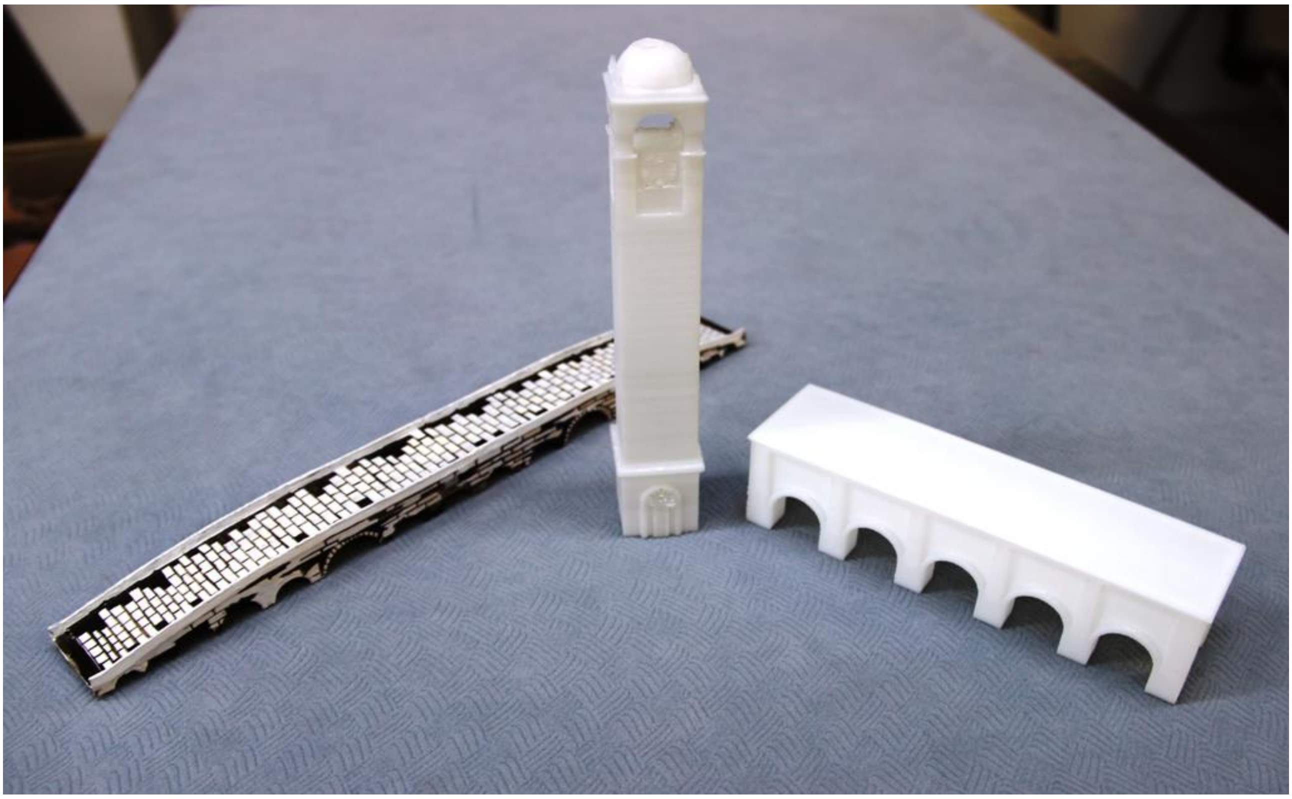
PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing: Three historical sites in our city, more specifically the Roman stone bridge, the Ottoman bazaar, and the clock tower

Why this object?

These objects to be printed induces the pupils to use and enhance their mathematical knowledge as regards to the subject of geometrical objects within the compulsory curriculum.

The topics for this experiment has been chosen in accordance to the curriculum of 9th and 10th grade classes. These topics include rectangular prism, triangular prism, circumference, parabola, functions, symmetry, semicircles, parabolic curves, truncated pyramids and range measurements.



PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ basic computer skills for 3d design and printing
- ✓ mathematical knowledge for measurement, calculation and computing

THE TEACHERS TEAM INVOLVED

5 teachers have been involved in the experimentation:

List each teacher' subject/domaine:

2 teachers of mathematics

2 teacher of art and design

1 teacher of technical/computer support

Rationale of the Teachers Team

2 mathematics teachers were chosen in order to give the pupils the continuous supervision and support for mathematical skills needed for the mathematical modelling phase during which mathematical knowledge for the measurement, calculation and computing of the model is required.

2 art and design teachers and 1 teacher for technical/computer support were chosen in order to help the pupils transfer and use their earlier mathematical modelling data into the computer so that they can 3d-print their models.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:

Number of pupils: 40

Type of group: the combination of art&design and shoe making classes

Number of classes: 2

Scholar curriculum specialisation of the class(es) involved: 2

"Special needs" students: No

Entry level assessment: We used the survey method to see the level of the pupils in 1) motivation and interest, 2) mathematical skills, 3) computer and design skills.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	Geometrical objects
Topics related to the Learning Objectives of experimentation	Measurement, scaling, mathematical modelling
Total number of hours dedicated to completion of the experimentation	9

OTHER RELATED SUBJECT	Sketch-Up Pro
Didactic Topics related to the Learning Objectives of experimentation	Software training for teacher and pupils
Total number of hours dedicated to completion of the experimentation	15

OTHER RELATED SUBJECT	IT

Didactic Topics related to the Learning Objectives of experimentation	Hardware training for teacher and pupils
Total number of hours dedicated to completion of the experimentation	15

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** SketchUp Pro because of its ease to use and free license.

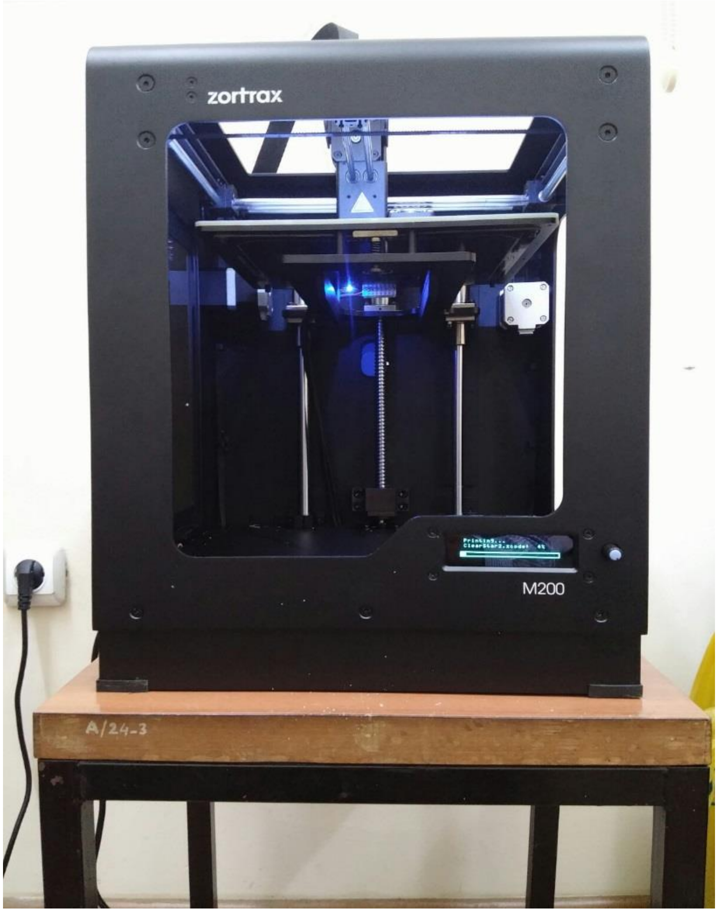
- **SOFTWARE(S) for object PRINTING:** Zotrax Z-Suite. We used this software because it is the software that supports our printer specifications and it has a simple user friendly interface.

- **3D PRINTER:** Zortrax M200, costs about USD 2000

Technical details:

PHYSICAL DIMENSIONS
Without Spool 345 x 360 x 430 mm [13.6 x 14 x 17 in]
With Spool 345 x 430 x 430 mm [13.6 x 17 x 17 in]
Shipping Box 460 x 470 x 570 mm [18 x 18.5 x 22.4 in]
Weight 13 kg [28.7 lbs] Shipping weight 20 kg [44 lbs]
TEMPERATURE Ambient Operation Temperature 15°-35° C [60°-95° F]
Storage Temperature 0°-35° C [32°-95° F]
ELECTRICAL AC input 110/240V ~ 2 A 50/60 Hz
Power requirements 24 V DC @ 11 A Power consumption ~ 190W
Connectivity SD card [included], WiFi*
SOFTWARE
Software bundle Z-Suite®
File types .stl, .obj, .dxf
Supports Mac OS X / Windows XP, Windows Vista, Windows 7, Windows 8
PRINTING
Print technology LPD - Layer Plastic Deposition
Build volume 200 x 200 x 185 mm [7.87 x 7.87 x 7.28 in]
Layer resolution settings Advanced: 25-50* microns [0.000984-0.0019685 in] Standard: 90-400 microns [0.003543-0.015748 in]
Wall thickness Minimal: 400 microns Optimal: 800+ microns
Resolution of single printable point 400+ microns
Filament Diameter 1.75 mm [0.069 in]
Filament Type Z-Filament Series
Nozzle diameter 0.4 mm [0.015 in]
Minimum single positioning 1.5 microns Positioning precision X/Y 1.5 microns Z single step 1.25 microns
Extruder maximum temperature 380° C [716° F]

Heated platform maximum temperature 110° C [230° F]



IMPORTANT: Time necessary to print 1 (object of the experimentation) with this 3D printer is 16 hours

