Pedagogical Resources IN Teaching Science, Technology, Engineering, Mathematics

TEACHER-LED EDUCATIONAL EXPERIMENTATIONS FOR DEVELOPMENT OF SCIENTIFIC LITERACY COMPETENCES

Intellectual Output N. 5

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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: Istituto d'Istruzione Secondaria Superiore "A.Berenini"

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Chapter 1. Teacher-led educational programme for development of scientific 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 referred to science) towards the achievement of objectives related to scientific knowledge and concepts for the understanding of phenomena; scientific processes of description, explanation and prediction; contexts/situations applied to the areas of life-health, earth-environment, science-technology.

Through application of this methodological approach, abstract conceptualization of science field 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, in order to learn understand how concepts apply to processes and contexts.

The proceeding suggested is in line with the recommendations of the Programming Document "SCIENCE EDUCATION IN EUROPE NATIONAL POLICIES PRACTICES AND RESEARCH", where it identifies as a priority "to make pupils and students understand what science is used for, namely through contact with companies in science-related fields".

According to the document, the findings of PISA 2006 show that in Europe the knowledge of science is more linked to the knowledge of theoretical concepts rather than to the understanding of processes and of the way in which these concepts apply to reality. What students are not clear about is how science works, how it applies to life. Many studies highlight how the students' lack of interest for science is largely due to the fact that it is not presented in the context of their interests and of their experiences.

The contextualization of scientific subjects is recommended by most of policy documents EU27, for primary schools, and EU29 for lower secondary schools. As regards the issue of contextualization, most European countries have focused their experimentations on three main themes:

1) application of science to environmental sustainability

2) application of science and technology to daily life situations

3) connection between science and human body functions

Therefore the need is to develop formative methodologies that create a connection between scientific theories and scientific reasoning, the understanding of phenomena and their interpretation, but also anchor them to reality, showing students how scientific thinking can solve problems and how it applies to processes and situations in real life and/or to social issues.

1.2 HOW THE EDUCATIONAL PROGRAMME HAS BEEN VALIDATED

The Didactic Programme here presented has been conceived to understand how concepts apply to processes and contexts. Teachers have evaluated the areas of scientific literacy where their pupils have greater difficulties and for which the experimentation and programme modelling would have to be activated.

The form of experimentation developed included a support designed to promote, as part of the ordinary curriculum, a style of learning based on practice, with the effect of demonstrating the relevance of scientific disciplines 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 scientific 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:

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PRINTSTEMPROJEC

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

TEACHER-LED DIDACTIC EXPERIMENTATIONS FOR DEVELOPMENT OF SCIENTIFIC LITERACY COMPETENCES **Teachers-Team Members Tool**	
Teachers Team identified: which teachers will be involved to carry out activities	<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 ☐ 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 scientifc skills:

Evaluate the areas of scientific 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 phenomena.

Requirements about Learning Objectives:

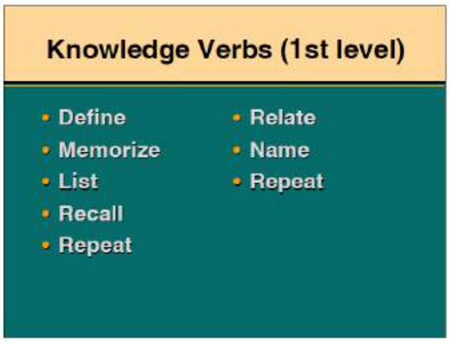
⇒ The scientific skills that have been taken into consideration are the ones that relate to:
- scientific concepts (physics, chemistry, biology, earth science),
- scientific processes (describing, explaining and predicting scientific phenomena, understanding what a scientific investigation is, interpreting research data or an experiment)
- applying science to life situations.

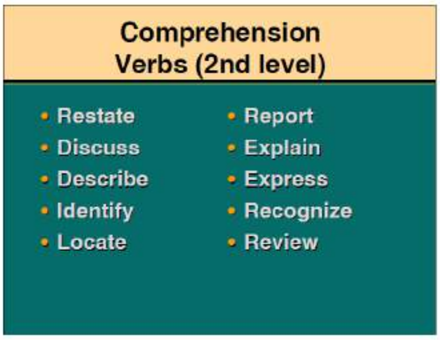
⇒ Learning Objectives should refer to the scholar curriculum of students according to the class attended, since the aim of experimentation is to improve students' skills in the STEM subjects/contents directly related to their curriculum,

⇒ 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:





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".

<u>What is 3D printing and how it works – The Basics</u>

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	A little more brittle than ABS Melts at a lower temperature Softens at 50°, lower than ABS

	Gives off very little fumes Low toxicity Low UFP's Reduced distortion compared to 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,

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⇒ 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:

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⇒ 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: Science 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 many hours *(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 Scientifc 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 scientific-related contents?				
4	Were the exercise with use of the 3D printer useful to improve your knowledge and understanding of scientific concepts/phenomena related to the object that you designed and printed?				
5	Did you appreciate the use of the 3D printer in learning theoretical rules and scientifc 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 scientific 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 scientific 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 TWO – STOREY HOUSE IN SECTION (1epalchanion – Greece)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) Skill of drawing something visible, evolving on the following process: see - observe – analyze - compose

2) Capability of coming up with and expressing an idea, concerning the construction of a mechanical part or a group of components or a useful object and proceeding to a drawing with accurate information

3) Capability of using the drawing with a view to supplying information on the volume and position of objects in space

4) Ability of expanding our conception of the three – dimensional aspect of space, in order to function more easily and effectively in the Construction – Building Domain and introduce innovations to it.

SPECIFIC Learning Objectives

1) Being able to identify the several parts of a construction (floors, beams, columns), associate them to several volumes and compose them, in order to achieve the desired result.

2) Being able to realize the constructing phases of a building (foundations – ground floor – first floor – roof setting)

3) Being able to realize that varied drawings, such as plans, elevations, sections, axonometric, drawings in prospect can be 3D drawn, which offers us the possibility to create 3D models, resulting in 3D printing.

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

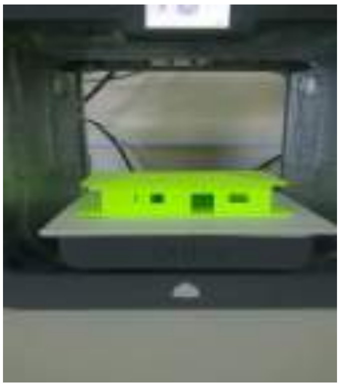
In identifying the Learning Objectives we took into consideration the fact that our school has been hosting a Constructions – Designing Field of Studies for decades. The introduction of 3D printing technology to our teaching methodology, could not escape our interest. At the same time, we have been witnessing our students' inability to deal with basic geometrical concepts, making teachers of this particular field of studies go back to syllabus of earlier classes and teach these notions again. This phenomenon, together with our students' inability to connect Mathematical knowledge to the real world, frequently made them avoid the interesting and promising field of Constructions – Designing, despite their initial desire to follow these courses. As a consequence, we decided that the specific learning objectives mentioned above would be our first priority, in order to overcome this obstacle and arouse our students' interest back to our field.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a two – storey house in section.

Why this object?

The object would enable pupils to understand in detail the levels of a building and their connection devices such as stairs and other special constructive details. Moreover, by observing the building in section, they realized all the stages of its construction. Last but not least, by asking them to draw a new building of their own, they improved their abilities, avoiding mistakes and coming up with functioning drawings.


PREREQUISITES

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

- ✓ Basic knowledge of Mathematics - Geometry
- ✓ Basic knowledge of Computers use
- ✓ Basic knowledge of Technical Drawing

THE TEACHERS TEAM INVOLVED

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

One teacher of Technical drawing / CAD

Rationale of the Teachers Team

The teacher involved in the team was chosen because Mr. Petrakis Yiannis is a Civil Engineering teacher and has been teaching Design using AUTOCAD for years in our school.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 17 (for each class) → 34 in total

Type of group: one single class

Number of classes: 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 Geometry and Mathematics was improved.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN SCIENTIFIC SUBJECT	TECHNICAL DRAWING / CAD
Topics related to the Learning Objectives of experimentation	Teaching students the basic skills of technical drawing on paper, is considered as a major prerequisite in order to achieve successful 3D printing results. Moreover, teaching the commands and the whole function of the CAD software is considered the base of the whole philosophy on which the 3D printing technology depends. Furthermore, we believe that through the whole process of 3D drawing, students can realize in depth the connections among shapes and solids, go on with accurate measurements, revising their knowledge of areas, volumes, circumference, etc. This way, the main Objective of the PRINT STEM project is achieved. Lack of knowledge on behalf of teachers or students will undoubtedly lead to downloading and copying files from pre-set libraries, which we do not regard as a defective aspect of the project. However, we decided to take advantage of the knowledge and teaching experience of Mr. Petrakis and invite students to the magic world of 3D drawing.
Total number of hours dedicated to completion of the experimentation	18

OTHER RELATED SUBJECT	GEOMETRY
Didactic Topics related to the Learning Objectives of experimentation	Teaching of dimensions, areas and volumes of several shapes and solids, such as square, rectangle, circle, ellipse, trapezium, polygon, cone, cube, cylinder, pyramid, etc.

Total number of hours dedicated to completion of the experimentation	4

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN: 123D_Design-Autodesk**
- **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. http://www.3dsystems.com/**

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
http://www.3dsystems.com/shop/support/cube/videos

IMPORTANT: Time necessary to print 1 two-storey house in section with this 3D printer is 12 hours, at standard mode (200 microns)

- **PLASTIC MATERIAL:**
  PLA Plastic Cartridge for CubePro
  ABS Plastic Cartridge for CubePro

IMPORTANT: Quantity of this material necessary to print 1 two-storey house in section is: 90% of a material package of a cost of 50€.

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 2

People involved: 1

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

Number of hours dedicated: 2

People involved: 1

3rd - Entry level assessment

Number of hours dedicated: 2

People involved: 1

4th - Training Unit on GEOMETRY:

Number of hours dedicated: 4

People involved: 1 teacher + 34 students

Didactic methodology used to teach the contents:

- Teaching several basic geometrical shapes
- Drawing these geometrical shapes on paper in scale
- Teaching of geometrical shapes' composition (adding / subtracting solids) for the final idea's achievement
- Teaching basic geometrical knowledge, such as area of shapes, volumes, etc.

5th - Training Unit on TECHNICAL 3D DRAWING Subject:

Number of hours dedicated: 4

People involved: 1 teacher + 34 students

Didactic methodology used to teach the contents:

- Drawing on checked paper
- Drawing in scale, making measurements in centimeters and millimeters, adding and subtracting dimensions

- Presenting the target object of our study
- Discussion and opinion exchange on the process to be followed
- Laboratory practice:
  - o Introduction to composed picture production technology
  - o Basic two – dimensional shapes drawing – analysing the basic methods of 2D data visualisation
  - o Transformations in space – introduction to structures and descriptive methods of 2D data
  - o Presentation of 3D visualisation basic commands – Geometry on surface
  - o Object sequence – projections
  - o 3D drawing of polygons, circles, parallelograms
  - o Visit to real-life sites, where students had the chance to observe, measure and draw real-life objects, of several shapes and dimensions. Returning back to class, they proceeded with transfer of their drawings to 3D drawings.

➢ Familiarisation to 3D graphics printing

6th - 123D Design of the object:

Number of hours dedicated: 6

People involved: 1 teacher + 34 students

Didactic methodology used:

➢ Design of ground floor outline using polyline

➢ 3M height using *exdrude* of ground floor outline

➢ Design of 1st floor outline using *extrude 3m* command

➢ Design of 1st floor doors and windows using *extrude 3m –subtract* command

➢ Design of 1st floor balconies using *circle* command for balconies

➢ Connection of two floors using *move* command

➢ Roof design

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

Number of hours dedicated: 4

People involved: 1 teacher + 34 students

Didactic methodology used:

- Preparation of 3D models and extraction of STL files
- Introduction of STL files and studying the printer's software


8th - Object printing:

Number of hours dedicated: 6

People involved: 1 teacher + 34 students

Didactic methodology used:

We divided the class to several sub-groups, assigning different roles and responsibilities to each of them. To be more specific:

Team 1 was responsible for :

1. collecting all STL files
2. introducing them to the printer's software
3. altering them as far as colour selection and other features are concerned, according to the PLA material that were available with our printer

Team 2 was responsible for creating 3D models.

Team 3 was responsible for observing the whole process and taking record of problems that arose during it.

Team 4 was responsible for going through a problem solving process, with the help and guidance of the teacher, in order to prevent the same problems from arising once more.

There were some cases that objects had to be re-printed mainly because students were not able to realise in which of these objects supportive material was necessary or not. In that case, we used to recycle the teams' responsibilities and roles.

9th - End of experimentation

Number of hours dedicated: 2

People involved: 1 teacher + 34 students

Didactic methodology used:

Each student presented

- his / her idea (4 – inclined roof)
- geometrical shapes used during drawing
- commands used while working on the drawing software
- mistakes during drawing / printing process

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main scientific subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of giving them a test to answer, which consisted of the following parts:

Part 1 → Multiple-choice questions on theory (30% of the whole grade)

Part 2 → Laboratory test practice which included assignments on teaching topics of the whole semester, such as drawing a spare part from scratch up to the level of producing its 3D model. (35% of the whole grade)

Part 3 → Laboratory test practice which included assignments on STL files extraction, selection of the proper method according to each case, taking into account certain conditions such as organising the whole process up to printing, taking simple steps in order to accomplish each task, assessing the necessity of supportive material, etc. (30% of the whole grade)

and recorded the following learning results:

1) improvement of the students' knowledge concerning basic Geometry notions at a percentage of about 65%

2) very good response to Technical Drawing teaching, bringing about quite satisfactory results, with intelligent ideas and effective drawing techniques

3) satisfactory performance to brainstorming, recording and problem solving situations

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

1) Students did not seem to conquer the use and function of the 3D software in depth, mainly due to the following factors:

a. the complexity of the commands and the philosophy going through such software (sometimes even non-proportioned to the students' age and former theoretical background, including their knowledge of English)

b. the fact that a successful printing result depends mainly on very minor details that the person which uses the 3D software has to take into consideration and be extremely attentive with, which our students were not capable of realising not to mention implementing them in their works.

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

To start with, the experience of participating in the PRINT STEM project as a whole was a lesson itself. The innovative 3D printing technology consisted a topic that attracted our interest – as teachers – and intrigued us to use it in our classes, given the fact that we have been experiencing our students' difficulty dealing with STEM subjects for ages. However, we have to admit that despite our initial awareness of this type of technology – owing to the specialisation of Mr. Petrakis – we had never imagined that it could be used in order to teach STEM subjects and increase our students' interest and motivation.

There are certain aspects of the experimentations that we would like to comment on. To be more specific:

1. It is crucial to assure beforehand that a satisfactory number of teachers of different specialisations 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 IO5 experimentations are concerned – and this proved really tiresome. This is not only due to the fact that the teaching and the process followed throughout the experimentations, was an individual responsibility, but also because there was a lot of paperwork (filling in Survey Reports, Questionnaires, etc.) to be done, together with the difficulty that arose when teaching of different but essential for the enhancement of the students' theoretical background had to take place; not to mention, troubleshooting for the printer and the software which we will refer to later.

2. Another very important point to be taken into consideration is the necessity for a Teachers' training course on Technical Drawing and the use of 3D Drawing software. This is due to the fact that firstly, technical drawing and 3D drawing software use are prerequisites for the successful outcome of the experimentations and secondly, such knowledge is acquired only by teachers who have graduated from Civil Engineering Universities and not by teachers of other subjects. When teachers cannot teach the basic skills of 3D Drawing, it is inevitable that they will end up to pre-set libraries, not giving their students the chance to associate theoretical knowledge to creation.