- **PLASTIC MATERIAL:** Filament Z-ABS, 50 euros average cost, to be bought via websites of zortrax,3bfab, alibaba

Technical details of the filament:

Type	Spool
Dedicated to	Zortrax M200
Technology	LPD
Hardware requirements	No
Surface	Mat
Hardness	Medium
Elasticity	Medium
Impact strength	Medium

Tensile strength	Low
Shrinkage	Medium
Mechanical treatment	Yes
Chemical treatment	Yes
Weight	800 g (1.76 lb) net. wt. (+/- 3%)

IMPORTANT: Quantity of this material necessary to print 1 (object of the experimentation) is: depends on the type of inside filling of the object, our average during experiments is 20 m per object

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

(List the actions you carried out, on logical-temporal sequence)

1° - Definition of Learning Objectives and object to be printed

Number of hours dedicated: 10

People involved: Mathematics and art & design teachers and printer technician

2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved

Number of hours dedicated: 8

People involved: Mathematics and art & design teachers

3° - Entry level assessment

Number of hours dedicated: 8

People involved: Mathematics and art & design teachers, pupils

4° - Training Unit on Mathematical/Geometrical Subject:

Number of hours dedicated: 40

People involved: Mathematics and art & design teachers, pupils

Didactic methodology used to teach the contents: front lesson, pupils self-study, laboratory work, group work, conventional teaching methodology in the classroom

5° - Training Unit on Software Training Subject:

Number of hours dedicated: 15

People involved: Mathematics and art&design teachers, printer technician, pupils

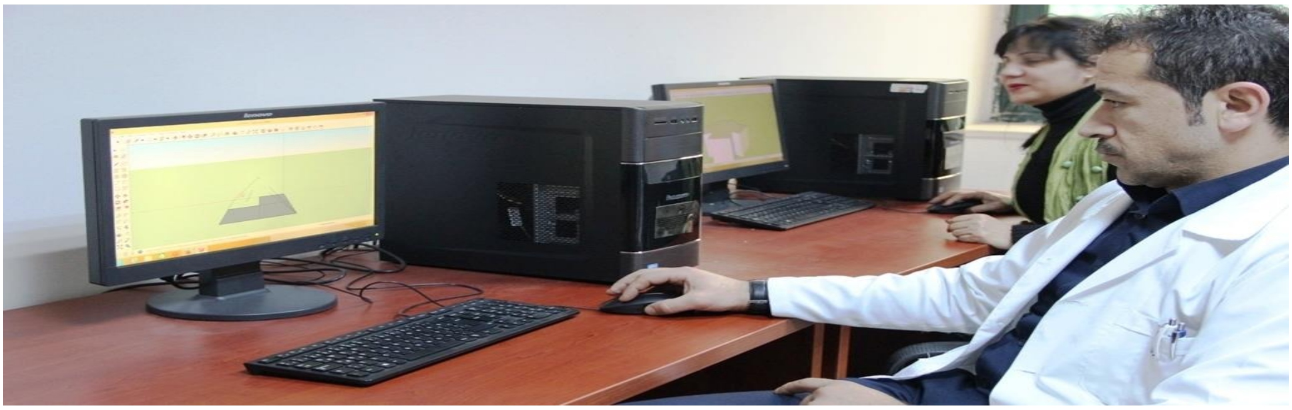
Didactic methodology used to teach the contents: front lesson, pupils self-study, laboratory work, group work

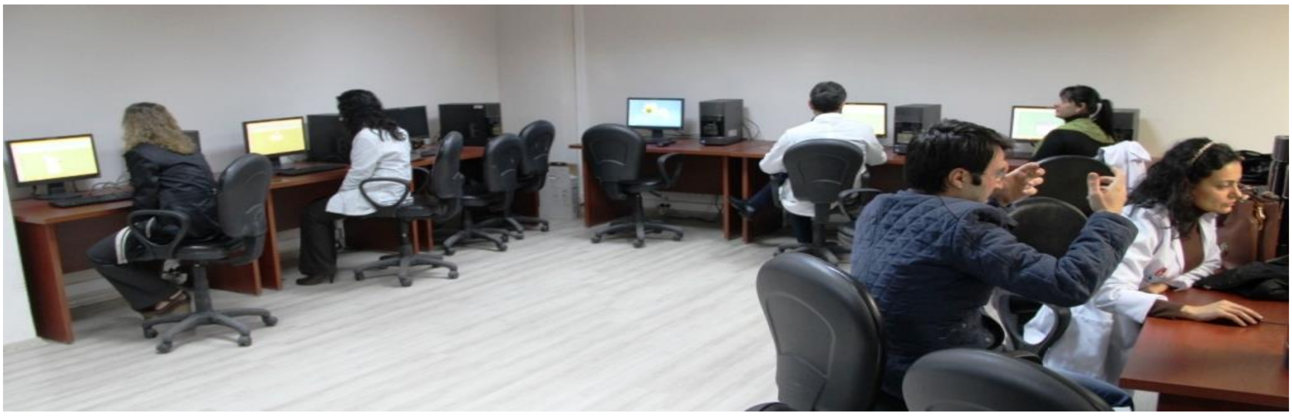
6° - CAD Design of the object:

Number of hours dedicated: 6

People involved: Mathematics and art&design teachers, printer technician, pupils

Didactic methodology used: describe what you did, how and why (front lesson, pupils self-study,…, laboratory work, group work…) front lesson, laboratory work, group work





<u>7° - Transfer of the object designed to 3D printing software:</u>

Number of hours dedicated: 7

People involved: Mathematics and art&design teachers, printer technician, pupils

Didactic methodology used: laboratory work, group work

<u>8° - Object printing:</u>

Number of hours dedicated: 7+6

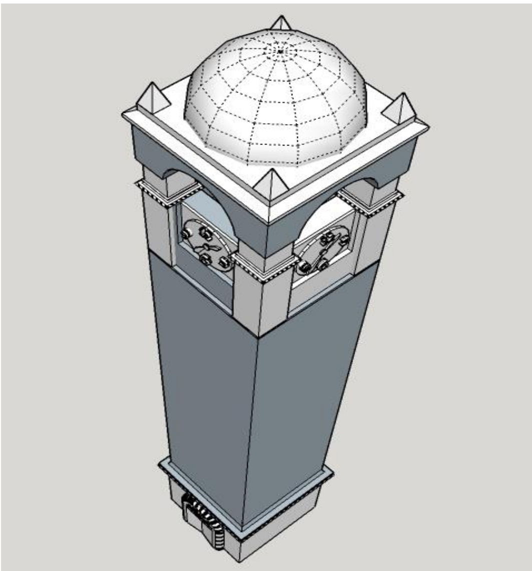
People involved: Mathematics and art&design teachers, printer technician, pupils

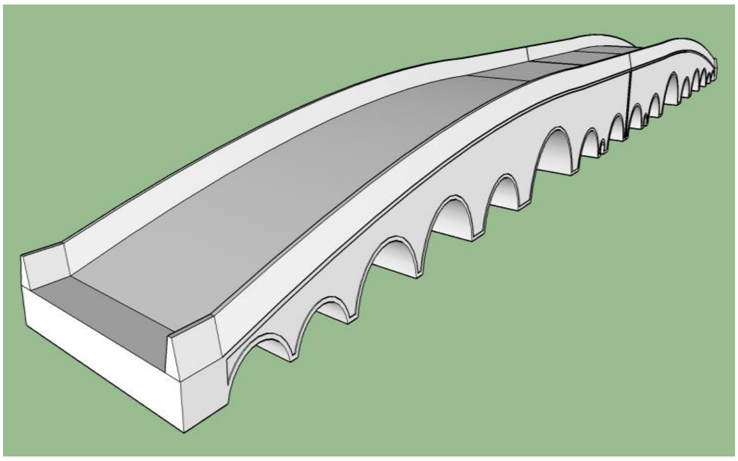
Didactic methodology used:

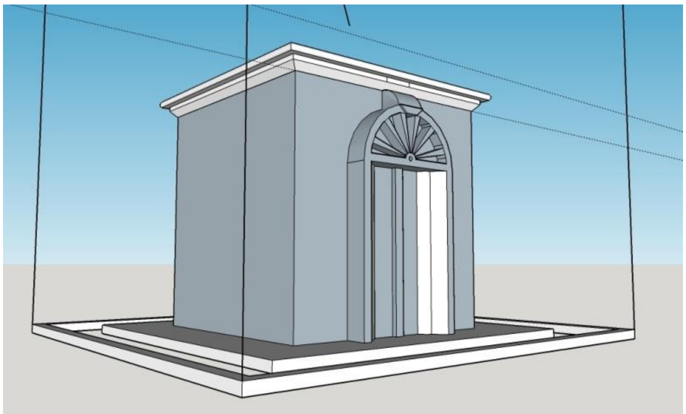
For the successful implementation of the experiment a series of actions were carried out:

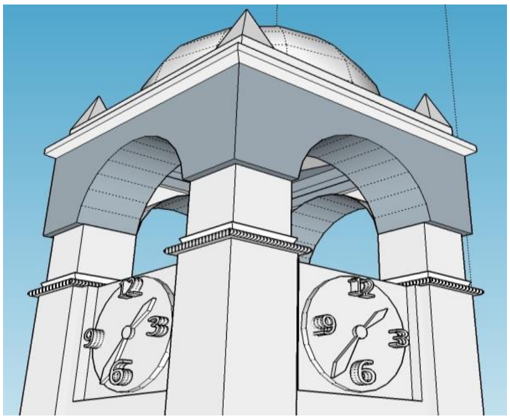
1. Distribution of tasks among pupils
2. Visiting the sites planned to be designed
3. Making research and collecting data about the structures to be modelled
4. Mathematical computing
5. Modelling the objects on the computer