3. 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. The most important obstacle is the difficulty in describing the problem that has arisen in a pivot language, like English, combined with the reasonable and well-excused inability of Business partners to be able to offer troubleshooting techniques for all types of 3D printers that School partners are using.

4. We consider the duration of each lesson (2 hours) too little time to proceed with exhaustive teaching of the necessary knowledge, such as what we have explained in detail above in Part III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION. Furthermore, the printing time needed was too much over the end of the lesson, restricting students from enjoying the final stage of their thinking and working.

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ It introduces such an innovative process, like 3D printing technology, with a view to teaching students how to realise your idea
- ✓ It rewards students' creativity and offers them the chance to feel useful and productive, since they can touch what had once been just a picture in their heads
- ✓ It gives students the opportunity to realise, mainly in part, that the majority of objects around them have emerged from a production line. Moreover, they seem to appreciate more special characteristics of objects, such as their texture, the material from which they have been made. In general, students seem to be able to realise many more aspects of the quality of a product than what they realised by simply looking or even using it.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ Printing process is really time - consuming
- ✓ Lack of technical support for the 3D printer (defective PLA materials)
- ✓ The desired printing outcome varies, depending on details of the object drawn, making the final selection difficult, since it has to be assessed beforehand whether or not supportive material is to be needed.
- ✓ One 2-hour session per week does not seem to be sufficient time for organised experimentations to be carried out.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

Given the valuable experience we have gained through our participation in the PRINT STEM project, we would kindly recommend the following:

- ✓ Make sure that Teachers' Training program takes place before the beginning of the experimentations

- ✓ Depend the selection of hardware and software on the special knowledge of Expert Technicians and not Teachers
- ✓ Try to eliminate the options of hardware and software to be used, so that more exhaustive and effective technical support can be offered by Business partners, when problems arise, either concerning the software use or the printer's proper function
- ✓ Make sure that no Interdisciplinary Team consists of fewer than 5 teachers in each School partner's institution, with fluency in English
- ✓ Target the project to more specialised classes, of Drawing Field of Studies, rather than General Education ones, since it is really difficult to teach Drawing to students who are not only interested but also may not be physically gifted to meet the expectations of this particular subject.

2.2 3D LED LIGHT (Kirby Stephen Grammar School – UK)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) Understanding application of 3D Printing in Industry.

2) Introduction to LED lighting technology

3) Chemistry of polymers

SPECIFIC Learning Objectives

1) How 3D Printing can be used for prosthetics

2) Calculating current

3) Polymer production

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

An existing 3D Printing project was used as a possible starting point for the project. The Chemistry teacher realised that the use of the polymers for 3D Printing dovetailed neatly with the GCSE curriculum. The technology behind LED lighting was seen as a bit of an add on. However the physics area was developed further by discussion of electron flow and a few simple electrical measuring tests.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a 3D LED light.

Why this object?

The object would enable pupils to have a high level of success in designing and manufacturing within the STEM day as output IO5 was designed as an intensive one day event.

PREREQUISITES

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

- ✓ Basic understanding of using 3D Design Software, such as Sketchup.
- ✓ Basic understanding of electrical flow
- ✓ Basic understanding of what inorganic Chemistry is.

THE TEACHERS TEAM INVOLVED

(number) teachers have been involved in the experimentation:

List each teacher' subject/domaine:

1 teacher of Physics

1 teacher of Chemistry

1 teacher of Design & Technology

Rationale of the Teachers Team

The teachers involved in the team were chosen because they had the necessary skills to teach these subjects. Being a small school we have a limited choice of teachers. Enthusiastic, positive and keen teachers are the most important. However there would be the possibility in the future of training one teacher to deliver all aspects of the project. Depending on the strengths of that particular teacher the project could be tailored to suit the strengths of that particular person.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 41

Type of group: 1 mixed group and 1 group which elected to do the project.

Number of classes: 2

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

"Special needs" students: 5 of the students had been categorized as being Gifted and Talented. 2 students had dyslexia**.** 4 students had been assessed as requiring support in reading and writing. 2 students were seen as having behavioral problems.

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

(List the different subjects interested by the experimentation and describe how/why they were related in order to get to a successful result on the pupils)

MAIN SCIENTIFIC SUBJECT	Physics
Topics related to the Learning Objectives of experimentation	Electrical flow
Total number of hours dedicated to completion of the experimentation	5

OTHER RELATED SUBJECT	Chemistry
Didactic Topics related to the Learning Objectives of experimentation	Polymer technology, application and manufacture.
Total number of hours dedicated to completion of the experimentation	5

OTHER RELATED SUBJECT	Design & Technology
Didactic Topics related to the Learning Objectives of experimentation	Use of accurate manufacture, tolerance and assembly
Total number of hours dedicated to completion of the experimentation	5

OTHER RELATED SUBJECT	Learning use of 3D Modeling software.

Didactic Topics related to the Learning Objectives of experimentation	Following tutorials.
Total number of hours dedicated to completion of the experimentation	1

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** Sketch up V8
- **SOFTWARE(S) for object PRINTING:** Cura
- **3D PRINTER:** Ultimaker 2

IMPORTANT: Time necessary to print 9 objects 1 hour.

- **PLASTIC MATERIAL:** PLA used as it is marginally cheaper than ABS but is supposed to have less chance of distortion.

IMPORTANT: Quantity of this material necessary to print 1 is approx. 10mm 2

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 30 mins.

People involved: 3, Physics, Chemistry and Design & Technology.

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

Number of hours dedicated:

Physics: 1hour for Power Point and 1hour preparation

People involved: 1 teacher and 1 technician (to set up experiments).

Chemistry 2 hours for Power Point and 2 hours planning and preparation.

People involved: 1teacher and 1 technician (to set up).

Design & Technology 1hour for planning and preparation of the day. Design work booklet and task having already been completed. This had been developed for another project and took approx. 3hours.

People involved: 1 teacher

3° - Entry level assessment

Number of hours dedicated: Existing assessment data, simple test and specifically asking pupils if they learnt anything.

People involved: 1 to give out assessment and collect it in from pupils. One person took overall charge of the assessment and had this checked by the other teachers. Changes were mde as necessary.

4° - Training Unit on Physics Subject:

Number of hours dedicated: 1hour

People involved: 1 teacher with 22 pupils

Didactic methodology used to teach the contents: Front of class, group experiments and worksheet.

5° - Training Unit on Chemistry Subject:

Number of hours dedicated: 1hour

People involved: 1 teacher with 22 pupils

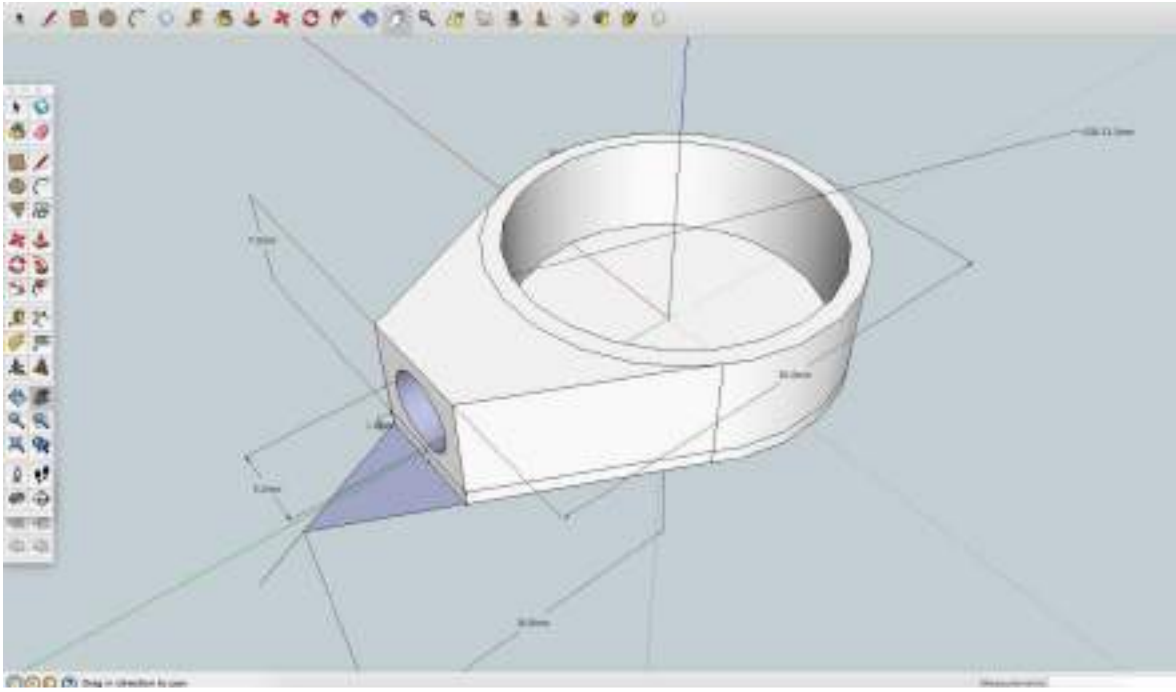
Didactic methodology used to teach the contents: This had a lot more variety of teaching methods, interactive, Utube clips, experiments and discussion. Pupils were very positive about this aspect of the course.

6° - (software) Design of the object:

Number of hours dedicated: 1hour with pre-training in other years, ie pupils had spent approx. 3hours on tutorials prior to the task.

People involved: 1 teacher of Design & Technology

Didactic methodology used: Pupils follow self study work booklets but also support one another.



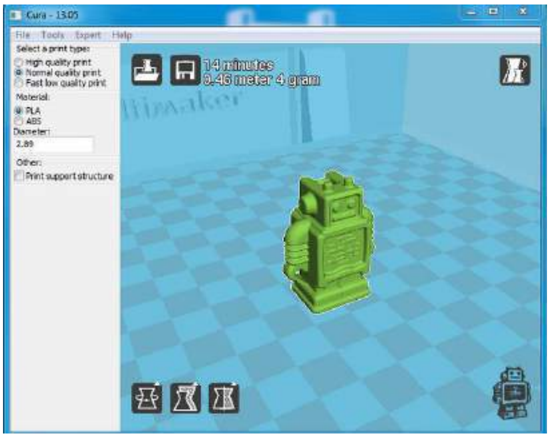
Use of Trimble Sketch-up for the 3D Designing software.

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

Number of hours dedicated: 1hour for each group of 20. Spare models had been printed out to allow for incorrect or mal-formed models.

People involved: 1 person

Didactic methodology used: Pupils did this themselves. Pupils were shown how to transfer the 3D Design to Cura software then collect 9 and print out although a lot of help was given in supervising pupils doing this. Pupil ambassadors, ie competent pupils were used to help others.



Cura Software for transferring 3D Design to a format the 3D Printer can use. This software is an open source programme and will work on other printers as well as Ultimaker printers for which it was deigned.

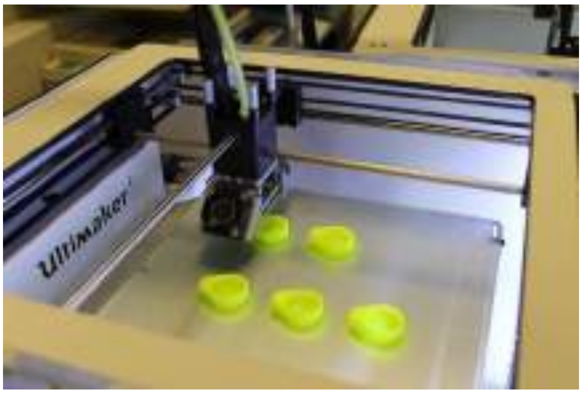
8° - Object printing:

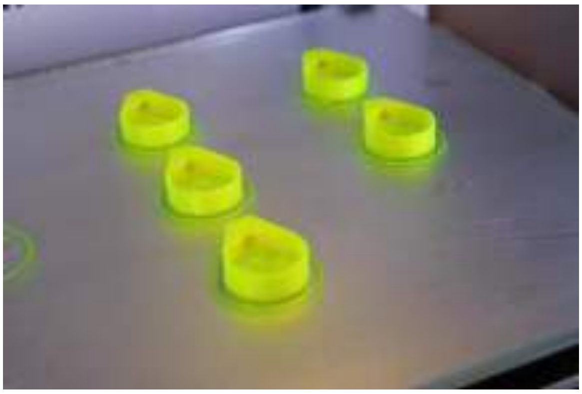
Number of hours dedicated: 5hours to print out with 1hour for printing out a separate component required which pupils would not be able to produce in the time available.

People involved:

Didactic methodology used: Due to the time constraints of the project the organising of the prints was done by a Technician. Some pupils were able to use conversion software to convert their 3D models. However the slower pupils were unable to do this. Fortunately a tea break was placed at the end of each session this enabled the Technician to go around and make any alterations and save pupils work after converting the 3D design.

Spare components had been printed to enable students who made mistakes to have a finished product at the end of the day. The buttons for the top of the light were printed out for the pupils so that there was enough time at the end of the day to assemble the work.





9° - End of experimentation

Number of hours dedicated: 1 hour

People involved: 3

Didactic methodology used: this was simply an evaluation given to pupils to assess and gain feedback. This was completed during the assembly of the final product. This was quite effective as groups could circulate between completing the evaluation and assembling their product / light

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

1) Some of the lower ability pupils really like the practical aspects of the project and suggested that the 3D Printer should be used in lower years. Some found the theoretical aspects a little less interesting but thought that the 3D Printer did add more of an interest to the project.

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) All pupils were engaged, even pupils considered with behavioural issues.

2) Good cooperation between all pupils.

3) Good relationships between staff and pupils.

MEDIUM TERM IMPACTS:

In order to assess the long-term acquiring by pupils of the scientific knowledge and skills stimulated by the experimentations, a specific evaluation test have been submitted 4/6 months after the job done:

The scores and results obtained by the pupils revealed that there was an 88% improvement in pupils understanding. This equated to a 47% increase in test scores.

LESSONS LEARNT

The project was a little rushed and could have had a better impact if it had been completed over 1.5 days. This would have given time to print out the projects. We managed this during the day but it was a little fraught.

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Quick, short and efficient in it's use of time.
- ✓ Proved to be interesting for pupils.

WEAK POINTS OF THE EXPERIMENTATION:

(Be punctual in writing each bullet point)

- ✓ Too rushed.
- ✓ Printing components leaved no room for error.
- ✓ Time was very tight.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ I intend to use this project in lower years and teach the Physics within the Design & Technology part of the school curriculum.
- ✓ The possibility of further collaborative work between D&T and Science subjects.