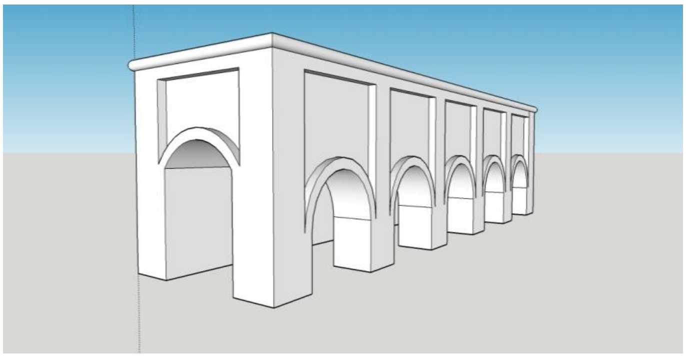
6. Sending the objects to the 3d printer











9° - End of experimentation

Number of hours dedicated: 8

People involved: Mathematics and art & design teachers, pupils

Didactic methodology used: Once the objects were printed collectively, teachers and pupils gathered in the laboratory to discuss the results.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main mathematical subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of

1) written exam

2) analysis of the objects printed

Direct observation on pupils - made by each member of the Teachers Team during the experimentations - enabled to record to the following further learning and/or "transversal" results:

1) enthusiasm due to their creative desires

2) motivation due to their direct involvement in the process

3) comparing and learning

LESSONS LEARNT

- ✓ It always takes more time than planned to execute an experiment
- ✓ Always start with the smallest and smaller piece(s) of the object to be printed
- ✓ Getting familiar with the handware and software aspects of the 3d printing demands professional assistance

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ More tangible, less abstract aspects of mathematics
- ✓ Learning by doing

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ A certain level of computer literacy required
- ✓ High skills for computer-based graphical design

RECOMMENDATIONS

- ✓ Choose well your technician
- ✓ Have a group cohesion among the group of pupils involved
- ✓ Teachers to be involved must be enthusiastic about the 3d printing (there is negative correlation between age & seniority and enthusiasm for newer teaching methods)
- ✓ Make a good survey of the pupils from the start of the experiments, but be careful not to count anybody out without due examination (a seemingly undiligent pupil could come eventually out as the brightest and most creative one in the group)

2.4 SAMPLES OF GEOMETRICAL SOLID OBJECTS (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) Face the main critical tasks.

2) Respect the priorities of Mathematics.

3) Insert mathematics in a multidisciplinary context.

4) Increase the interest and the participation of low level pupils.

SPECIFIC Learning Objectives

1) Angular measurements.

2) Area and volume calculation.

3) Geometric reasoning about the working principles of a device.

4) Connection between geometric characteristics and biology.

How the Learning Objectives have been identified by teachers and why?

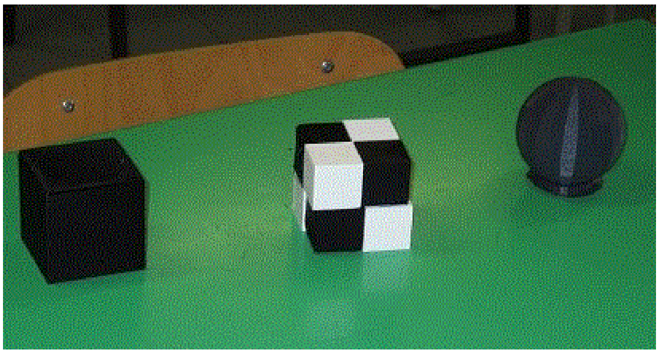
In each class the teachers identified the learning objectives to respect the scholar curriculum according to the period of carrying out the experimentation, in order to fully integrate the exercise within the scholar year.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing many samples of geometrical solid objects progressively halved.

Why this objects?

The Biology teacher had to explain an important law of nature, the students seem not to understand it in an appropriate way. She asked the help of her math colleague so…
The objects enable pupils to realize the relevance to keep the S/V ratio within fixed limit is in order to have cellular shapes apt to life.



PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ Functions.
- ✓ Measurements.
- ✓ 3D basic Geometry.
- ✓ Biological context (shape and size of cells).
- ✓ Basic computer knowledge and competences.
- ✓ Basic knowledge and competences in technical drawing (achieved with the kind help of some pupils of the current third class M.A.T.).

THE TEACHERS TEAM INVOLVED

Two teachers have been involved in the experimentation:

List each teacher' subject:

1 teacher of **Mathematics**.

1 teacher of **Science**.

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I04 implementation and they expressed their interest.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:

Number of pupils: 12

Type of group: single class.

Number of classes: 1

Scholar curriculum specialization of the class involved: Accounting, Bookkeeping and Marketing.

"Special needs" students:

2 Pupils. Everyone took part to the job on the basis of their own capabilities.

Entry level assessment: Standard tests.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	Mathematics
Topics related to the Learning Objectives of experimentation	✓ Functions (graph, behaviour...). ✓ Measurements (area, volume). ✓ 3D basic Geometry (polyhedrons). ✓ Basic computer knowledge and competences (Excel). ✓ Basic knowledge and competences in technical drawing (Sketchup).
Total number of hours dedicated to completion of the experimentation	16

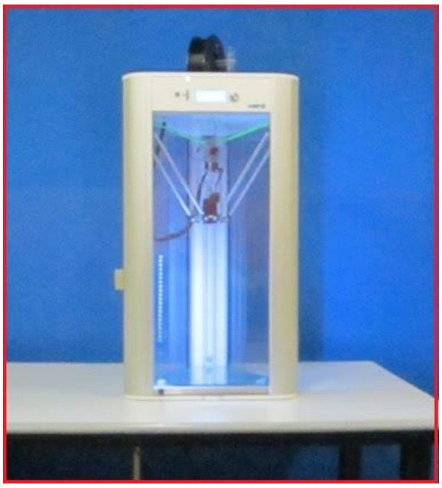
OTHER RELATED SUBJECT	Science
Didactic Topics related to the Learning Objectives of experimentation	✓ Basic principles of cellular metabolism. ✓ Basic elements of the structure of a cell. ✓ Eukaryote and prokaryote cells. ✓ Shape and size of cells.
Total number of hours dedicated to completion of the experimentation	10

II) PRINT STEM LAB: THE TECHNOLOGIES

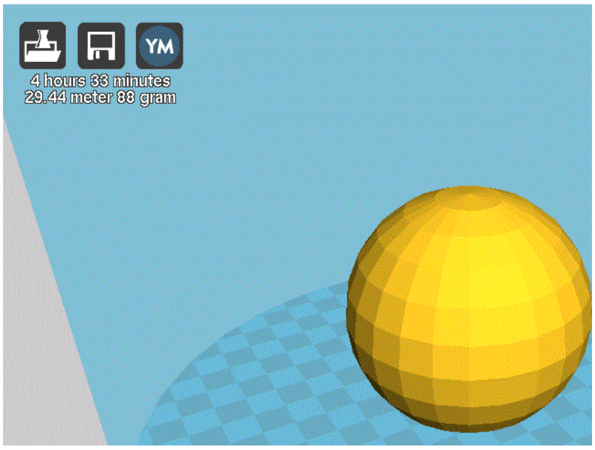
- **SOFTWARE for object DESIGN:** SKETCHUP.
  Easy to use, open source, see tutorials in http://www.architectionary.com/SketchupTutorials

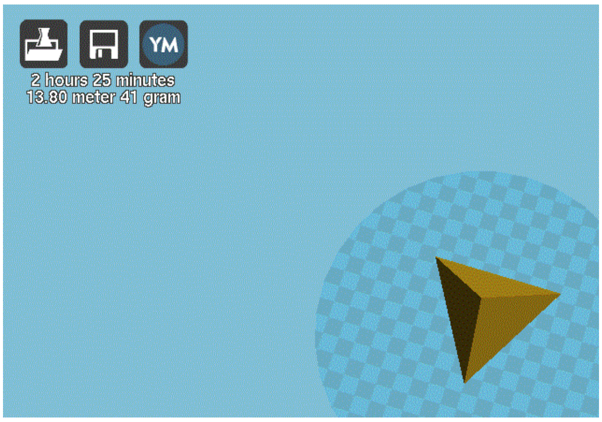
- **SOFTWARE for object PRINTING:** CURA
  Easy to use, open source, see tutorials in https://www.youtube.com/watch?v=biCWssfil2A

- **3D PRINTER:** WASP



IMPORTANT: Time necessary to print: Different sizes, different times. On average 2 hours each





- **PLASTIC MATERIAL:** PLA

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

<u>1° - Definition of Learning Objectives and object to be printed</u>

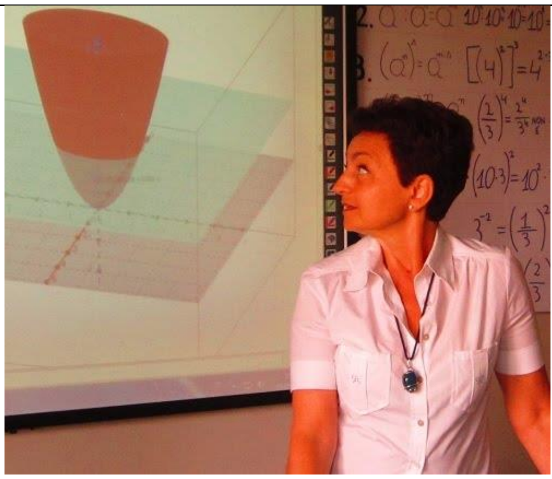
Number of hours dedicated: 1

People involved: 2 Teachers.

<u>2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved</u>

Number of hours dedicated: 1

2 Teachers.

 Prof. M Bertocchi - Mathematics	 Prof. R. Bazzani - Science

<u>3° - Entry level assessment</u>

Number of hours dedicated: 1

2 Teachers.

<u>4° - Training Unit on Mathematics</u>

Number of hours dedicated: 8

People involved: Mathematics teacher.

Didactic methodology used to teach the contents:

- Frontal lesson.
- Pupils self-study.
- Laboratory work.
- Group work.

5° - Training Unit on Science:

Number of hours dedicated: 4

People involved: Science teacher.

Didactic methodology used to teach the contents:

- Frontal lesson.
- Pupils self-study.
- Laboratory work.

6° - CAD Design of the object:

Number of hours dedicated: 6

People involved: mathematics and science teachers with the help of elder students.

Didactic methodology used: The curriculum of this class doesn't include any graphics subject. The 3D drawing and further printing have been achieved thanks to the kind help of some elder pupils who, at the beginning phases of the PRINTSTEM project, successfully experimented the 3D printing techniques, becoming today a valid aid for the team.

Students

Elder students

See also: https://sites.google.com/a/fr.itsosgadda.it/print-stem/experimentations/2-c

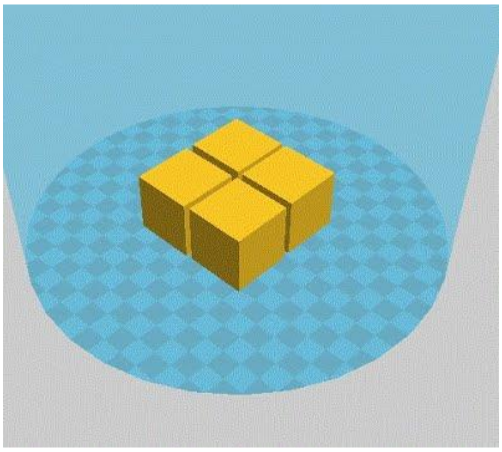
7° - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 1

People involved: Coordinator of the project + teachers involved.

Didactic methodology used:

The students were informed about the main line of the setting of the files with slicer.



8° - Object printing:

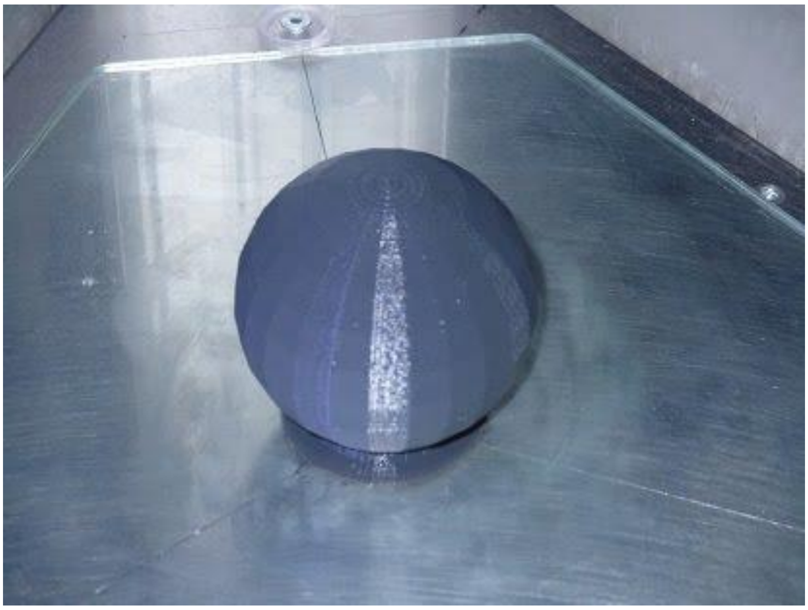
Number of hours dedicated: 1

People involved: Coordinator of the project + teachers involved.

Didactic methodology used:

The students were informed about the main technical characteristics of the 3Dprinter.

They attended the beginning of the 3D printing.



9° - End of experimentation

Number of hours dedicated: 3

People involved: 2 teachers involved.

Didactic methodology used:

Pupils completed the experimentation with an accurate theoretical-practical analysis of the topic.

A final test has been submitted to pupils.

See also: https://sites.google.com/a/fr.itsosgadda.it/print-stem/experimentations/2-c

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main mathematical subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of a suitable written test and recorded the following learning results:

1) Better degree of competence in comparing geometrical objects with the calculation of surface and volume of spheres and cubes and their ratio.

2) Better degree of competence in evaluating dynamic variables and their behaviour by means of a graph.

3) Competence in applying mathematical topics to natural objects.

Direct observation on pupils - made by each member of the Teachers Team during the experimentations - enabled to record to the following further learning and/or "transversal" results:

1) Improve the approach to mathematical sciences.

2) Ability to deal with different subjects in a "multidisciplinary approach".

3) Ability to use the software "sketch up" for geometry .

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation.
- ✓ Learning of new software and technical devices.
- ✓ The 3D-printer allowed the realization of theoretical concepts.
- ✓ Use of scientific English.
- ✓ Multidisciplinary approach.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ The presence of only one 3D-printer with the high number of pupils involved extended the execution time.

RECOMMENDATIONS

- ✓ The 3d printer is going to be a new didactical tool but it isn't a new distinct subject.
- ✓ During a class council, the teachers of the team decide how to organize the activity.
- ✓ The teachers choose the topic in accordance with the ordinary didactic planning of the class.

- ✓ Plan with care the phases of the activity in order to avoid waste of time.
- ✓ A general information about the 3D printer technology has to be given to the teachers of the team.
- ✓ Each teacher of the team collaborates in different way, in accordance with his cultural background.
- ✓ Few teachers of the team should be specialized in dealing with the 3Dprinter.
- ✓ The students can be at the beginning interested about the operation of the machine, but not for a long time.
- ✓ The printing can be noisy, put the 3D printer in an appropriate room.
- ✓ Programme the slicer accurately, in order to avoid waste of material.
- ✓ Keep the 3D printer tidy .
- ✓ Carry out a frequent level setting of the machine, having pre-heated the bed.

2.5 MECHANICAL TRISECTOR (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) Face the main critical tasks.

2) Respect the priorities of Mathematics.

3) Insert mathematics in a multidisciplinary context.

4) Increase the interest and the participation of low level pupils.

SPECIFIC Learning Objectives

1) Angular measurements.

2) Area and volume calculation.

3) Geometric reasoning about the working principles of a device.

4) Connection between geometric characteristics and biology.

How the Learning Objectives have been identified by teachers and why?

In each class the teachers identified the learning objectives to respect the scholar curriculum according to the period of carrying out the experimentation, in order to fully integrate the exercise within the scholar year.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a mechanical trisector.

Why this objects?

The mathematics teacher faced the angle measurement and the congruence theorems.
The operating principles of the instruments seemed suitable to be treated with those concepts.

A convex angle divided in three congruent parts.

A concave angle divided in three congruent parts.

PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ Angle measurements.
- ✓ Basic Rational Geometry .
- ✓ 3D basic Geometry.
- ✓ Basic computer knowledge and competences.
- ✓ Basic knowledge and competences in technical drawing.

THE TEACHERS TEAM INVOLVED

Two teachers have been involved in the experimentation:

List each teacher' subject:

1 teacher of **Mathematics**.

1 teacher of **Graphics**.

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I04 implementation and they expressed their interest.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:

Number of pupils: 19

Type of group: single class.

Number of classes: 1

Scholar curriculum specialization of the class involved: Maintenance and Technical Assistance.

"Special needs" students: none.

Entry level assessment: Standard tests.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	**Mathematics**
Topics related to the Learning Objectives of experimentation	✓ Angle measurements (use of the protractor). ✓ Basic Rational Geometry (congruence theorems). ✓ 3D basic Geometry. ✓ Basic computer knowledge and competences. ✓ Basic knowledge and competences in technical drawing (Sketchup).
Total number of hours dedicated to completion of the experimentation	18

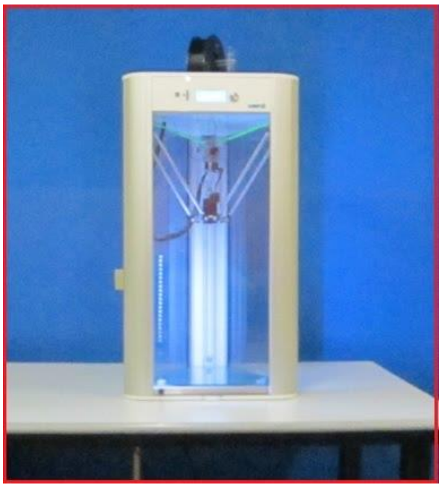
OTHER RELATED SUBJECT	**Graphics**
Didactic Topics related to the Learning Objectives of experimentation	✓ Represent three-dimensional objects. ✓ Read and interpret graphs in orthogonal projection. ✓ 3D basic Geometry. ✓ Basic computer knowledge and competences. ✓ Basic knowledge and competences in technical drawing (Sketchup).
Total number of hours dedicated to completion of the experimentation	10

II) PRINT STEM LAB: THE TECHNOLOGIES

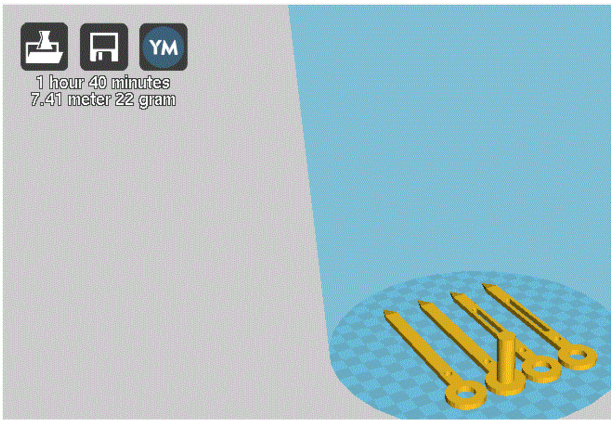
- **SOFTWARE for object DESIGN:** SKETCHUP.
  Easy to use, open source, see tutorials in http://www.architectionary.com/SketchupTutorials