2.3 PERIODIC TABLE OF ELEMENTS (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 physics and chemistry

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 physics and chemistry are down-to-earth sciences which they can also learn by doing in addition to traditional methods such as abstract thinking and mathematical computing

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

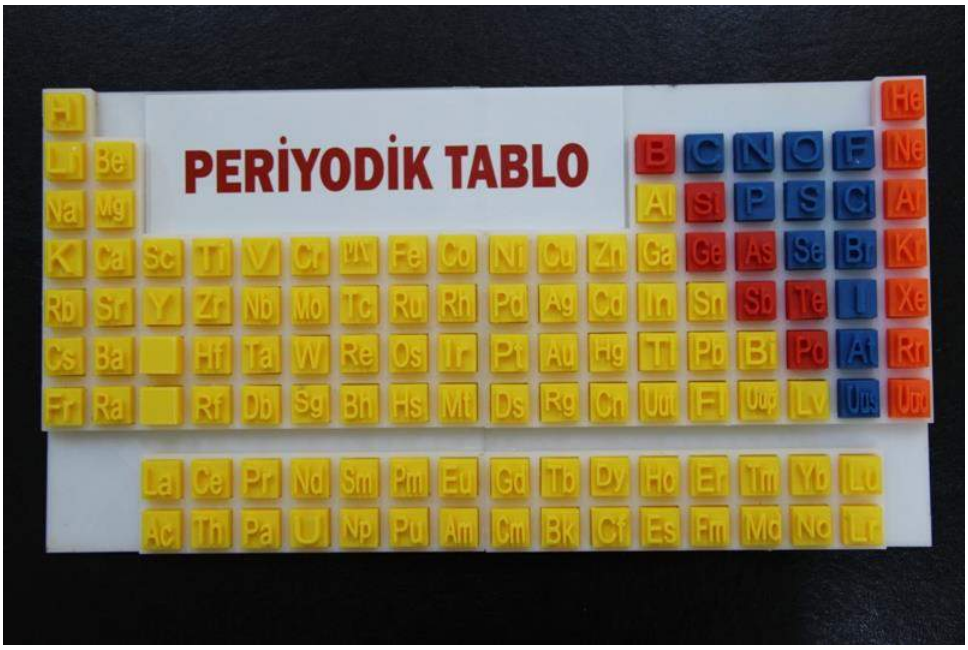
… (among other reasons, there can be also the respect of the compulsory scholar curriculum according to the period of carrying out the experimentation, in order to fully integrate the exercise within the scholar year…) Our Ministry of Education has a directive for the contents of compulsory curriculum for 9th and 10th grade classes. The contents of physics curriculum include energy, mass and elements. The periodic table of elements that informs pupils about the atomic number, density and electrons of these elements is thus a crucial topic. 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 the periodic table of elements

Why this object?

The object would enable pupils to (describe why you chose the object: which kind of reasoning and scientific skills direct learning it would stimulate on pupils while getting to the result and/or pupils difficulties on the subject that leaded you to chose the object) This object to be printed induces the pupils to use and enhance their knowledge of physics and chemistry as regards to the subject of elements within the compulsory curriculum.



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
- ✓ basic physics and chemistry knowledge of elements

THE TEACHERS TEAM INVOLVED

4 teachers have been involved in the experimentation:

List each teacher' subject/domaine:

1 teacher of biology

1 teacher of physics

1 teacher of chemistry

1 teacher of technical/computer support

Rationale of the Teachers Team

The teachers involved in the team were chosen because (describe why each teacher was needed to carry out successfully the experimentation, include specific references to the skills required to lead properly the students on each experimentation phase)

3 science teachers were chosen in order to give the pupils the continuous supervision and support for physics and chemistry knowledge needed for the modelling phase.

1 teacher for technical/computer support was chosen in order to help the pupils transfer and use their earlier scientific 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) basic knowledge of natural sciences, 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 SCIENTIFIC SUBJECT	Physics, Chemistry, Biology
Topics related to the Learning Objectives of experimentation	The periodic table of elements
Total number of hours dedicated to completion of the experimentation	19

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:** write the software you used and why it is proper for the completion of experimentation :SketchUp Pro because of its ease to use, free license

- **SOFTWARE(S) for object PRINTING:** write the software you used and why it is proper for the completion of experimentation. Specify if it is open source and add links to useful tutorials available on the web : Zortrax Z-Suite

- **3D PRINTER:** write technical details of the printer(s) you used + its cost

  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]

add the picture

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

- **PLASTIC MATERIAL:** write technical details of the material you used (PLA or ABS or else) + its average cost + where it is possible to buy it : 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%)

- + add the picture

- 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 16 m per object

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 10

People involved: Physics, chemistry, biology teachers and printer technician

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

Number of hours dedicated: 8

People involved: Physics, chemistry, biology teachers

Add picture of the teachers team

3° - Entry level assessment

Number of hours dedicated: 8

People involved: Physics, chemistry, biology teachers and pupils

4° - Training Unit on Science Subject:

Number of hours dedicated: 40

People involved: Physics, chemistry, biology teachers and 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: Physics, chemistry, biology teachers, printer technician and pupils

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

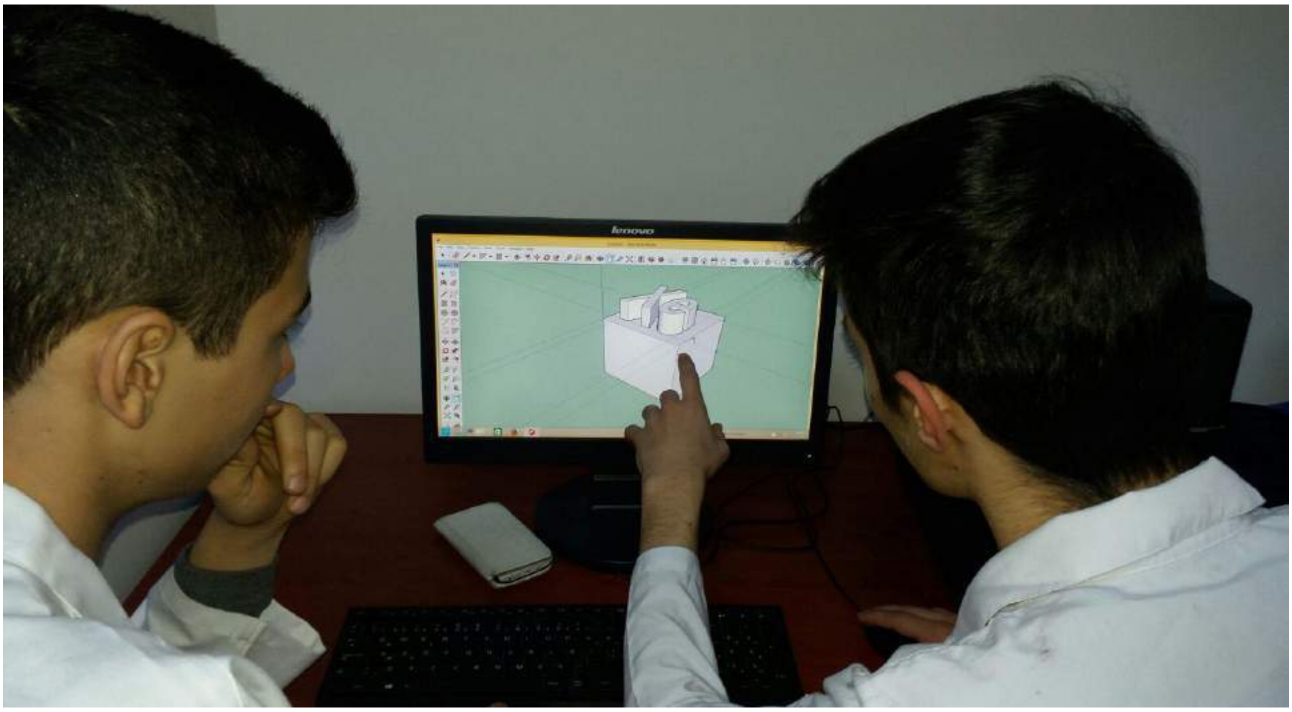
6° - Design of the object:

Number of hours dedicated: 6

People involved: Physics, chemistry, biology teachers, printer technician and pupils

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

Add technical and pupils pictures + link to files

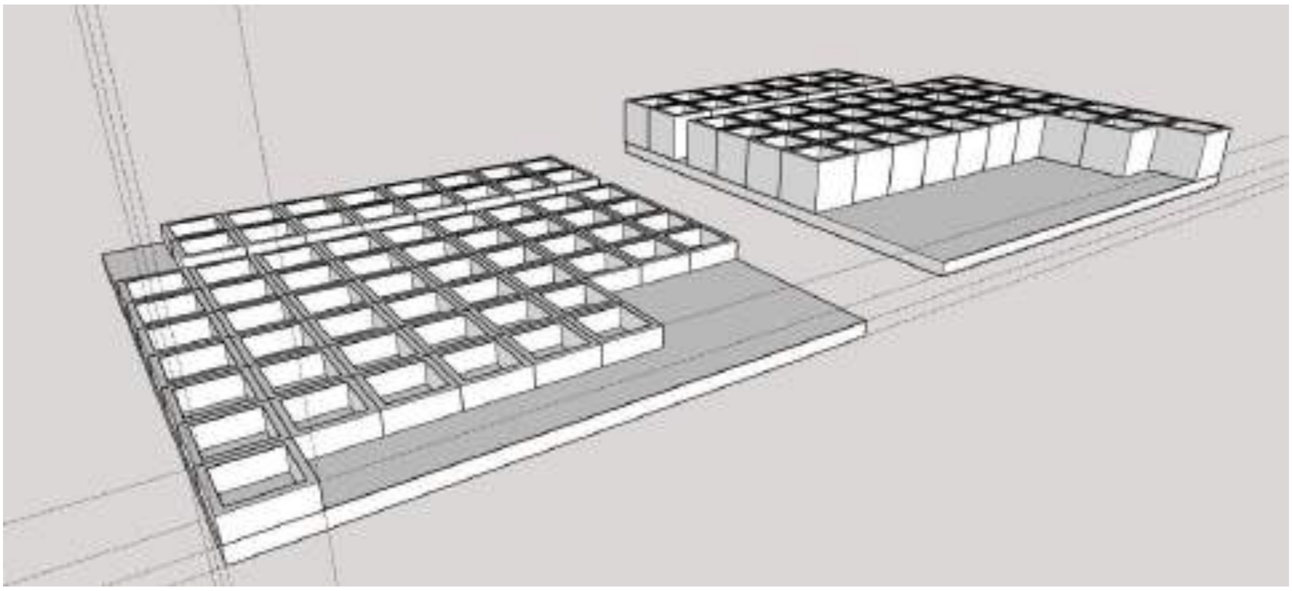


7° - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 7

People involved: Physics, chemistry, biology teachers, printer technician and pupils

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



8° - Object printing:

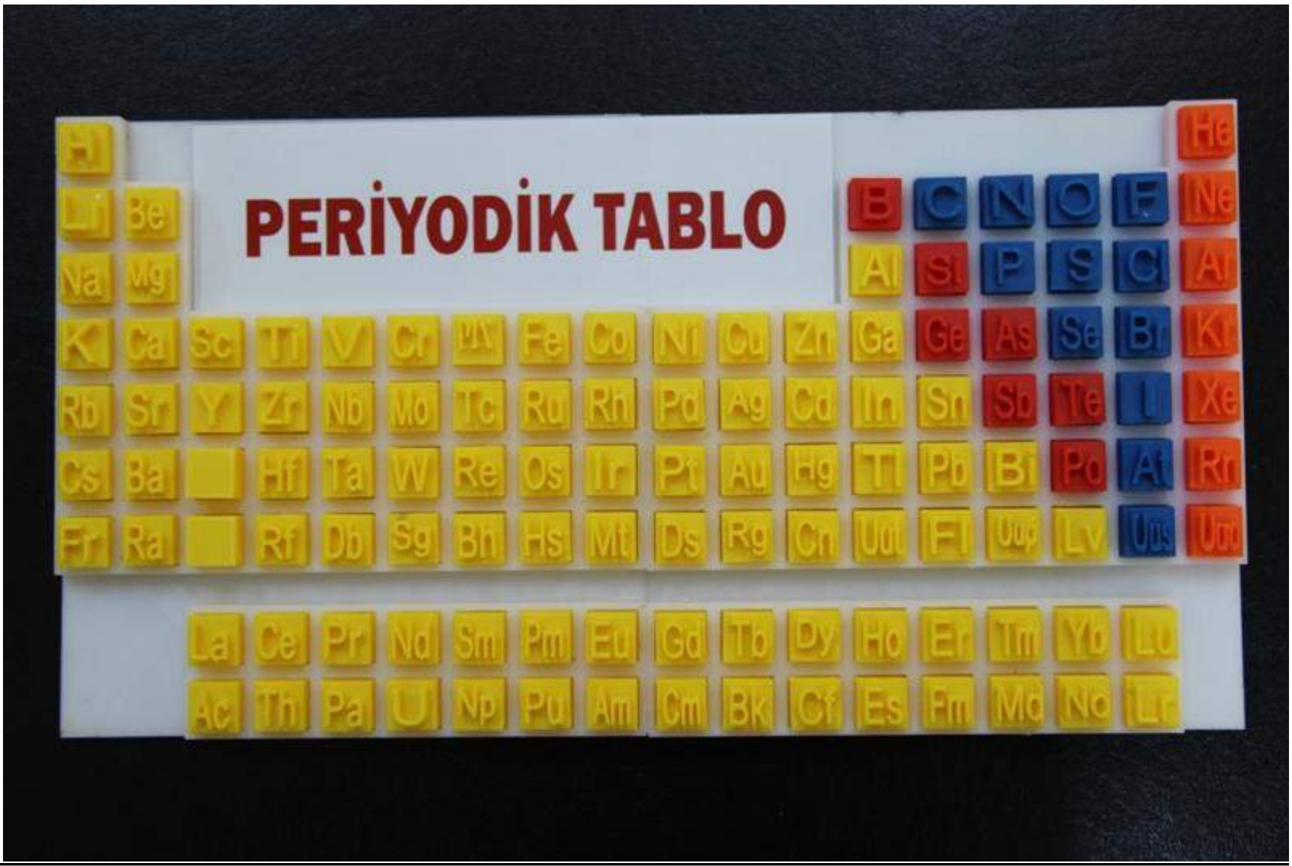
Number of hours dedicated: 7+6

People involved: Physics, chemistry, biology teachers, printer technician and pupils

Didactic methodology used: describe what you did, how and why (front lesson, printing in small groups and direct observation, personal printing by each student, teachears printing for all the class…) describe the possible necessity to re-print objects, which problems arised etc

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

1. Distribution of tasks among pupils
2. Making research and collecting data about the structures to be modelled
3. Modelling the objects on the computer
4. Sending the objects to the 3d printer


PERİYODİK TABLO

9° - End of experimentation

Number of hours dedicated: 8

People involved: Physics, chemistry, biology teachers and 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 scienctific subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of .....(ad hoc written/oral exam or within the planned scholar test of the subject including other topics than the experimentation-related ones) and recorded the following learning results:

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

As if it is a brainstorming, list any final comment/lesson learnt during the experience. Be as much exhaustive as possible, any comment will help other teachers to prevent difficulties when preparing an experimentation. Lessons learnt must refer to any aspect of experimentation that can influence its successfulness: teachers team, training to teachers, technical problems with printers, difficulties of softwares, pupils motivation, teachers motivation, time dedicated to the experimentation, etc. Use also answers from the pupils questionnaire to detect lessons learnt

- ✓ It always takes more time than planned to execute an experiment
- ✓ Mistakes during the experiment phase seems to be inevitable (we experienced twice with the misprints of the object)
- ✓ Getting familiar with the handware and software aspects of the 3d printing demands professional assistance

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Less abstract and more practical method of teaching
- ✓ Learning by doing and from your own mistakes.

WEAK POINTS OF THE EXPERIMENTATION:

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

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

Also on the basis of the LESSONS LEARNT above listed, write down any recommendation (be the most exhaustive possible, any comment, of any kind will

Be punctual in writing each bullet point

- ✓ 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)

2.4 FLOATING RAFT (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 science.

SPECIFIC Learning Objectives

1) Knowing how to apply the principle of Archimedes.

2) Calculate solids' volumes.

3) Be able to draw and recognizes complex solids.

4) Be able to draw and print 3D solids.