- **SOFTWARE for object PRINTING:** CURA
  Easy to use, open source, see tutorials in https://www.youtube.com/watch?v=biCWssfil2A

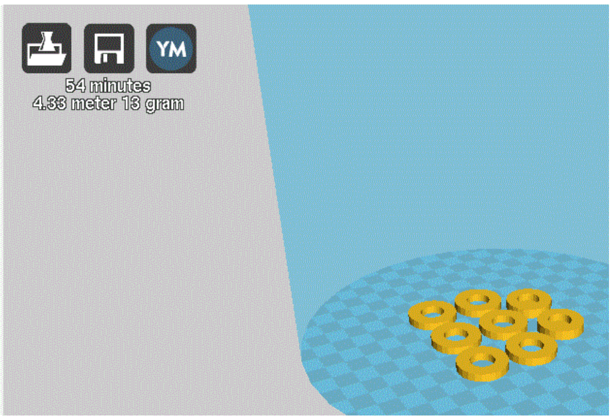
- **3D PRINTER:** WASP



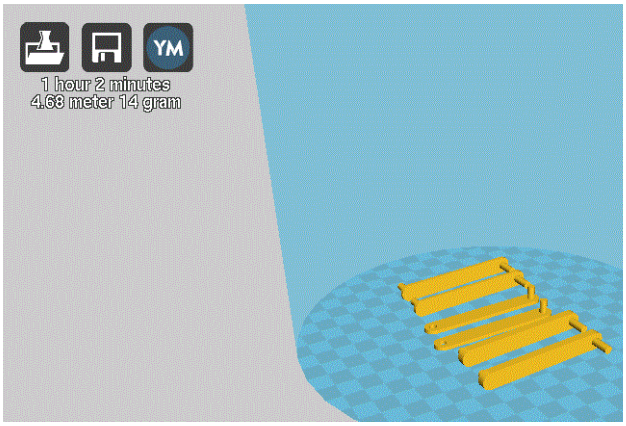
IMPORTANT: Time necessary to print. Different parts, different times.



Rays.



Washers.



Sliding shafts

PLASTIC MATERIAL: PLA

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

1° - Definition of Learning Objectives and object to be printed

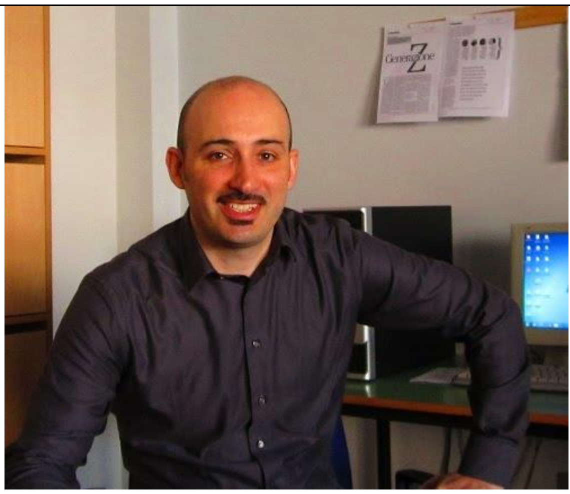
Number of hours dedicated: 1

People involved: 2 Teachers.

2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved

Number of hours dedicated: 1

<table>
<tr><td>2 Teachers.

Prof. L. Amadasi - Mathematics</td><td>
Prof. V. Mangione - Graphics</td></tr>
</table>

3° - Entry level assessment

Number of hours dedicated: 1

2 Teachers.

4° - Training Unit on Mathematics

Number of hours dedicated: 10

People involved: Mathematics teacher.

Didactic methodology used to teach the contents:

- Frontal lesson.
- Pupils self-study.
- Creation of a set of forms that the pupils had to fill in.
  This led them to demonstrate the working principles of the device working in group.
- Laboratory work.

5° - Training Unit on Graphics:

Number of hours dedicated: 4

People involved: Graphics teacher.

Didactic methodology used to teach the contents:

- Frontal lesson.
- Pupils self-study.
- Laboratory work.

6° - CAD Design of the object:

Number of hours dedicated: 8

People involved: mathematics and Graphics teachers with the help of elder students.

Students

Elder students helping.

A practical definition of congruence.

Making use of a Compass, draw the triangle ABC, with $AB = 16cm$, $BC = 10cm$ and $AC = 16cm$.
Compare your triangle with your friends' one. You can do it by superimposing the sheets in front of a source of light.
If all the measurements are correct, the triangles perfectly coincide. If two figures exactly coincide, they are said *congruent.*
We have so checked the third congruence theorem, that says: *If two triangles have congruent the three sides, then the triangles are congruent.*

A form.

See also: https://sites.google.com/a/fr.itsosgadda.it/print-stem/experimentations/2-d

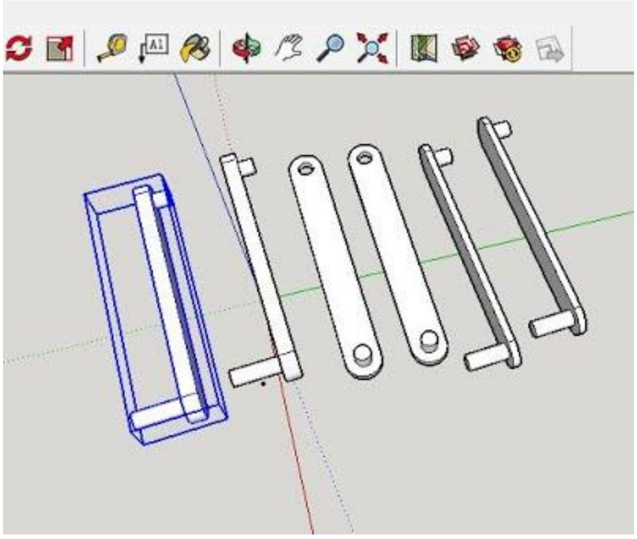
7° - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 1

People involved: Coordinator of the project + teachers involved.

Didactic methodology used:

The students were informed about the main line of the setting of the files with slicer.



A .skp file ready to be exported.

8° - Object printing:

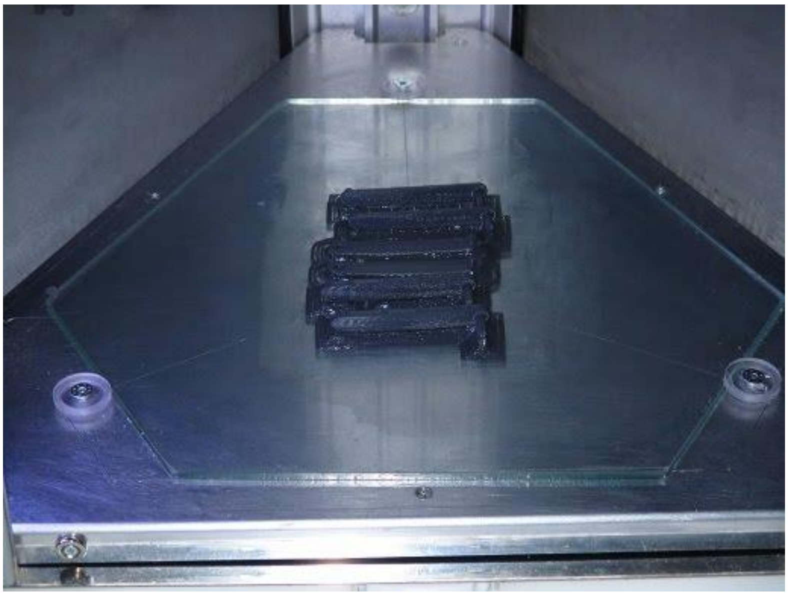
Number of hours dedicated: 1

People involved: Coordinator of the project + teachers involved.

Didactic methodology used:

The students were informed about the main technical characteristics of the 3Dprinter.

They could attend to the beginning of the 3D printing.



<u>9° - End of experimentation</u>

Number of hours dedicated: 3

People involved: 2 teachers involved.

Didactic methodology used:

Pupils completed the experimentation with an accurate theoretical-practical analysis of the topic.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main mathematical subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of standard tests (Oral exam, group evaluation, evaluation of the set of forms).

1) Increasing of interest for a traditionally unloved topic.

2) Increasing of ability in angle measurements and in geometric draw.

3) Persistent difficulty in facing theoretical aspect of the topic.

3) Interest on CAD design.

Direct observation on pupils - made by each member of the Teachers Team during the experimentation - enabled to record to the following further learning and/or "transversal" results:

1) Increasing of the capability of work in group in a difficult class.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ The basic practice of measuring angles is carried out.
- ✓ High level students can find an effective practical application of abstract concepts.
- ✓ The use of a simple CAD software as Sketchup can lead some enthusiastic pupils to face successfully more complex CAD software.
- ✓ The charm of the new device can increase the attention of a chaotic class.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ The assembly of the instrument is quite difficult: were needed several attempts.
- ✓ The subject doesn't fit low level students.
- ✓ The bureaucratic aspect of the experimentation: too repetitive.