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

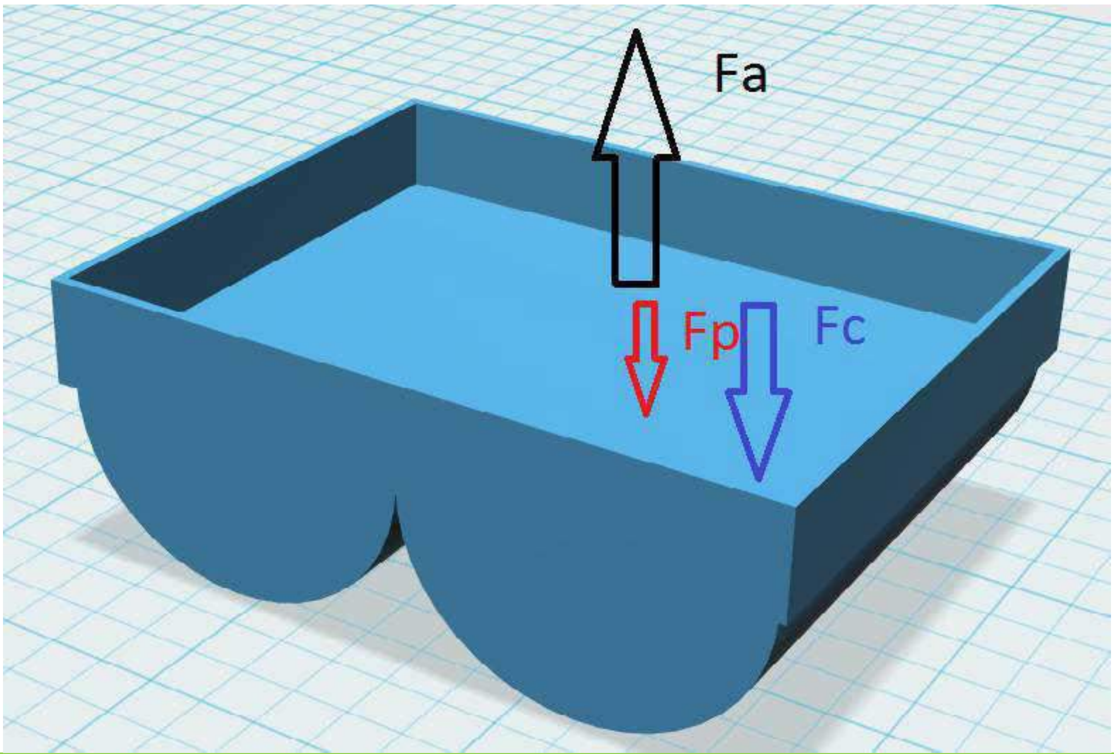
The law of Archimedes is normally comes in the second year program. The calculation of the maximum load allowed by the raft implies interesting skills on the calculation of the volumes, use of density, changes of measure units.

PRINTED OBJECT

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

Why this object?

The main purpose of the project is to create a "raft". Students can create it whatever they like, but before doing the 3D printing they have to calculate the maximum weight it can carry. During the project, however, they will have to pay attention to its shape: they must be able to calculate its volume in order to measure its weight force and the Archimedes Screw. After the printing of the raft, they will be put in a basin full of water and loaded with coins until sinking. Pounds weight must be the same as the ones calculated with Archimedes' principle. The weight of the boat must take into account the reduction of 80% set in the filling of the 3D printer



PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation no special prerequisites were necessary because the law of Archimedes was in the normal programming. Students come to this form knowing the concepts of force, mass density, weight force. As for the 3D design software we used the Autodesk 123D Design, is a very simple software that boys learn deftly in 2-4 hours.

THE TEACHERS TEAM INVOLVED

4 teachers have been involved in the experimentation:

1 teacher of PHYSICS (main scientific subject)

1 teacher of MATHS

1 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. The teacher of Applied Sciences has introduced the use of "123D Design" with the support, for the design theoretical aspects, of the Technical Drawing teacher. During the Stem Print Laboratory

these teachers had provided support for the use of 3D and the 3D printer software.
The math teacher has followed the students in the calculation of the volumes of the raft and the teacher of Physics in Archimedes force calculation and experimental verification of the results.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:
Number of pupils: 26

Type of group: one single class

Number of classes: 1

Scholar curriculum specialization of the class involved: 2A - Electonics - Industrial Technical Institute (ITI)

"Special needs" students: one student with difficulty settings in motor coordination. The student, moving in a wheelchair, takes notes using a PC assisted by a special education teacher. Verbal communication is not always clear but highlights significant skills.

Entry level assessment: each subject performed a entrance test for recognizing students with greater risk of dropping out. The initial test showed significant difficulties in science subjects for the following reasons. The first year the class was quite messy: some students behaved badly and they were not admitted to following year. Then the students improved, but some problems still remain. Pupils of technical institute usually have a low propensity to study theoretical subjects. They choose this course of study for the presence of several activities with immediate applications.

SETTING UP THE EXPERIMENTATION

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

- ✓ **SUBJECTS INVOLVED**

MAIN STEM SUBJECT	PHYSICS
Topics related to the Learning Objectives of experimentation	Barycenter (3h); Pressure, Liquid's laws (3h); Archimedes' Principle, solid floating (4h).
Total number of hours dedicated to completion of the experimentation	10

OTHER RELATED SUBJECT	MATHS
Didactic Topics related to the Learning Objectives of experimentation	1. Regular solids (3h); 2. Complex solids (5h); 3. Equations in different order (3h).
Total number of hours dedicated to	11

completion of the experimentation	

OTHER RELATED SUBJECT	TECHNICAL DRAWING
Didactic Topics related to the Learning Objectives of experimentation	1. Solid drawing, orthogonal projection, axonometry (4h); 2. Complex solids (2h); 3. Drawing of complex solids (4h).
Total number of hours dedicated to completion of the experimentation	10

OTHER RELATED SUBJECT	APPLIED SCIENCES
Didactic Topics related to the Learning Objectives of experimentation	1. 2D shapes, and basic 3D solids (4h); 2. 3D solids modelling (4h); 3. Complex solids and 3D printing (2h).
Total number of hours dedicated to completion of the experimentation	8

II) PRINT STEM LAB: THE TECHNOLOGIES

SOFTWARE(S) for object DESIGN: 123D Design – Autodesk (www.123dapp.com/design), easy to learn in a few hours without requiring any special prerequisites. It is a free program and does not require a PC with special resources.

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
Filament diameter: 1.75 mm / 3.00 mm*
Filaments used: ABS,PLA, PET, Nylon, Flex, Polystyrene, Laywood, Experimenta

€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)

- **ACTION PLAN AND DURATION OF THE EXPERIMENTATION**

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

Number of hours dedicated: 6 for teacher.

People involved: 6 class teachers.

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

Number of hours dedicated: 6 (for teacher).

People involved: 4 class teachers.

3° - Entry level assessment
Number of hours dedicated: 3 (for teacher).

People involved: 4 teachers.

4° - T raining Unit on PHYSICS Subject:

Number of hours dedicated: 10.

People involved: 1 teacher and students.

Didactic methodology used to teach the contents: front lesson, pupils self study.

5° - Training Unit on MATHS Subject:

Number of hours dedicated: 11.

People involved: 1 teacher and students.

Didactic methodology used to teach the contents: front lesson, pupils self study.

6° - Training Unit on TECHNICAL DRAWING Subject:

Number of hours dedicated: 10

People involved: 1 teacher and students

Didactic methodology used to teach the contents: front lesson, pupils self study

7° - T raining Unit on APPLIED SCIENCES Subject:

Number of hours dedicated: 10.

People involved: 1 teacher and students.

Didactic methodology used to teach the contents: front lesson, pupils self study.

8° - "123D Design – Autodesk" design of the object :

Number of hours dedicated: 20.

People involved: 4 teacher and the students.

Didactic methodology used to teach the contents: laboratory work, group work, problem solving.
The students were divided into 5 groups that have chosen their own leaders. They had to draw the raft of their imagination but also with the problem of calculating the volumes of PLA and the volume of liquid displaced. From the estimate of the weight force (with reduced density of PLA from the printing process) and Archimede force the students estimated the maximum load allowed. Printed the raft and immersed in water will lead to sinking charging it with coins. The weight of the coins should match with the expected value. This activity not only asks to draw 3D but also to make calculations, become familiar with the unit, make measurements.

9° - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 4.

People involved: 1 teacher and students.

Didactic methodology used: laboratory work.
Students were guided in practical use of CURA software to generate the gcode file.

10° - Object printing:

Number of hours dedicated: 10.

People involved: 1 teacher and students.

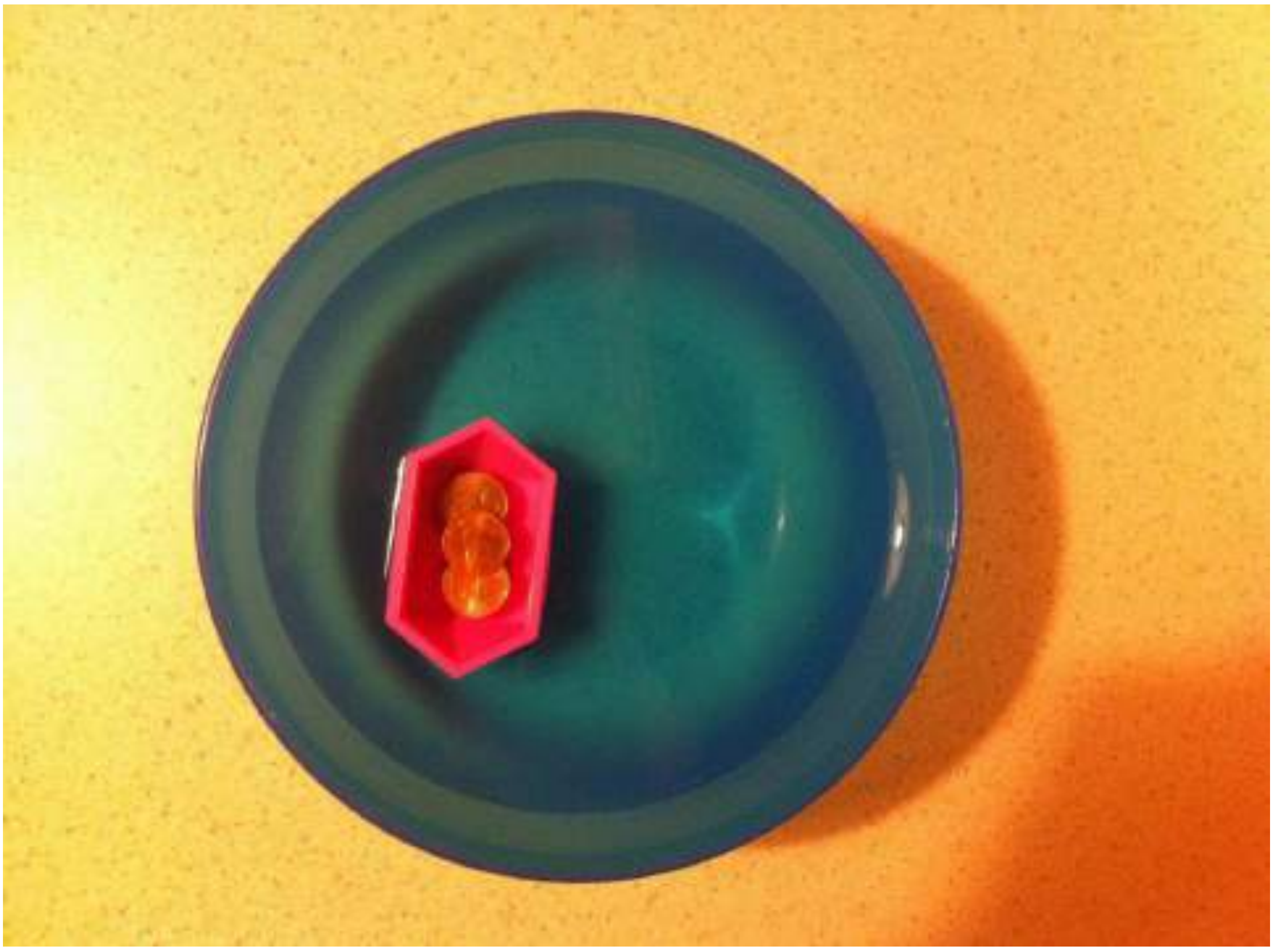
Didactic methodology used: students have printed their 3D objects.

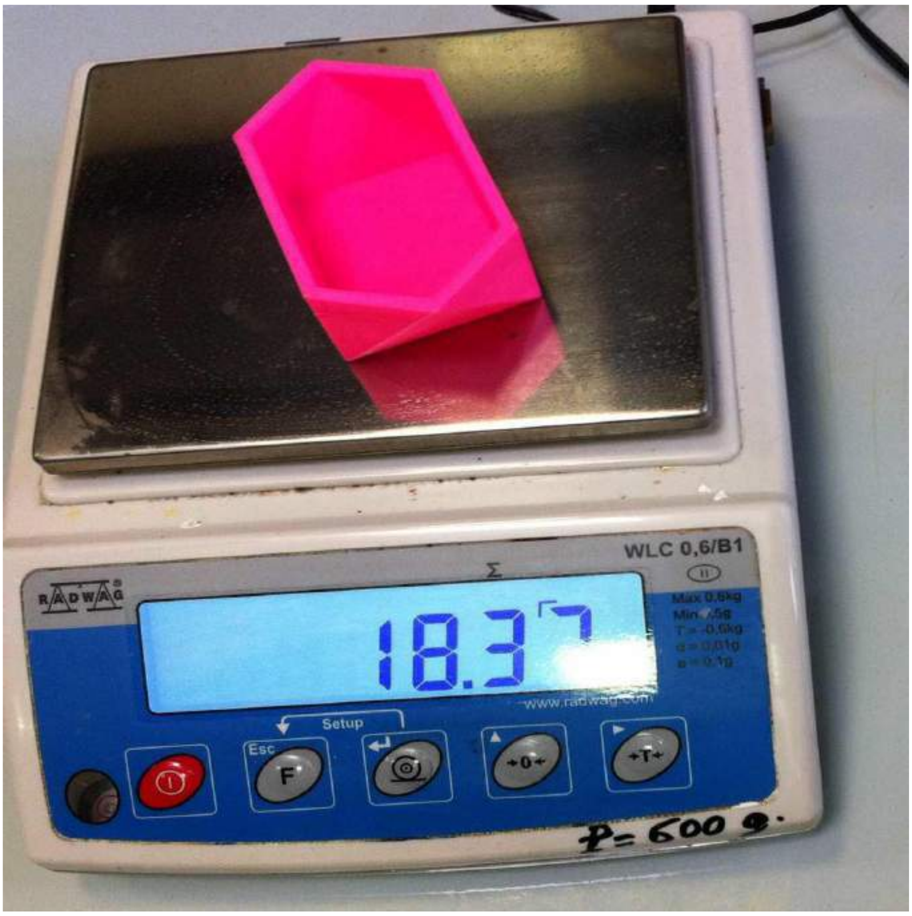
11° - End of experimentation

Number of hours dedicated: 10.

People involved: 4 teachers and students.

Didactic methodology used: all the groups have reached their target making a raft which was to support a weight confirmed by experimental measurements. Each teacher has carried out a final check to measure the increase in theoretical skills.