RECOMMENDATIONS

- ✓ The 3d printer is going to be a new didactical tool but it isn't a new distinct subject.
- ✓ During a class council, the teachers of the team decide how to organize the activity.
- ✓ The teachers choose the topic in accordance with the ordinary didactic planning of the class.
- ✓ Plan with care the phases of the activity in order to avoid waste of time.
- ✓ A general information about the 3D printer technology has to be given to the teachers of the team.
- ✓ Each teacher of the team collaborates in different way, in accordance with his cultural background.
- ✓ Few teachers of the team should be specialized in dealing with the 3Dprinter.

- ✓ The students can be at the beginning interested about the operation of the machine, but not for a long time.
- ✓ The printing can be noisy, put the 3D printer in an appropriate room.
- ✓ Programme the slicer accurately, in order to avoid waste of material.
- ✓ Keep the 3D printer tidy .
- ✓ Carry out a frequent level setting of the machine, having pre-heated the bed.

2.6 GOLDEN SPIRAL (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) construction of geometric shapes either by using compass and pencil or by Autocad

2)to calculate perimeters and area of geometric shapes

3) to work with ratios and proportions

4) to work with unlimited aperiodic decimal numbers (irrational)

5) to work with Pitagora's theorem

SPECIFIC Learning Objectives

1)to work with gold ratio

2)definition of Fibonacci sequence

3) to follow iterative procedures

4)construction of Gold rectangle

5) construction of gold spiral

8) to work with arch of a circumferences

9) to find the Fibonacci sequence in gold spiral

How the Learning Objectives have been identified by teachers and why?

This topic allows to face various learning objects, mixing both geometric and algebraic approach. There are important concepts , difficult to learn : ratios, proportions, iterative procedures, irrational numbers, Pitagora's theorem.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing : gold spiral on a little thick rectangular base, a 3D shape that has gold rectangles as bases and height that increases accordingly to Fibonacci sequence.

Why this object?

The object would enable pupils to:

1. Verify the approximate value of the gold ratio by directly measuring the length of the sides of the gold rectangles;
2. Find that the length of the rectangle's sides are in the Fibonacci relation, i.e. each side is the sum of the previous two;
3. Combine the abstract approach (that uses numbers and letters, calculus with polynomials) with the experimental one, thanks to real objects in their hands;
4. Compare the abstract iterative procedures with the real touchable construction.

PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ Basic knowledge in 2D geometry: polygons, circles, circumference, Pitagora's theorem;
- ✓ Q set: operate with fractions and decimal numbers;
- ✓ Operate with polynomials;
- ✓ Basic CAD-skills.

THE TEACHERS TEAM INVOLVED

Five teachers have been involved in the experimentation:

List each teacher' subject/domaine:

1 teacher of Computer graphics (CAD);

1 teacher of 3D printing

2 teachers of Math

1 support teacher

Rationale of the Teachers Team

The teachers involved in the team were chosen because :

One teacher of Computer graphings (CAD) to draw objects by CAD;

One teacher of 3D printing to help pupils in printing objects;

Two teachers of math, for each one of the two classes 2 A and 2B, for training unit;

One support teacher for special needs students.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:

Number of pupils: 40 (24+16)

Type of group: Students worked in intra-class groups composed by 3-4 members.

Number of classes: 2

Scholar curriculum specialisation of the class(es) involved:2 A: Computer science; 2 B: Computer science and AFM

“Special needs” students: dyslexic and dyscalculic students, students that follows a specific plan because of cognitive diseases

Entry level assessment: One preliminary test was given in order to test pupils basic knowledge about geometry and rational numbers. The test was submitted in electronic format and the results show that the entry level was sufficient on average for both classes.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

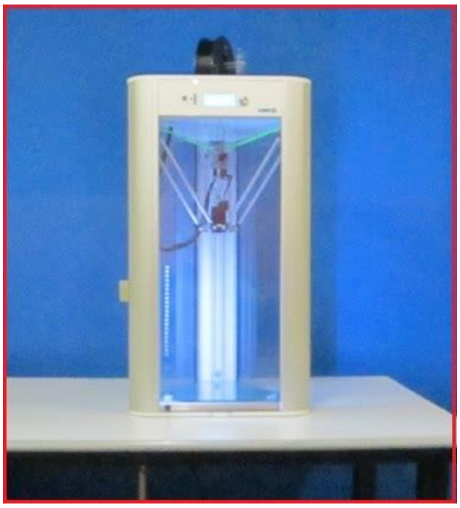
(

MAIN MATHEMATICAL SUBJECT	Gold shapes : gold ratio, gold rectangle, gold spiral
Topics related to the Learning Objectives of experimentation	1)Working with segments, proportions, ratios 2)Working with geometric constructions , polygons, circumference, Pitagora's theorem, ratios 3)Working with iterative procedures, geometric constructions, circumference, ratios.
Total number of hours dedicated to completion of the experimentation	6

OTHER RELATED SUBJECT	Computer graphics
Didactic Topics related to the Learning Objectives of experimentation	CAD design of the object
Total number of hours dedicated to completion of the experimentation	3

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** CAD, the most used for 2D and 3D graphic design
- **SOFTWARE(S) for object PRINTING:** CURA, very easy to use, open source. Link to tutorial: https://www.youtube.com/watch?v=biCWssfil2A
- **3D PRINTER:** COBOT and WASP DELTA 2040. COBOT is built up by former students of the school and is made mainly of stainless steel.



First REPRAP printer commericlized in Italy, sold online (www.wasproject.it) and cost near to € 3.000,00

- **PLASTIC MATERIAL:** PLA 1,75 mm diameter
  Cost vary in a wide range (from 20 to 40 euros/kg);

  - For Italian school only: look at MEPA market
  - For all the other people:
    Take a look on EBAY.COM, AMAZON.COM
    Suggested site for price and good quality filament (PLA) : www.marwiol.pl

IMPORTANT: Quantity of this material necessary to print 1 (object of the experimentation) is:

Tablet: 26 m ; 77 g PLA; 5 hours (0,2; 0,8; 0,8; 30; 60)
3D: 55 m; 163 g PLA; 10 hours 47 min.

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

1° - Definition of Learning Objectives and object to be printed

Number of hours dedicated: 4

People involved:2

2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved

Number of hours dedicated:1

People involved:5

3° - Entry level assessment

Number of hours dedicated:2

People involved:3

4° - Training Unit on Math Subject:

Number of hours dedicated:6

People involved:3

Didactic methodology used to teach the contents: front lesson (less) and group work (more)

5° - CAD Design of the object:

Number of hours dedicated:

People involved:

Didactic methodology used: front lesson, laboratory work, group work

6° - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 4

People involved: 3DPrint teacher + Special needs Teacher

Didactic methodology used: laboratory work, group work

7° - Object printing:

Number of hours dedicated: 4

People involved: 3DPrint teacher + Special needs Teacher

Didactic methodology used: printing in small groups and direct observation

8° - End of experimentation

Number of hours dedicated:2

People involved: 2

Didactic methodology used: class reasoning and final test and evaluation

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main mathematical subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of ad hoc written exam and recorded the following learning results:

The students were all stimulated to work and be active during group-activity. They work together to find the answers. The printed objects allowed to think about real shapes, providing them a tangible proof of what they had drawn.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Cooperative learning during group activity;
- ✓ More than one subject involved in the same unit;
- ✓ Mixture between abstract and experimental approach.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ Lack of time.

2.7 GEAR WHEEL (IISS A.BERENINI – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

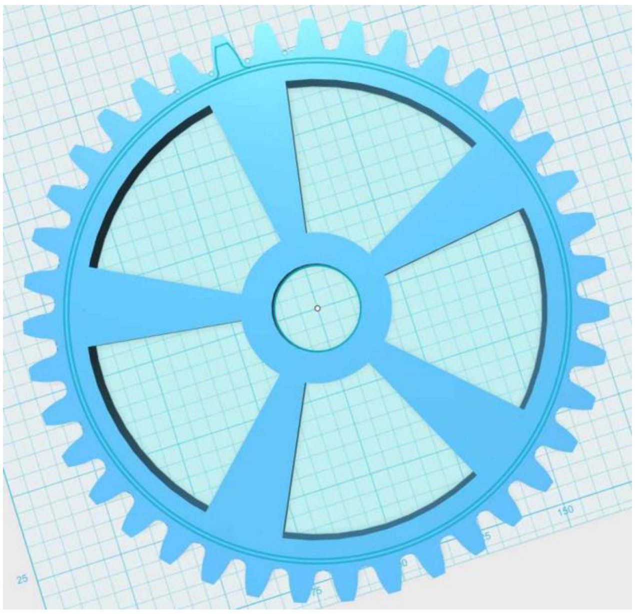
GENERAL Learning Objectives
1) Improving the learning of students at risk of dropping.
2) Improve the ability to work in teams.
3) Get used to working in "solving problems".
4) Improve skills in digital technologies.
5) Learn some of the practical aspects of mathematics.

SPECIFIC Learning Objectives
1) Circumference and circle property
2) Goniometry
3) Able to draw and recognizes complex solids.
4) Be able to draw and print 3D solids.

How the Learning Objectives have been identified and why?
The correct design of a gear requires to project a clear "tooth", in order that the mechanical motion transmission would be efficient, with constant torque.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a GEARWHEEL.



Why this object?

Students studying mechanical normally use CAD drawing. Plan and design parts to be produced is an integral part of their course work. These are traditional topics of Mechanics.

PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ CAD2D use

THE TEACHERS TEAM INVOLVED

4 teachers have been involved in the experimentation:

List each teacher' subject/domaine:
1 teacher of Maths
1 teacher of Physics
2 teacher of Technical drawing
1 teacher of Applied sciences

Rationale of the Teachers Team
The skills needed to work in a laboratory Print Stem necessarily require the participation of more subjects. In addition to Mathematics, Physics and Applied Sciences they have treated the dynamic aspects and Technical Drawing provided support for 3D design.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:
Number of pupils: 22
Type of group: single class
Number of classes: 1
Scholar curriculum specialization of the class(es) involved: Mechanics
"Special needs" students: no
Entry level assessment: written test.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

MAIN STEM SUBJECT	MATHS

Topics related to the Learning Objectives of experimentation	Circumference and circle: central angles, peripherical angles and their relations; sector of a circle; external , secant and tangent straight lines and tangents' properties; external, concentric, secant and tangent circumferences; circular ring. 2. Goniometry: sinus, cosinus and tangent and their value in special angles; study of right-angle triangles through goniometry.
Total number of hours dedicated to completion of the experimentation	10 hours theory in the classroom 1 hour verification 2 hours computer lab

OTHER RELATED SUBJECT	PHYSICS
Didactic Topics related to the Learning Objectives of experimentation	1. Circular motion; 2. Second principle of dynamics; 3. Machine's work an power.
Total number of hours dedicated to completion of the experimentation	9 hours of theory in the classroom 1 hour verification

OTHER RELATED SUBJECT	TECHNICAL DESIGN
Didactic Topics related to the Learning Objectives of experimentation	1. Basic knowledge about Inventor software; 2. 2D cogged wheel drawing; 3. Extrusioning and printing of the 3D cogged wheel.
Total number of hours dedicated to completion of the experimentation	6 hours theory in the classroom 12 hours computer lab

OTHER RELATED SUBJECT	APPLIED SCIENCES
Didactic Topics related to the Learning Objectives of experimentation	1 Straight teeth cogged wheel, movement transmission, gear train; 2. Evolvent cogged wheel side-view drawing; 3. 3D print of the gear.
Total number of hours dedicated to completion of the experimentation	9 hours theory in the classroom 6 hours to file and print 3D conversion

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** Autocad 2D – 3D
- **SOFTWARE(S) for object PRINTING:** CURA 14.12.1 (ultimaker.com). It is a free program and does not require a PC with special resources.
- **3D PRINTER:** Delta WASP 20x40 printer (www.wasproject.it)

INFORMATION ON 3D PRINTING
Technologies: fused filament fabrication
Cylindrical Print Area: Ø 200 mm – 400 mm h
Max Print weight: 442 mm
Nozzle diameter: 0.4 mm/changeable nozzle

Print resolution: 0.05 mm < 0.25 mm
Accuracy X, Y 0.012 mm / 0.005 mm Z axis
Maximum speed: 300 mm / s

€2.370,00(VAT excluded)

- **PLASTIC MATERIAL:** PLA (affordable to wasproject)

Filament diameter: 1.75 mm / 3.00 mm*
Filaments used: ABS,PLA, PET, Nylon, Flex, Polystyrene, Laywood, Experimenta
IMPORTANT: Time necessary to print 1 (floating raft) with this 3D printer is about 1-2 hour
IMPORTANT: Quantity of this material necessary to print 1 floating draft is: 5 meters, 15 grams.

€20,00 (VAT ecluded) (1Kg)

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

1° - Definition of Learning Objectives and object to be printed
Number of hours dedicated: 3 for teacher.
People involved: involved teachers and students

2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved
Number of hours dedicated: 2 for teacher.
People involved: teachers of the various projects and school administrator

3° - Entry level assessment
Number of hours dedicated: 1 for STEM teacher
People involved: students and STEM teachers

4° - Training Unit on Maths Subject:
Number of hours dedicated: 10
People involved: maths teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work

5° - Training Unit on Physics Subject:
Number of hours dedicated: 9
People involved: physics teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work.

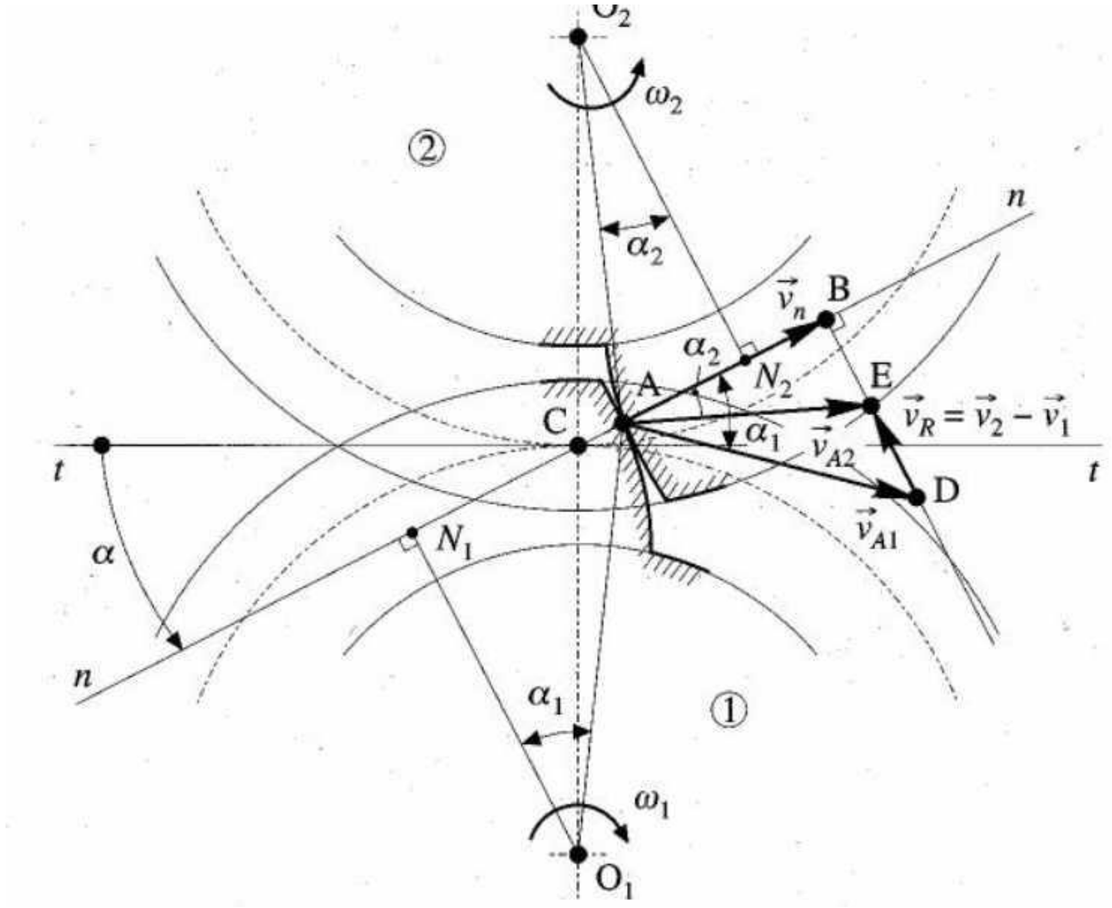
6° - Training Unit on Applied Sciences Subject:
Number of hours dedicated: 9
People involved: applied sciences teacher
Didactic methodology used to teach the contents: front lesson and group work.

7° - Training Unit on Technical Design Subject:
Number of hours dedicated: 6
People involved: drawing teacher
Didactic methodology used to teach the contents: front lesson and group work.

8° - CAD Design of the object:
Number of hours dedicated:12
People involved: drawing teacher
Didactic methodology used: laboratory work and group work.

9° - Transfer of the object designed to 3D printing software:
Number of hours dedicated: 2
People involved: teacher of applied sciences
Didactic methodology used: laboratory work.

°**9 - Object printing:**
Number of hours dedicated: 6
People involved: teacher of applied sciences
Didactic methodology used: laboratory work.



TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

Mathematics teachers have carried out two assessments, one just finished the theoretical modules and another after the trial. Below the results of evaluations.

Marks of Entry Test show that:
· 15 students got bad marks (lower than 5/10)
· 4 students got good marks (6/10 and above)
· the average of the marks is 3.93 (very low)

Marks of Final Test show that:
· 13 students got bad marks (lower than 5/10)
· 6 students got good marks (6/10 and above)
· the average of the marks is 4.60 (not sufficient)

The interest in this subject appeared to be extremely weak. Applications of mechanics do not constitute a sufficient incentive to the mathematical study.

The class in object is characterized by remarkable limits from the point of view of theoretical approach. Several students find complications in studying scientific and mathematical subjects and the interest in studying stays quite low.
Regarding the practical activities, such as Technical drawing or AS, students are willing to participate and show interest in what they are doing. Most of the students who chose to study Mechanics course are mainly interested in practical activities more than theoretical activities. Following a 3D design and printing course, which requires little theory knowledge, may improve the learning of scientific and mathematical subjects.

To a significant effect on the study of maths would be needed to carry out numerous experiments on small parts of the program. This activity should be developed through the all school year. The increase in the time required for a topic would involve a reduction in the number of knowledge scheduled but probably increased student's ability.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- Work in groups to foster mutual help and the ability to organize work.
- We have improvements in Maths skills if the 3D printing will require their effective use.

WEAK POINTS OF THE EXPERIMENTATION:

- If you want to use a complex and professional software as Autocad an additional course, to achieve the necessary prerequisites, must be done.
- If no teacher has adequate computer skills you need a refresher course before start the experimentation.
- The 3R release should not detract from the objective of Maths subjects learning.
- Take care of the adequacy of laboratory: PCs, software, 3D printer and the availability of at least a competent teacher.

RECOMMENDATIONS

- Ensure, at first, the efficiency of the print stem laboratory: PCs, software, printer.
- Be sure to format at least one teacher on the use of software and the 3D printer including its maintenance.
- If you want to use 3D complex software and the necessary prerequisites are not in possession

of students, include a course on 3D design before starting the project. Students must be able to work independently to get a good result. The student must be autonomous in 3D design, other teachers only provide support on their specific subject. In doubt, select a simple software like 123D Design.