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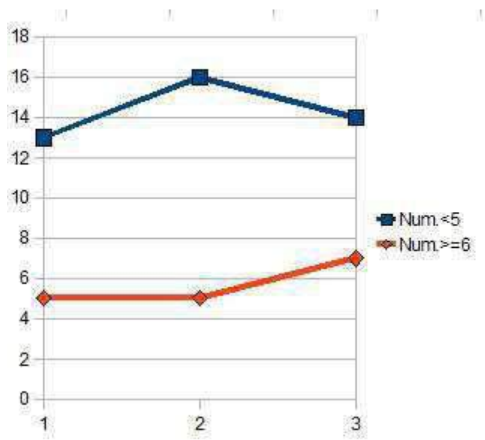
TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main scientific subject interested by the experimentation assessed, after experimentation pupils achievement of Learning Objectives, by means of written test (ten questions: 6 multiple choice questions and 4 open-ended questions) and recorded the following learning results:

- PHYSICS

Marks of Entry Test show that:
· 13 students out of 25 got bad marks (lower than 5/10)
· 5 students out of 25 got good marks (6/10 and above)
· the average of the marks is 4.72 (extremely bad)
As we can see the class has a lot of problems probably because of a particular difficult first year.
Marks of Intermediate Test show that:
· 16 students out of 25 got bad marks (lower than 5/10)
· 5 students out of 25 got good marks (6/10 and above)
· the average of the marks is 4.90 (extremely bad)
It is showed how bad pre-requisites owned by the students make the work difficult to do. Only 5 students understand didactical units usefully. As you can see the number of the students who got bad marks increases from 13 to 16.
Marks of Final Test show that:
· 14 students out of 25 got bad marks (lower than 5/10)
· 7 students out of 25 got good marks (6/10 and above)
· the average of the marks is 5.00 (not sufficient)
We can see little improvements, the number of students who got insufficient marks reduced from 16 to 14, students who got good marks improved from 5 to 7, the average of the marks grows up even if it is still not sufficient. A little the improvement of the average mark is showed



2) The students worked well with great commitment to overcome the various difficulties encountered. Unfortunately, the theoretical knowledge of a general nature are not increased by much. Their improvement is limited to the results carried out practical activities. The thing was discussed with the students, probably more effect on regular study are only possible with a continued practice activities. Direct observation on pupils - made by each member of the Teachers Team during the experimentations - enabled to record to the following further learning results:

1) For mathematics are repeated the same considerations made for physical. For Technical Drawing and Applied Sciences, being practical materials the results were always good. This confirms the strong inclination to the practical activities of the ITI student.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Use simple as 123D Design CAD software to allow students to work right away on their own.
- ✓ Included in the group of teachers at least one teacher with adequate computer skills to guide

students in the design and 3D printing.

- ✓ Include all the teachers needed to complete the necessary skills to deal with the problem.
- ✓ Choose well the object to be printed. Print objects that require a useful deepening of scientific reference material.
- ✓ The laboratory activities are not restricted to the design and 3D printing. The main activities are mainly those of study, research, analysis, calculation and design using scientific skills to be explored.
- ✓ Work in groups to foster mutual help and the ability to organize work.
- ✓ We have improvements in science skills if the 3D printing will require their effective use.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ If you want to use a more complex and professional software 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 science subjects learning.
- ✓ Take care of the adequacy of laboratory: PCs, software, 3D printer and the availability of at least a competent teacher.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ 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.
- ✓ Keep scientific 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 scientific 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.

2.5 ANIMAL CELL (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) Analysis of reciprocal, structural and dimensional relationship of cell elements,
2) dimensional measuring, using scale proportions to draw or make objects,
whose measures could differ

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing an animal cell model.

PREREQUISITES

In order to reach the defined Learning Objectives of the experimentation, the following prerequisites were required to pupils:
KNOWLEDGES:
· As the cell represents the first concept, prerequisites are not requested
· Measure theory
· Equivalence
· CAD skills
SKILLS:
· how to use units of measure
· how to pass from one unit to another
· how to use CAD programs

THE TEACHERS TEAM INVOLVED

4 teachers have been involved in the experimentation:

List each teacher' subject/domaine:
1 teacher of Biology
1 teacher of Physics
1 teacher of Math
2 teacher of Technical drawing

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 Biology, Mathematics, Physics 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: 19
Type of group: single class
Number of classes: 1
Scholar curriculum specialization of the class(es) involved: Liceo
"Special needs" students: no
Entry level assessment: multiple choice written test and questions

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	BIOLOGY

Topics related to the Learning Objectives of experimentation	Structural and functional characteristics of prokaryotic and eukaryotic cells (animals and plants)
Total number of hours dedicated to completion of the experimentation	8 hours theory in the classroom 1 hour verification

MAIN STEM SUBJECT	PHYSICS
Topics related to the Learning Objectives of experimentation	Measurement, percentage and proportions
Total number of hours dedicated to completion of the experimentation	8 hours theory in the classroom 1 hour verification

OTHER RELATED SUBJECT	MATH
Didactic Topics related to the Learning Objectives of experimentation	unit of measurement, exponentiation, approximate calculations, relative and absolute measurement errors
Total number of hours dedicated to completion of the experimentation	11 hours of theory in the classroom 1 hour verification

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN: Inventor 2009"(Autodesk)**
- **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 Biology Subject:
Number of hours dedicated: 8
People involved: physics teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work.

5° - Training Unit on Maths Subject:
Number of hours dedicated: 11
People involved: maths teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work

6° - Training Unit on Physics Subject:
Number of hours dedicated: 8
People involved: physics teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work.

7° - Training Unit on Technical Drawing:
Number of hours dedicated: 10
People involved: drawing teacher
Didactic methodology used to teach the contents: front lesson and group work. Solid drawing, othogonal projection, axonometry (4h); Complex solids (2h); 3. Drawing of complex solids (4h).

8° - CAD 2D/3D Design of the object:
Number of hours dedicated: 6
People involved: drawing teacher
Didactic methodology used: laboratory work and group work. 2D shapes, and basic 3D solids (2h); 3D solids modelling (4h); Complex solids and 3D printing.

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. Thanks to the software "Cura" and the Wasp 3D printer "Delta2040" it was possible to realize the second part of the project

10° - Object printing:
Number of hours dedicated: 6
People involved: teacher of mathematics
Didactic methodology used: laboratory work. Before starting, the Biology teacher explained the cell structure and components.
The cell was projected as a " tridimensional puzzle", made up of:

- inferior base
- superior shell
- inferior internal side
- superior internal side
- 2 mitochondria
- inferior endoplasmic reticulum
- superior endoplasmic reticulum
- inferior Golgi apparatus
- superior Golgi apparatus
- inferior nucleus
- superior nucleus
- nucleolus

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The final result of the lab work is 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. The results achieved are better than expected, thanks to the students' good work and motivation

Although the group is quite motivated, a lot of students haven't achieved an efficient study method yet and they have to improve their logical and deductive skills.
Therefore the class has been chosen for the experimentation to reach the following educational aims:

1. Learning to work in a team to improve cooperation and communication.
2. Increasing the linguistic and digital skills.
3. Encouraging the students' learning to build up their knowledge

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

At the end of the project, the use of 3D printer improved the students' knowledge and skills, thanks to the making of a 3D animal cell.
Some of them had a few problems with Maths and Physics probably due to a lack of self confidence.
Anyway the final result was good and the students showed a positive attitude and through the study of different subjects, they improved their learning style.
Standard lessons weren't disrupted by the setting of the project and the success of the "PRINT STEM" project can be useful to spend more time on useful lab activities.

WEAK POINTS OF THE EXPERIMENTATION:

- If no teacher has adequate computer skills you need a refresher course before start the experimentation.
- 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 STEM subjects 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.

2.6 SAMPLES LABELLED BY CAPITAL LETTERS and A RACK FOR TEST TUBES (IISS GADDA – Italya)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) Face the scientific subjects with a new lab tool.

2) Learn to operate in a multidisciplinary context.

3) learn to work in group.

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

Specific Learning Objectives

1) Chemical analysis.

2) Construction of objects apt to scientific laboratory experiment.

3) Scientific experimentation .

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.

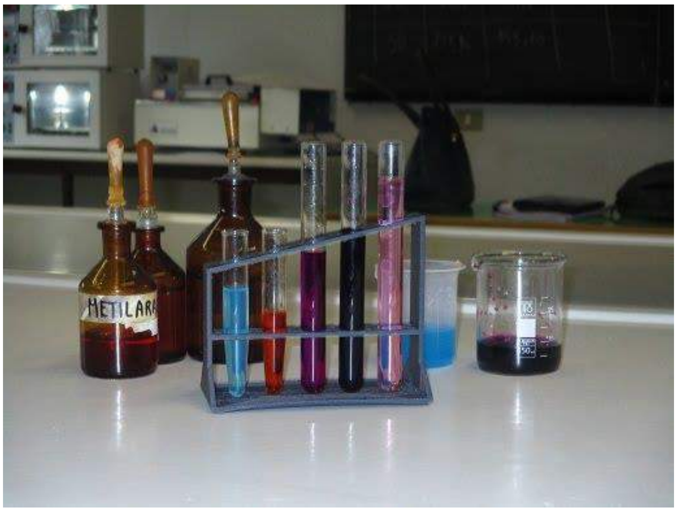
PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a set **of samples labelled by capital letters (to be chemically analyzed) and a rack for test tubes**.

Why this object?

Our school is specializing in material chemistry. Investigating the chemical properties of PLA was an useful lab exercise; creating a lab tool was the natural consequence of that.

Samples.



Rack for test tubes.

PREREQUISITES

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

- ✓ Density.
- ➢ Concentration.
- ➢ Acid and base compounds.
- ✓ 3D basic Geometry.
- ✓ Basic computer knowledge and competences.
- ✓ Basic knowledge and competences in technical drawing.

THE TEACHERS TEAM INVOLVED

2 teachers have been involved in the experimentation:

1 teacher of Chemistry.

1 teacher of Graphics.

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I05 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: 17

Type of group: single class.

Number of classes: 1

Scholar curriculum specialization of the class involved: Computer Science and Communications

"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 SCIENTIFIC SUBJECT	CHEMISTRY
Topics related to the Learning Objectives of experimentation	➢ Applying formulas. ➢ Write a scientific report. ➢ Data collection. ➢ Use of chemical laboratory equipment. ➢ Safety regulation in chemical lab.
Total number of hours dedicated to completion of the experimentation	16

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 and AUTOCAD).
Total number of hours dedicated to completion of the experimentation	10

II) PRINT STEM LAB: THE TECHNOLOGIES

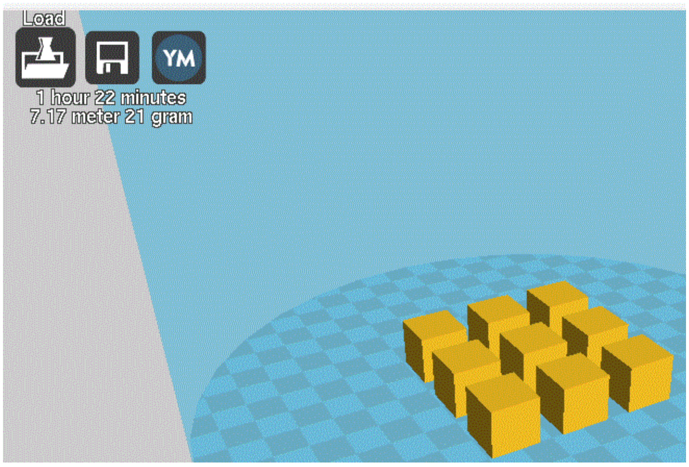
- **SOFTWARE for object DESIGN:** SKETCHUP.
  Easy to use, open source, see tutorials in http://www.architectionary.com/SketchupTutorials

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

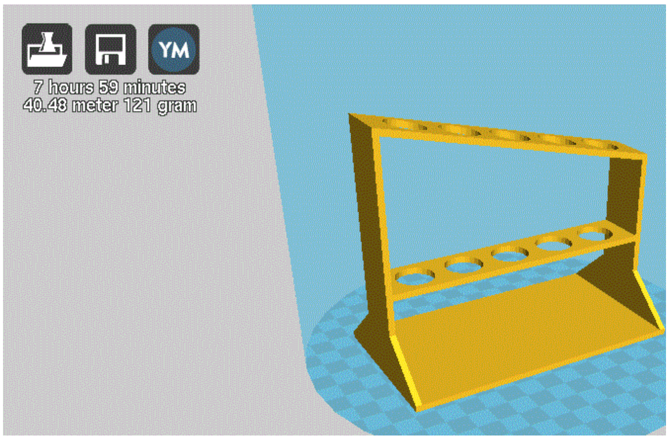
- **3D PRINTER:** WASP

PLASTIC MATERIAL: PLA It's possible to buy it online**.**

IMPORTANT: Quantity of this material necessary for printing:



Quantity of material and time.



Quantity of material and time

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

2 Teachers.

 Prof. E. Iasoni – Chemistry	 Prof. V Mangione - Graphics.

3° - Entry level assessment

Number of hours dedicated: 1

2 Teachers.

4° - Training Unit on Chemistry:

Number of hours dedicated: 8

People involved: Chemistry teacher.

Didactic methodology used to teach the contents:

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

5° - Training Unit on Graphics:

Number of hours dedicated: 4

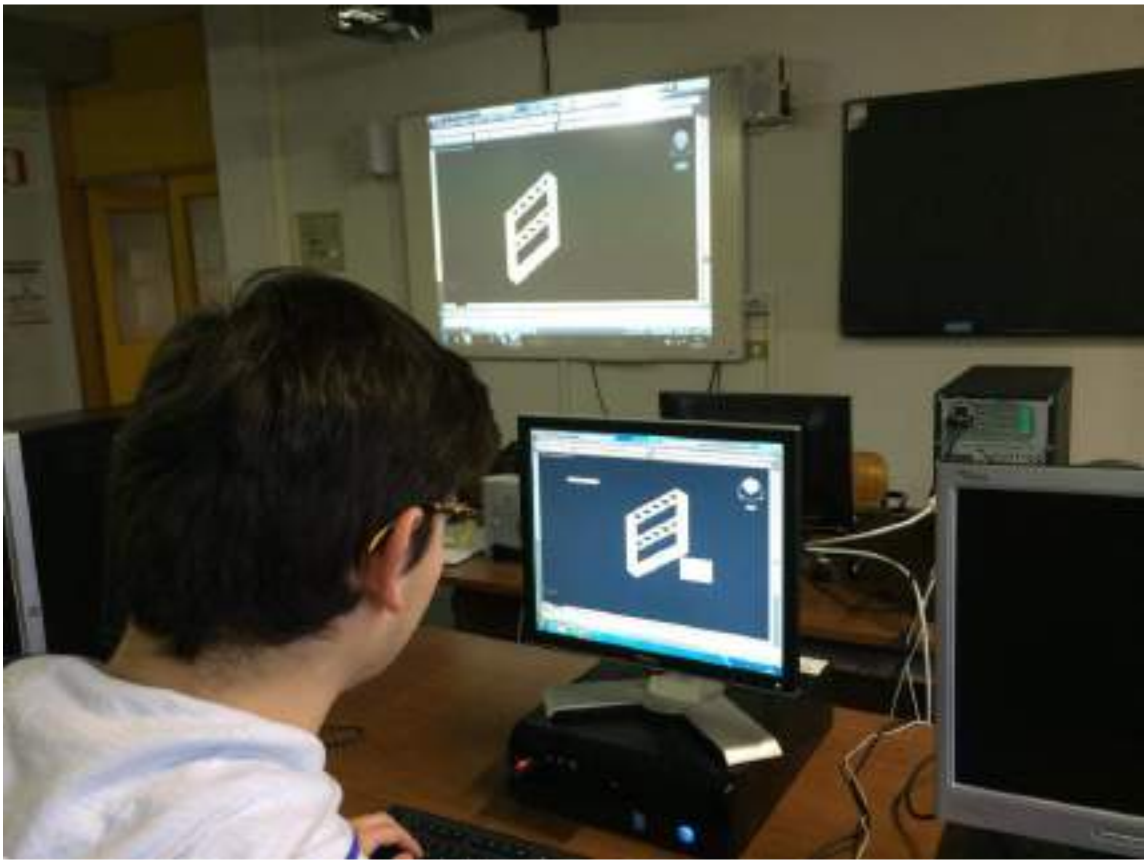
People involved: Graphics teacher.

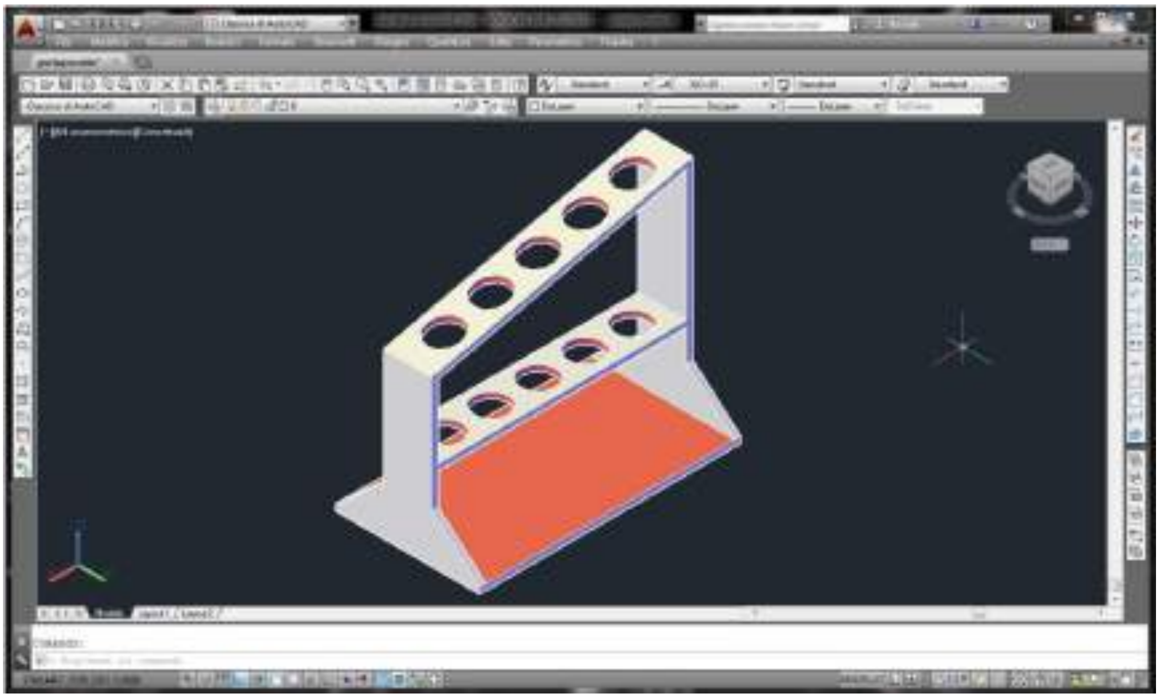
Didactic methodology used to teach the contents:

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

6° - CAD Design of the object:

- Number of hours dedicated: 6
- People involved: Graphics teacher.





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

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:

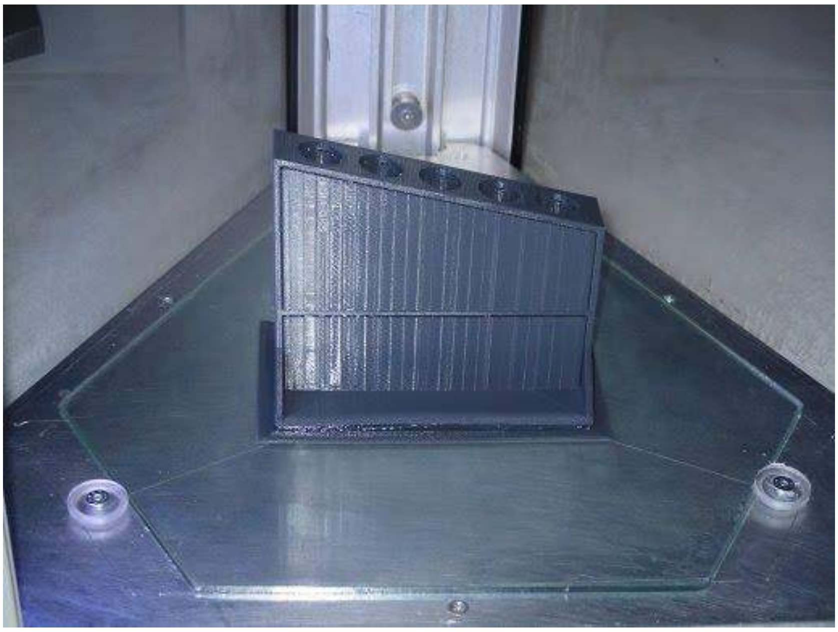
Number of hours dedicated: 1

People involved: Coordinator of the project + teachers involved.

Didactic methodology used:

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

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



9° - End of experimentation

Number of hours dedicated: 4

People involved: 2 teachers involved.

Didactic methodology used:

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

Pupils added a research about the chemical structure of PLA.

See the download at the webpage

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

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

TABELLA VALUTAZIONE PROGETTO

GRUPPO	NOMINATIVI	RACCOLTA MATERIALE RICERCA PLA	ORGANIZZAZIONE ANALISI LABORATORIO	STESURA RELAZIONE	PRESENTAZIONE FINALE LAVORO	CAPACITÀ DI COLLABORAZIONE ALL'INTERNO DEL GRUPPO E CON GLI ALTRI GRUPPI
1	St Fe Fo	BUONO	BUONO	BUONO		DISCRETO
2	K C A	DISCRETO	BUONO	DISCRETO		DISCRETO
3	N B D	BUONO	BUONO	BUONO	BUONO	DISCRETO
4	C C P C	DISCRETO	BUONO	DISCRETO		DISCRETO
5	N R Xl S	DISCRETO	BUONO	DISCRETO		DISCRETO

La partecipazione al progetto ha permesso di migliorare

le **capacità di collaborazione** tra i componenti del gruppo e tra i diversi gruppi.

Imparare **ad organizzare** un esperienza di laboratorio

Evaluation - Chemistry.

The teacher of the main scientific subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of standard tests.

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) Increasing capability of work in group.

2) Increasing capability of organizing a lab work.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation.
- ✓ The use of a simple CAD software as Sketchup can lead some enthusiastic pupils to face successfully more complex CAD software.
- ✓ The charm of a new device can increase the attention of the class.
- ✓ The 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 FOR NEW LEARNING EXPERIENCES

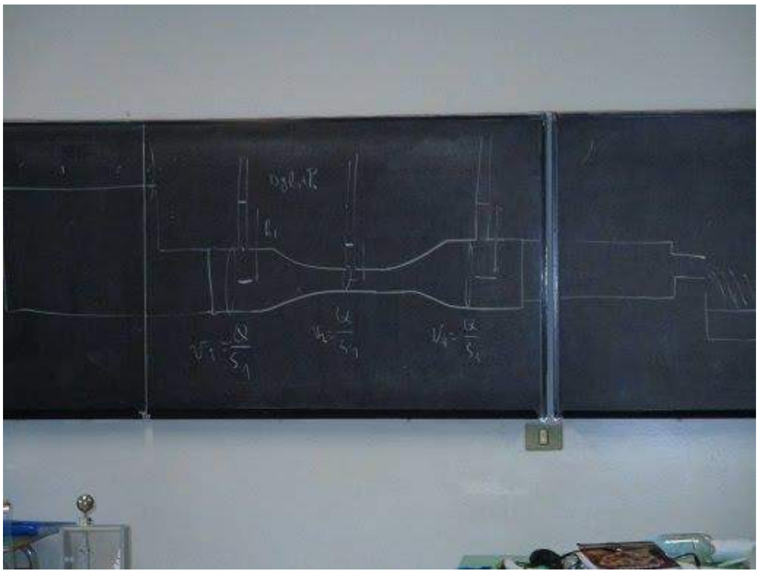
- ✓ The 3d printer is going to be a new didactical tool but it isn't a new distinct subject.
- ✓ During a class council, the teachers of the team decide how to organize the activity.
- ✓ The teachers choose the topic in accordance with the ordinary didactic planning of the class.
- ✓ Plan with care the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

PRINTED OBJECT

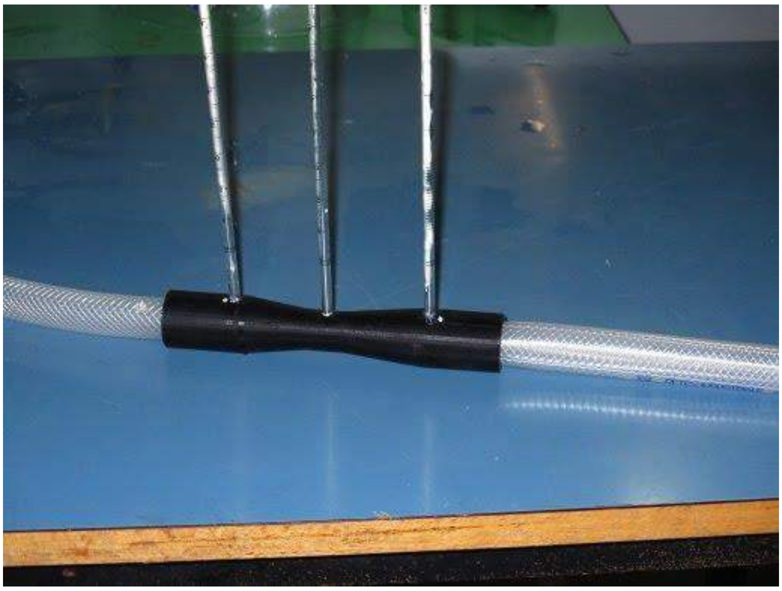
In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a **Venturi pipe**.

Why this object?

Our school is dealing with bodywork production companies; some of our elder students are performing internships in a firm where they can see the manner of working of a wind-chamber. Investigating the dynamics of fluids seemed an useful lab exercise; creating a lab tool was the natural consequence of that.



Theory.



The venture tube.

PREREQUISITES

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

- ✓ Basic concept of Physics.
- ✓ Basic concepts of hydrodynamics.
- ✓ Bernouilli's equation.
- ✓ 3D basic Geometry.
- ✓ Basic computer knowledge and competences.
- ✓ Basic knowledge and competences in technical drawing.

THE TEACHERS TEAM INVOLVED

2 teachers have been involved in the experimentation:

1 teacher of Physics.

1 teacher of Graphics.

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I05 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: 20

Type of group: single class.

Number of classes: 1

Scholar curriculum specialization of the class involved: Computer Science and Communications

"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 SCIENTIFIC SUBJECT	PHYSICS
Topics related to the Learning Objectives of experimentation	✓ Basic concept of Physics (speed, pressure, density, gravity…). ✓ Basic concepts of hydrodynamics (flow rate, flux…). ✓ Bernouilli's equation. ✓ Measurements in Physics lab.
Total number of hours dedicated to completion of the experimentation	17

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 and AUTOCAD).
Total number of hours dedicated to completion of the experimentation	8

II) PRINT STEM LAB: THE TECHNOLOGIES

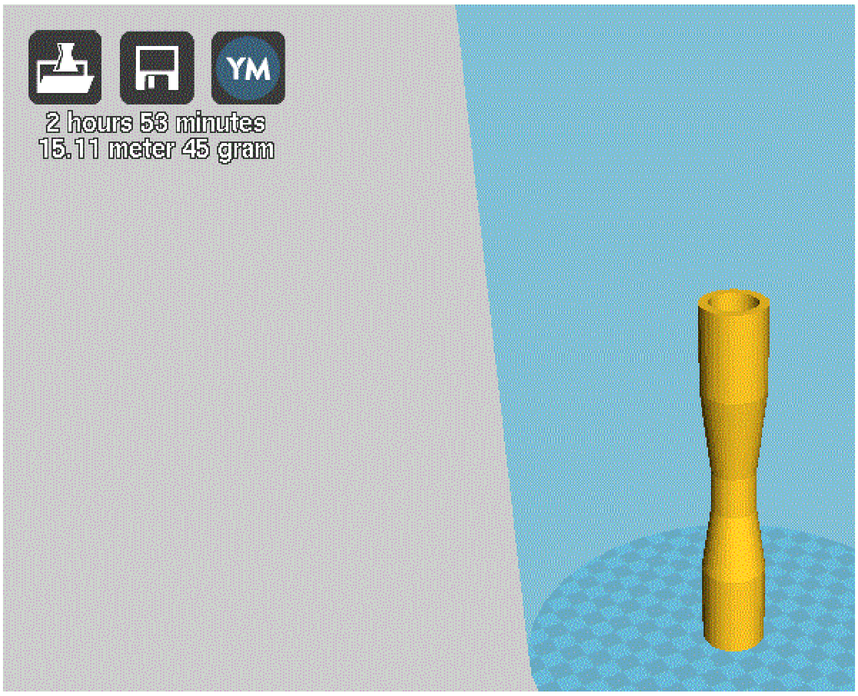
- **SOFTWARE for object DESIGN:** SKETCHUP.
  Easy to use, open source, see tutorials in http://www.architectionary.com/SketchupTutorials

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

- **3D PRINTER:** WASP

- **PLASTIC MATERIAL: PLA.**

It's possible to buy it online.



Quantity of material and time.

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 2

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

2 Teachers.

Prof. L. Quarantelli – Physics.

Prof. V Mangione - Graphics.

3° - Entry level assessment

Number of hours dedicated: 1

2 Teachers.

4° - Training Unit on Physics:

Number of hours dedicated: 4

People involved: physics teacher.

Didactic methodology used to teach the contents:

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

5° - Training Unit on Graphics:

Number of hours dedicated: 4

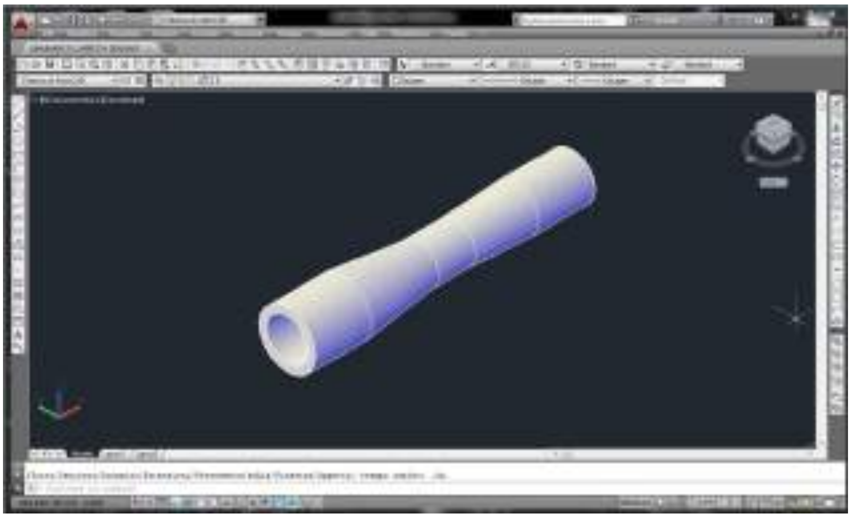
People involved: Graphics teacher.