- Keep Maths expertise always on top that you want to deepen, not the object to be printed.
- Choose well the object to be printed by assessing in detail the Maths experience should be used and what specific activities will generate their deepening.
- Include all teachers needed to have available all the specific skills required.
- Fix well the objectives of each subject and develop their programming.
- Making a first cycle of traditional lessons for the basic skills on each subject (2 weeks).
- Make an initial test to measure the skills acquired.
- Activate the laboratory stage when the student is able to work on its behal, for each specific problem he can always ask to the competent teacher.
- The boys, clarified the goal, work independently in the group led by a leader (2 week). They will use the hours of all the involved materials.
- Laboratory work includes the study, research, calculation and design using all subjects involved.
- The children will share the tasks and share the results by producing a report.
- At the end it will be an evaluation with another test and an interview with the groups.

2.8 SOLIDS (IISS A.BERENINI – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

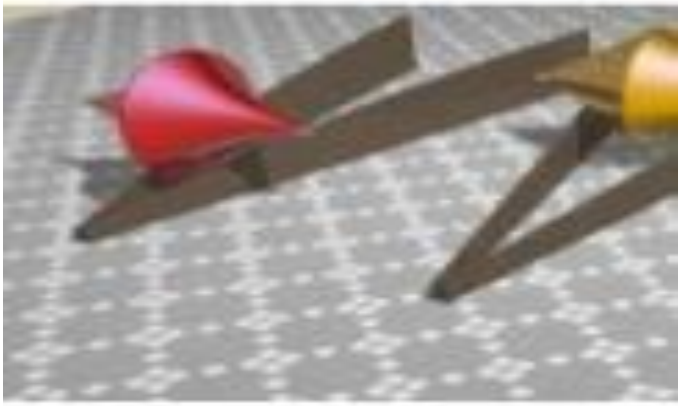
1) Help students achieve new skills and acquire a multinational dimension of learning through international cooperation
2) Use e-learning to improve language abilities
3) Create flexible learning strategies
4) Improve the learning of unmotivated students at risk of abandoning school and the low-skilled ones
5) Enhance teachers' proficiency.

SPECIFIC Learning Objectives

1) Observe the different behaviours of solids
2) Ability to measure all the elements in a triangle, starting from three of them of which one is a side

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing solids.
The experimentation consisted of an inclined plane made of two different divergent and inclined guides and of solids: double cone, cylinder, sphere and pseudo sphere.
We tried to explain the mechanic paradox (a double cone which " goes back to the top" of the inclined plane) and observe the movement of other rotation solids. The class was split into five groups of four students each, and they had to project and print a complete kit having different dimensions.



PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ Angles and rotation solids
- ✓ Barycentre and its meaning
- ✓ Measure theory
- ✓ Equivalences
- ✓ Basic use of Cad 2D
- ✓ Correct use of measuring instruments and units
- ✓ Correct use of scale laws in order to build proportional solids

THE TEACHERS TEAM INVOLVED

4 teachers have been involved in the experimentation:

List each teacher' subject/domaine:
1 teacher of Maths
1 teacher of Physics
2 teacher of Technical drawing
1 teacher of Applied sciences

Rationale of the Teachers Team
The skills needed to work in a laboratory Print Stem necessarily require the participation of more subjects. In addition to Mathematics, Physics and Applied Sciences they have treated the dynamic aspects and Technical Drawing provided support for 3D design.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:
Number of pupils: 22

Type of group: single class
Number of classes: 1
Scholar curriculum specialization of the class(es) involved: Mechanics
"Special needs" students: no
Entry level assessment: written test.

SETTING UP THE EXPERIMENTATION

In order to carry out the experimentation, the following aspects have been duly planned and prepared:

I) SUBJECTS INVOLVED

MAIN STEM SUBJECT	MATHS
Topics related to the Learning Objectives of experimentation	Goniometry: angles and their measure (grade/radiant); sine, cosine and tangent function definition and their geometrical representation; values of goniometrical functions of opposite, complementary, supplementary and notable angles. Trigonometry: right-angled triangles and sine theorems and their solutions
Total number of hours dedicated to completion of the experimentation	12 hours theory in the classroom 1 hour verification

OTHER RELATED SUBJECT	PHYSICS
Didactic Topics related to the Learning Objectives of experimentation	Rigid body dynamics. Use of rigid body's equilibrium equation and general knowledge of equilibrium condition, useful to solve real problems. Measuring and scale change (using proper proportional laws)
Total number of hours dedicated to completion of the experimentation	4 hours of theory in the classroom 1 hour verification

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** CAD 123D to design rotation solids
- **SOFTWARE(S) for object PRINTING:** CURA 14.12.1 (ultimaker.com). It is a free program and does not require a PC with special resources.
- ⍰ **3D PRINTER:** Delta WASP 20x40 printer (www.wasproject.it)

INFORMATION ON 3D PRINTING
Technologies: fused filament fabrication
Cylindrical Print Area: Ø 200 mm – 400 mm h
Max Print weight: 442 mm
Nozzle diameter: 0.4 mm/changeable nozzle
Print resolution: 0.05 mm < 0.25 mm
Accuracy X, Y 0.012 mm / 0.005 mm Z axis
Maximum speed: 300 mm / s

€2.370,00(VAT excluded)

- ⍰ **PLASTIC MATERIAL:** PLA (affordable to wasproject)

Filament diameter: 1.75 mm / 3.00 mm*
Filaments used: ABS,PLA, PET, Nylon, Flex, Polystyrene, Laywood, Experimenta
IMPORTANT: Time necessary to print 1 (floating raft) with this 3D printer is about 1-2 hour
IMPORTANT: Quantity of this material necessary to print 1 floating draft is: 5 meters, 15 grams.

€20,00 (VAT ecluded) (1Kg)

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

1° - Definition of Learning Objectives and object to be printed
Number of hours dedicated: 3 for teacher.
People involved: involved teachers and students

2° - Identification of Subjects related to experimentation and planning of the working hours for each subject involved
Number of hours dedicated: 2 for teacher.
People involved: teachers of the various projects and school administrator

3° - Entry level assessment
Number of hours dedicated: 1 for STEM teacher
People involved: students and STEM teachers
Before the printing, the students had to answer the questions of an objective test in order to assess their skills. The test consists of questions on physics, Maths and ITC. At the end of the project another test was given, to compare the results with the previous one, in order to evaluate the importance of the use of 3D printer in learning.

4° - Training Unit on Maths Subject:
Number of hours dedicated: 13
People involved: maths teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work

5° - Training Unit on Physics Subject:
Number of hours dedicated: 5
People involved: physics teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work.

7° - Training Unit on Technical Design Subject:
Number of hours dedicated: 6
People involved: drawing teacher
Didactic methodology used to teach the contents: front lesson and group work. The students learnt how to use the 123D Design, a free software offered by Auto-Desk.

8° - 123D Design of the object:
Number of hours dedicated: 8
People involved: drawing teacher
Didactic methodology used: laboratory work and group work. Thanks to the software “Cura” and the Wasp 3D printer “Delta2040” it was possible to realize the second part of the project

9° - Transfer of the object designed to 3D printing software:
Number of hours dedicated: 2
People involved: teacher of mathematics
Didactic methodology used: laboratory work.

°9 - Object printing:
Number of hours dedicated: 6
People involved: teacher of mathematics
Didactic methodology used: laboratory work.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The final result of the lab work is extremely positive as the students worked and designed all together trying to reach the same purpose. They are very proud of their job and they look forward to seeing it finished and at work.

We did not expect a significative, immediate improvement in knowledge and skills, which, however, took place unquestionably both in the core subject of the experimentation and in Physics, as the topic under exam is well defined and referred to a limited number of aspects.

The most positive effective is the more active involvement in the learning process which, relying on empathic and emotional reactions, can bring about a growth in interest and commitment towards the learning objects.

The fact that in the final stage of the project there were difficulties due to the malfunctioning of the 3D printer caused anxiety among the students (who were afraid of not being able to finish their work) but at the same time had an educational value because it made them aware of the unexpected problems that may arise in a process like this.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- Work in groups to foster mutual help and the ability to organize work.
- We have improvements in Maths skills if the 3D printing will require their effective use.

WEAK POINTS OF THE EXPERIMENTATION:

- If no teacher has adequate computer skills you need a refresher course before start the experimentation.
- The 3R release should not detract from the objective of Maths subjects learning.
- Take care of the adequacy of laboratory: PCs, software, 3D printer and the availability of at least a competent teacher.

RECOMMENDATIONS

- Ensure, at first, the efficiency of the print stem laboratory: PCs, software, printer.
- Be sure to format at least one teacher on the use of software and the 3D printer including its maintenance.
- If you want to use 3D complex software and the necessary prerequisites are not in possession of students, include a course on 3D design before starting the project. Students must be able to work independently to get a good result. The student must be autonomous in 3D design, other teachers only provide support on their specific subject. In doubt, select a simple software like 123D Design.
- Keep Maths expertise always on top that you want to deepen, not the object to be printed.
- Choose well the object to be printed by assessing in detail the Maths experience should be used and what specific activities will generate their deepening.
- Include all teachers needed to have available all the specific skills required.
- Fix well the objectives of each subject and develop their programming.
- Making a first cycle of traditional lessons for the basic skills on each subject (2 weeks).
- Make an initial test to measure the skills acquired.
- Activate the laboratory stage when the student is able to work on his/her own, for each specific problem he/she can always ask to the competent teacher.
- Laboratory work includes the study, research, calculation and design using all subjects involved.
- The children will share the tasks and share the results by producing a report.
- At the end it will be an evaluation with another test and an interview with the groups.