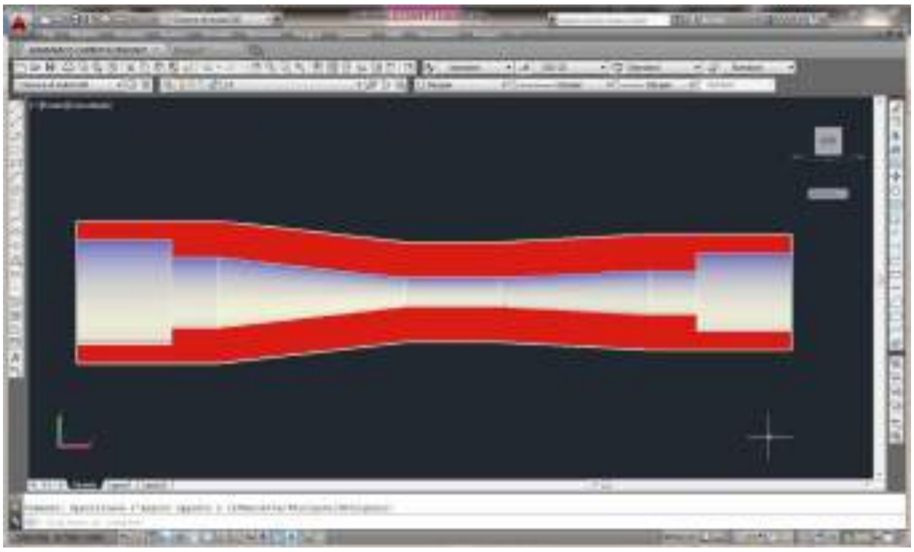
Didactic methodology used to teach the contents:

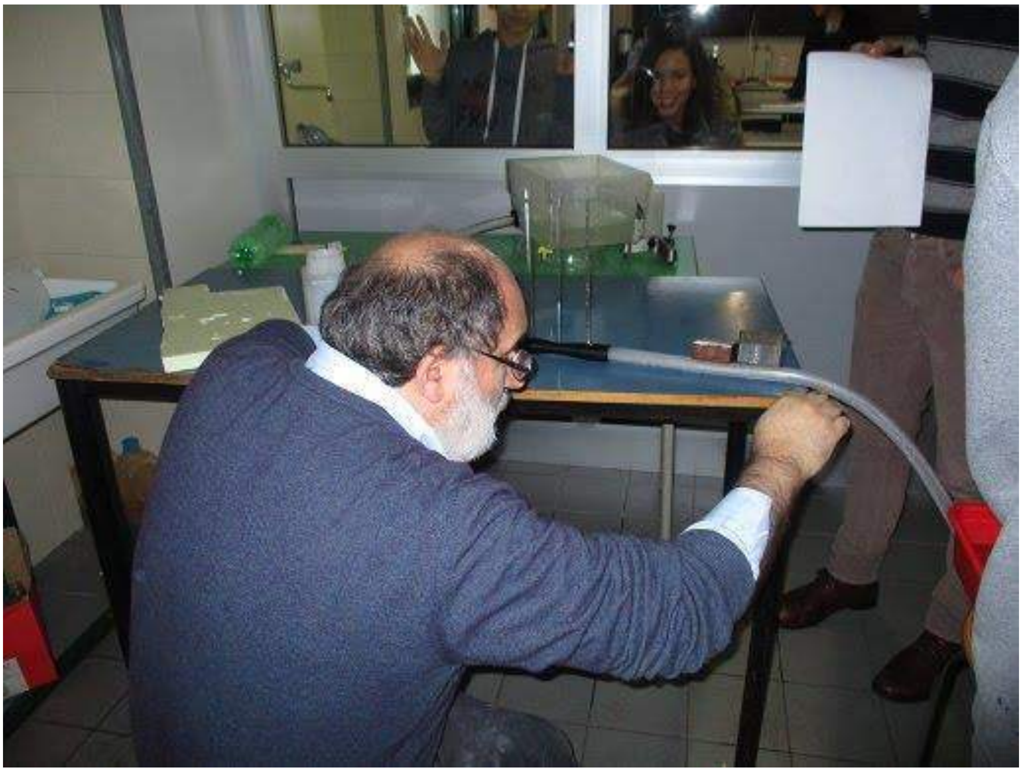
- Frontal lesson.
- Pupils self-study.
- Laboratory work.

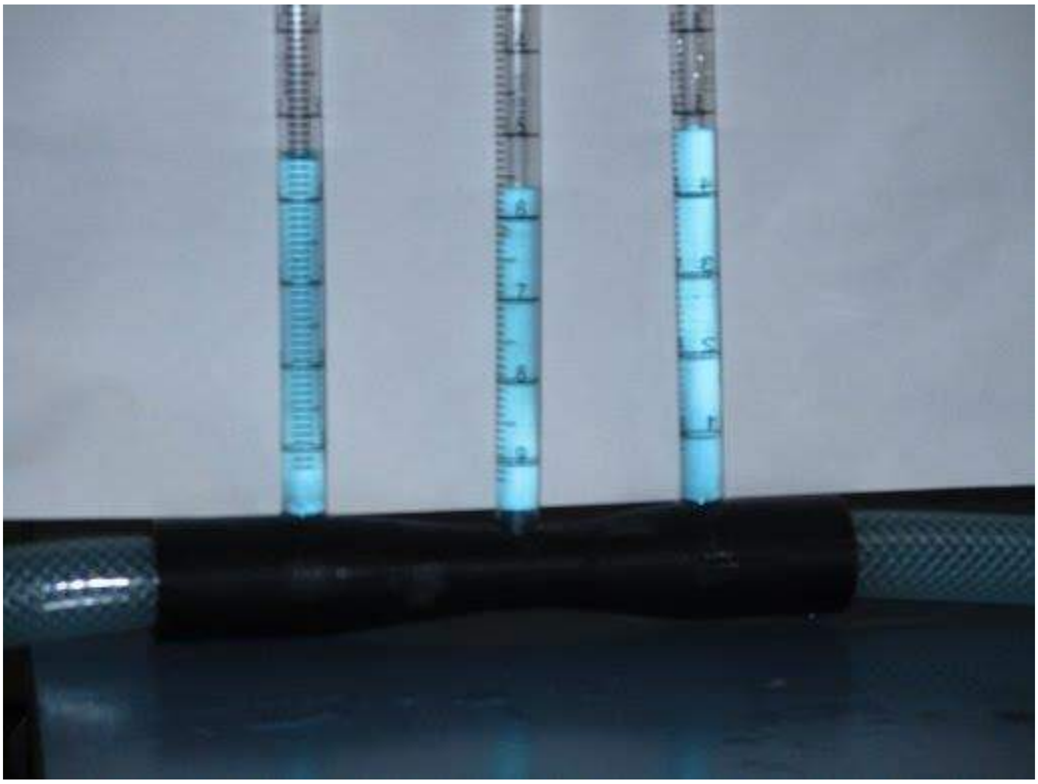
6° - CAD Design of the object:

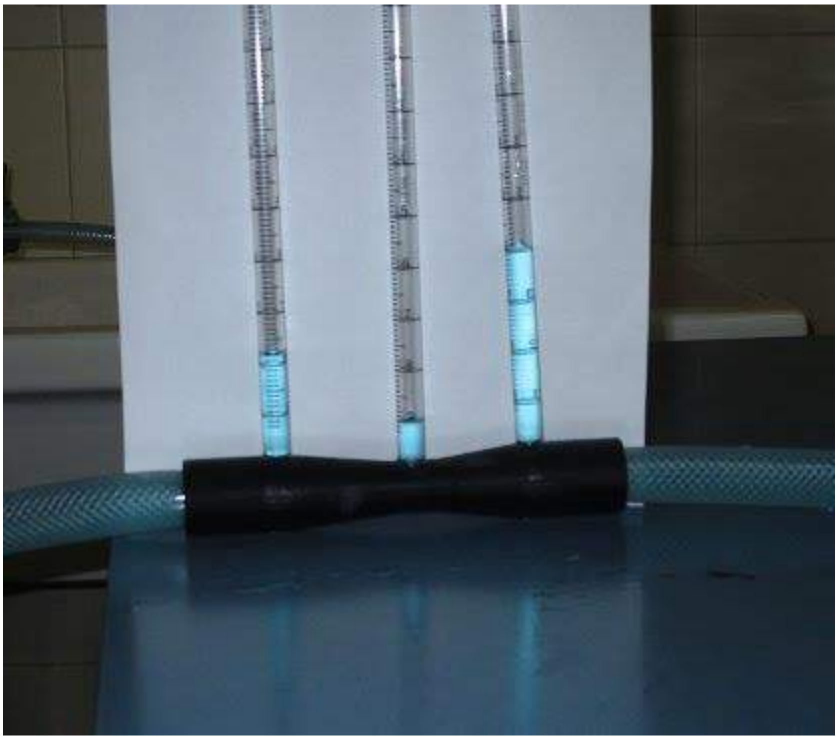
- Number of hours dedicated: 6
- People involved: Graphics teacher.











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

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

Number of hours dedicated: 2

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:

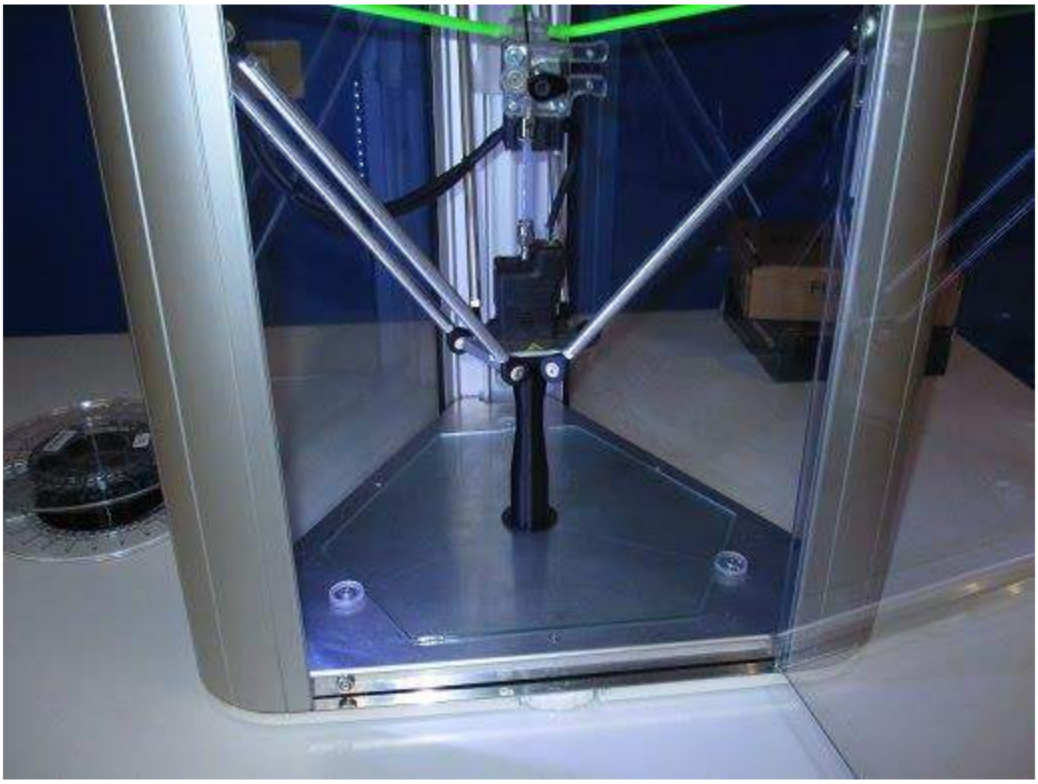
Number of hours dedicated: 2

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.



9° - End of experimentation

Number of hours dedicated: 4

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 scientific subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of standard tests.

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) Increasing capability of work in group.

2) Increasing capability of organizing a lab work.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation.
- ✓ The use of a simple CAD software as Sketchup can lead some enthusiastic pupils to face successfully more complex CAD software.
- ✓ The charm of a new device can increase the attention of the class.
- ✓ The 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 FOR NEW LEARNING EXPERIENCES

- ✓ 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.

2.7 ATOMIC ORBITALS (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the teachers team were:

GENERAL Learning Objectives

1) The Atomic Orbital Concept
2) Quantum numbers
3) Electron configuration
4) The periodicity of chemical elements related to the electron configuration
5) The electronegativity concept
6) The octet rule
7) Covalent and ionic bond

Specific Learning Objectives

1) Set energy, form and direction of an Atomic orbital starting from the quantum numbers values
2) How to disrtibute electrons of a chemical element in the atomic orbital
3) Set group and period of a chemical element inside the periodic table from the electron configuration
4) Establish the chemical bonds from the difference of electronegativity of the elements involved
5) Graphical representation of the chemical bonds also with molecular models

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

Reproduction of atomic orbitals provides a model that promotes the comprehension of the theoretical aspects of chemical bonds, which the second year students generally have difficulty assimilating.

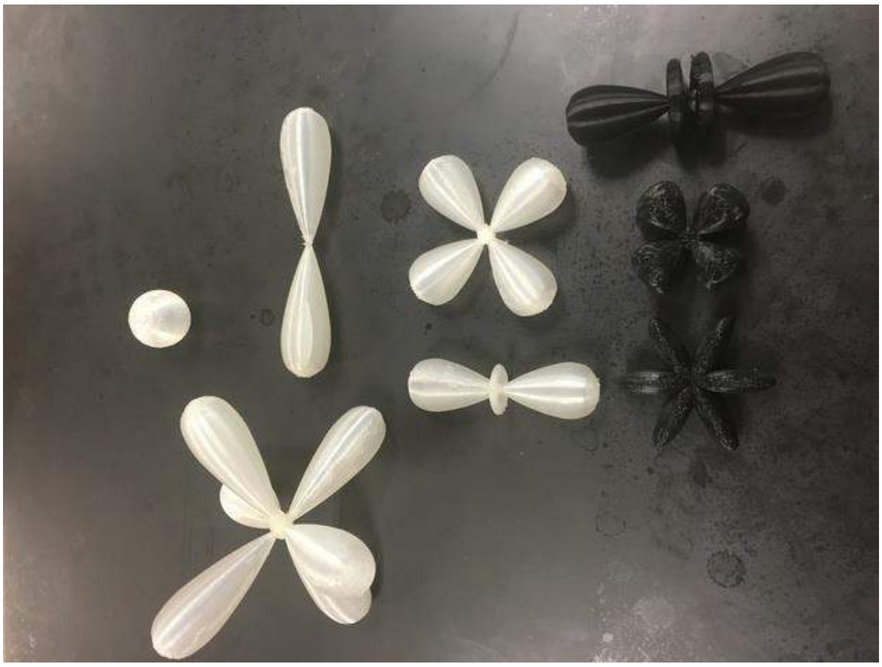
PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, teachers agreed on printing a set of atomic orbitals.

Why this object?

The object was chosen because:

1) It promotes comprehension of shape, direction and energy of atomic orbitals
2) It allows to set the electron distribution of an element starting from his position on the periodic table
3) It foster understanding properties of the different chemical bonds
4) It allows an experimental approach to theoretical concepts



PREREQUISITES

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

- Knowledge of the atomic structure
- Basic knowledge of AUTOCAD
- Be able to read the periodic table
- Knowledge of the periodic properties

THE TEACHERS TEAM INVOLVED

Four teachers have been involved in the experimentation:

1 teacher of Technical Design and Computer Graphics (CAD)

2 teachers of Chemistry

1 teacher of 3D printing

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I05 implementation: One teacher of Technical Design and Computer Graphics to draw the objects, one teacher of 3D printing to help pupils in the printing process, two teachers of Chemistry for the training unit.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 12

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

Number of classes: 1

Scholar curriculum specialisation of the class involved: Computer Science and Communications

"Special needs" students: 1 *special needs* student

Entry level assessment: the level of preparation, assessed by a written test and review lessons, presented a heterogeneous preparation, but generally poor. A couple of students had good intuition and an adequate level of preparation. After the entry level assessment we reformulated the initial programming objectives.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

Chemistry	CHEMISTRY

Topics related to the Learning Objectives of experimentation	1) The Atomic Orbital Concept 2) Quantum numbers 3) Electron configuration 4) The periodicity of chemical elements related to the electron configuration 5) The electronegativity concept 6) The octet rule 7) Covalent and ionic bond
Total number of hours dedicated to completion of the experimentation	8

TECHNICAL DRAWING AND COMPUTER DESIGN	Solid modelling
Didactic Topics related to the Learning Objectives of experimentation	1) working with AutoCAD commands: extrude, revolve, join, substract, intersect, slice. 2) Working with plane figures before moving to three-dimensional modelling 3) Identify the object structure to break down into simple solids
Total number of hours dedicated to completion of the experimentation	4

II) PRINT STEM LAB: THE TECHNOLOGIES

SOFTWARE(S) for object DESIGN: AUTOCAD as is the software that we have,

SOFTWARE(S) for object PRINTING: CURA for slicing. It can be downloaded at https://ultimaker.com/en/products/cura-software/list**. Is FREE but not sure it's open source. (I'm not able to find the source code!)**

3D PRINTER: The object was printed using COBOT and a WASP DELTA 2040. The COBOT is a 3D printer built by ex-student of the school. The price is around XXXX euro. It's built almost just by inox food grade steel, ceramic bearings and E3D V6 0.4 hotend.

3D PRINTER: WASP

- **SOFTWARE(S) for object DESIGN: AUTOCAD as is the software that we have,**

- **SOFTWARE(S) for object PRINTING: CURA for slicing. It can be downloaded at** https://ultimaker.com/en/products/cura-software/list**. Is FREE but not sure it's open source. (I'm not able to find the source code!)**

- **3D PRINTER: The object was printed using COBOT and a WASP DELTA 2040. The COBOT is a 3D printer built by ex-student of the school. The price is around XXXX euro. It's built almost just by inox food grade steel, ceramic bearings and E3D V6 0.4 hotend.**

It's the first commercial REPRAP printer in italy.

It's a DELTA printer, wich mean simple scalabilty (mean BIGGER !!!) printer.

It’s sell online (http://www.wasproject.it/w/) and it cost around 3000 euro.

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
(MEPA is a virtual marketplace for italian government structure only !!!)
- 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:
ATOM: 8 meters / 24 gr / 1 and half hours
ORBITALS: 8 meters / 24 gr / 1 and half hours
(time depend on many variable parameters!)

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 Teachers.

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

Number of hours dedicated: 4

People involved: 4

3° - Entry level assessment

Number of hours dedicated: 2

3 Teachers.

4° - Training Unit on Chem Subject:

Number of hours dedicated: 4

People involved: 2.

Didactic methodology used to teach the contents:

- Frontal lessons;
- Laboratory work
- Group work

5°/6° – CAD Design of the object:

Number of hour dedicated: 4

People involved: CAD teacher

Didactic methodology used:

- Frontal lessons on £D CAD basic commands;
- Laboratory work group

7°/8° - Transfer of the object designed to 3D printing software and object printing:

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

They could attend the beginning of the 3D printing.

9° - End of experimentation

Number of hours dedicated: 2

People involved: 2 teachers involved.

Didactic methodology used:

- Final test and class reasoning and comments on the whole experimentation

See the project at the webpage:

https://sites.google.com/a/fr.itsosgadda.it/print-stem/experimentations/2-a---langhirano/atomicorbital

TEACHER FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main scientific 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:

1) The use of software for 3D design, relative to the molecular orbitals, has helped to improve collaboration among the pupils. Subsequently we moved on to the printing stage. At this step, and in the final elaboration the interest and commitment of the students has improved.

At the end of the laboratory experience almost all pupils were able to:

• understand the electron configuration

• predict the position of an element in the periodic table

• predict the type of bond

• graphically represent the different chemical bonds

LESSON LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- Students have shown more attention, interest and participation towards a generally underappreciated topic
- They were able to create models for abstract concepts and apply their knowledge to predict compounds with certain characteristics
- Students have improved their ability to work in teams

- Good for students and teachers the involvement of more subjects simultaneously

WEAK POINTS OF THE EXPERIMENTATION:

Lack of time

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

All of the activities should be planned in detail at the beginning of the school year, and all the teachers involved should be already in service in the school.

2.8 PULLEY (IISS GADDA – Italy)

LEARNING OBJECTIVES

GENERAL Learning Objectives

1) Manual (with line, compass and protractor) and electronic (AUTOCAD) design of geometric shapes.
2) Representation in orthogonal projection of simple geometric shapes
3) Knowledge and use of physical quantities
4) Knowledge and use of physics formulas
5) Use of ratios and proportions
6) Planning and identification of logical connections and relational links
7) Communication and team work

Specific Learning Objectives

1) Knowledge of the conditions for equilibrium of a point and ability to apply the equation of equilibrium to rotation.
2) Knowledge of simple machines, of their advantages and ability to analyze a system consisting of levers and pulleys
3) Use of a hoist for lifting loads

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

The subject was chosen because scholar curriculum specialisation of the class involved was maintenance and technical support and the use of the simple machines and the comprehension of their principles is part of the output profile of the students, as well as in the annual program

PRINTED OBJECT

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

Why this object?

The object was chosen because:

1) The object shows the importance of knowledge of Physics (quantities, measurements, formulas, theoretical systems) in practical work;

2) It promotes knowledge of simple machines and the understanding of their physical principles of use;
3) It enables an experimental approach to abstract concepts.

PREREQUISITES

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

- Knowledge of geometric shapes and basic geometric concepts (polygons, solids, concepts of perimeter and area) and their manual graphical representation;
- Basic knowledge of AUTOCAD;
- Knowledge of orthogonal projections;
- Knowledge and application of the second law of motion;
- knowledge of the the concept of work and moment of a force.

THE TEACHERS TEAM INVOLVED

Four teachers have been involved in the experimentation:

List each teacher' subject/domaine:

1 teacher of Technical Design and Computer Graphics (CAD)

2 teachers of Physics

1 teacher of 3D printing

Rationale of the Teachers Team

The teachers involved in the team were chosen because:

One teacher of Technical Design and Computer Graphics to draw objects;

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

Two teachers of Physics for training unit.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 17

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

Number of classes: 1

Scholar curriculum specialisation of the class involved: Maintenance and technical support

"Special needs" students: dyslexic and dyscalculic students

Entry level assessment: the level of preparation, assessed by a written test and review lessons, presented a heterogeneous preparation, but generally poor. A couple of students had good intuition and an adequate level of preparation. After the entry level assessment we reformulated the initial programming objectives.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

Physics	Pulley

Topics related to the Learning Objectives of experimentation	1) Equations of static equilibrium; 2) Levers of the first, second and third kind; 3) Advantageous and disadvantageous machines; 4) Pulleys: fixed and mobile; 5) Hoist: simple and multiple; 6) Forces, distances, moments.
Total number of hours dedicated to completion of the experimentation	8

TECHNICAL DRAWING AND COMPUTER DESIGN	Solid modelling
Didactic Topics related to the Learning Objectives of experimentation	1) working with AutoCAD commands: extrude, revolve, join, substract, intersect, slice. 2) Working with plane figures before moving to three-dimensional modelling 3) Identify the object structure to reduce the complexity into simple solids.
Total number of hours dedicated to completion of the experimentation	4

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN: AUTOCAD as is the software that we have,**

- **SOFTWARE(S) for object PRINTING: CURA for slicing. It can be downloaded at https://ultimaker.com/en/products/cura-software/list. Is FREE but not sure it's open source. (I'm not able to find the source code!)**

- **3D PRINTER: The object was printed using COBOT and a WASP DELTA 2040. The COBOT is a 3D printer built by ex-student of the school. The price is around XXXX euro. It's built almost just by inox food grade steel, ceramic bearings and E3D V6 0.4 hotend.**

3D PRINTER: WASP

It's the first commercial REPRAP printer in italy.

It's a DELTA printer, wich mean simple scalabilty (mean BIGGER !!!) printer.

It's sell online (http://www.wasproject.it/w/) and it cost around 3000 euro.

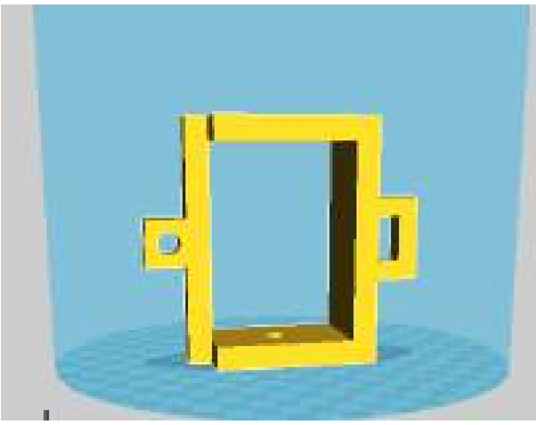
- **PLASTIC MATERIAL: PLA 1,75 mm diameter**

Cost vary in a wide range (from 20 to 40 euros/kg);

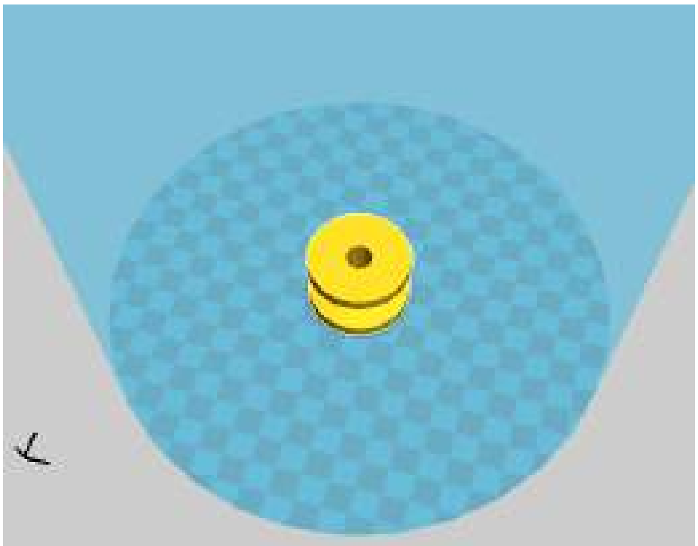
- For Italian school only: look at MEPA market
(MEPA is a virtual marketplace for italian government structure only !!!)

- 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

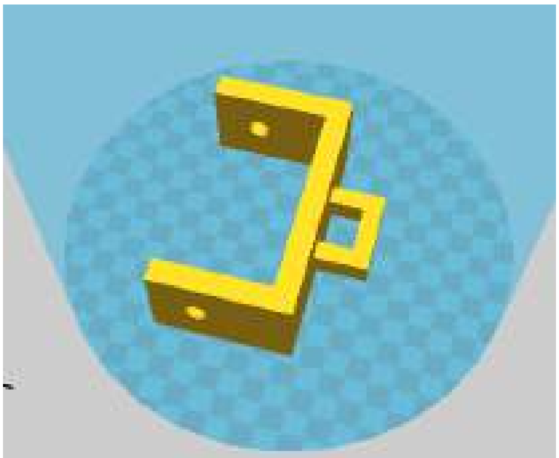
IMPORTANT: Quantity of this material necessary to print 1 object of the experimentation is:
Piece 1 : 29 Meter / 85 gr. / 4 hours;



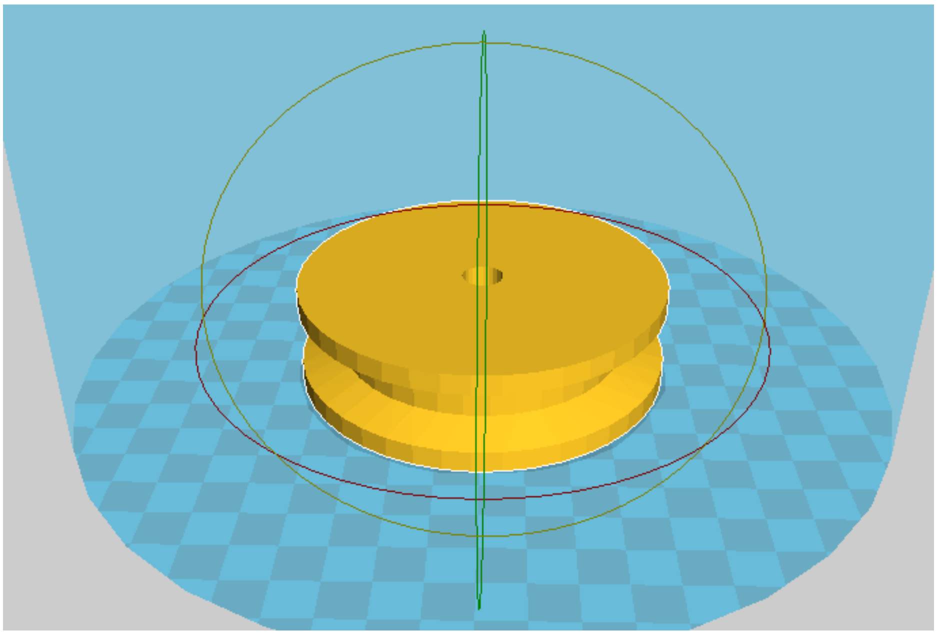
Piece 2 (pulley) 17 meters / 17 gr. / 1 hour each one (print more than one will reduce total time)



Piece 3: 37 meters / 68 gr / 4 hours;



Piece 4: 31 Meters / 90 gr. / 5 hours



III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 8

People involved: 3 Teachers.

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

Number of hours dedicated: 4

People involved: 4

3° - Entry level assessment

Number of hours dedicated: 4

3 Teachers.

4° - Training Unit on Phisics Subject:

Number of hours dedicated: 4

People involved: 2.

Didactic methodology used to teach the contents:

- Frontal lessons;
- Laboratory work
- Group work

5°/6° – CAD Design of the object:

Number of hour dedicated: 4

People involved: CAD teacher

Didactic methodology used:

- Frontal lessons on £D CAD basic commands;
- Laboratory work group

7°/8° - Transfer of the object designed to 3D printing software and object printing:

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

They could attend the beginning of the 3D printing.

9° - End of experimentation

Number of hours dedicated: 2

People involved: 2 teachers involved.

Didactic methodology used:

- Final test and class reasoning and comments on the whole experimentation

See the project at the webpage:

https://sites.google.com/a/fr.itsosgadda.it/print-stem/experimentations/2-a---langhirano/pulley-1

TEACHER FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main scientific 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:

1) The use of software for 3D design, in order to realize a pulley , has helped to improve collaboration among the pupils. Subsequently we moved on to the printing stage and then the mounting.

At this step, and in the final sperimentation of this simple machine the interest and commitment of the students has improved.

The laboratory experience has allowed most of the students to understand and learn how to use formulas explained during the frontal and / or review lessons.

In writing the laboratory report, the class was committed and engaged.

At the end of the laboratory experience almost all pupils were able to:

- Measure with the caliper the diameter of a pulley;

- Assembly the components to mount the pulley;

- Create drawings of their machines;

- Calculate the weight given the masses;

- Calculate the force required to lift a weight with the different types of pulleys.

LESSON LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- Students have shown more attention, interest and participation towards a generally underappreciated topic
- They were able to create models for abstract concepts and apply their knowledge to predict compounds with certain characteristics
- Students have improved their ability to work in teams
- Good for students and teachers the involvement of more subjects simultaneously

WEAK POINTS OF THE EXPERIMENTATION:

- Lack of time

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- All of the activities should be planned in detail at the beginning of the school year, and all the teachers involved should be already in service in the school;
- Pupils should already have the basics of 3D modeling softwares;
- Within each class there should be the highest number of possible working groups (ideal number of students per group: 3);
- In order to achieve a greater involvement in the activities, the evaluation should consider not only the final test results, but also the extra material produced by the students: photo slideshows, videos, etc.