Erasmus+ | AGENZIA NAZIONALE INDIRE

PRINTSTEM

Pedagogical Resources IN Teaching Science, Technology, Engineering, Mathematics

PUPIL-LED EDUCATIONAL EXPERIMENTATIONS WITH PROJECT WORK APPROACH

Intellectual Output N. 3

Release of final validated Intellectual Output: June 2016

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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, please visit http://www.printstemproject.eu/

Responsible Partner of IO3: Secondary School 1epalchanion

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Chapter 1. General Training Programme for Pupil-Led experimentations with 3D printer – Guidelines for Teachers

The main scope of the present document is to provide school teacher with Guidelines, in order to exploit for their use the results of experimentations done within PRINT STEM PROJECT experimentations.

The objective of such experimentations, when replicated, should be to give pupils a problem to be solved /objective to be achieved and instruct them, on the initiative of an individual or small group, in such a way, so that they will eventually be able to use 3D printing technology for its resolution/achievement, applying their mathematical and scientific skills in a way that may be observed and assessed by teachers.

The project work approach (with focus on design and applied technology), goes through every step of the process of engineering and production of an object: conception, design, modelling, execution.

As of project work concept, the activity can be conducted both as a curricular activities, in gourp, within classes, or as an extracurricular programme in the double meaning of: independent learning and pupil-led experimentation

1.1 LICENCE CONDITIONS FOR RE-USE OF THE DIDACTIC 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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PRINTSTEM_SABANCI
PRINTSTEMPROJECT_KSGS
PRINTSTEMPROJEC

1.2 THE PUPIL-LED APPROACH

During pupil-led experimentations, teachers should follow a specific process, which aims at:

- giving students the chance to observe the world around them in a more critical, thought-provoking way
- making students discover the vast uses and applications of 3D printing in goods' production, mirroring notions taught during STEM subjects' teaching
- helping students to develop their ability to come up with ideas, based on the knowledge which is considered as prerequisite, in order for their ideas to be achieved
- helping students to develop their ability to set the necessary conditions, in order for their designs to turn into reality
- helping students work based on their interests / hobbies, find how 3D printing can be implemented in them and follow a narrowing – down process, in order to realize which of the possible applications of 3D printing could be achieved, based on their knowledge and general conditions prevailing in our premises (potential and dynamics of our 3D printer, time needed for each idea to turn into a 3D model, etc.)

In order to meet these goals, the validated steps to be followed should be:

1. Assignment to students for online research about the fields of everyday life, in which 3D printing can be applied
2. Team work and presentation in Google Drive Presentation (which is a Share Tool) about their research results
3. Check of students Learning Objectives and evaluation whether they match STEM subject valuable learning
4. Revise of Learning Objectives by teachers intervention in order to make more challenging and useful for students
5. Browsing in Open Libraries, in order to spot designs of objects they had decided to print, based on the parameters mentioned above
6. Round-table discussion on objects printed, in order to examine the conditions necessary in order for each of them to be printed. The aim must be to make students go through a self-evaluation process before setting for their final experimentation
7. Carrying out
8. Actual 3D printing of each sub-group's desired object, after they had followed the whole process of drawing objectives with soaftware and transferred to files ready for the 3D printer (see Experimentations)

9. Final presentations of students of their project work, together with leassons learnt and observations

1.3 SIGNIFICANT FACTORS TO BE TAKEN INTO CONSIDERATION WHEN LEADING PUPIL-LED EXPERIMENTATIONS:

1. **Level of motivation with which the students approach mathematics and scientific subjects:**

In order to motivate students, we should focus on the approach we handle the subjects taught and on the methods used. It **is very important to make students realise in which factors of real life situations, the theory they are taught in class can be applied**. It is common for students to face difficulty in dealing with abstract laws of Mathematics and Science in general. Thus, it is crucial to attempt and achieve to make connections with the real world, so that the usefulness of these laws can be realised. This process will help pupils come up with ideas on certain disciplinary or/and interdisciplinary subjects for their experimentations, as well as the most suitable areas for favourable contextualisation or problem-solving.

Project work represents an active experimentation of the contents learnt during the formative process. It is inspired by the "learning by doing" approach and consists in the realisation, after a period of learning, of a final project/product, which should be concrete and assessable, in real contexts where the students become actual operators and seek solutions that are concretely realisable.

2. **Students‘ active involvement:**

- Teachers should also encourage the students' active participation, collaboration and exchange of ideas and difficulties encountered. This is the reason why project work is strongly encouraged, as it is the most effective learning method, through which students can operate as a whole, coming up with an idea, setting up the correct process in order to obtain the desired result, facing possible trouble and seeking solid and robust solutions.
- Initialy, through project work, students will be able to realise the reason why this knowledge is taught. Moreover, whatever learning process is followed, they will be asked to make personal decisions as well.
- Last but not least, it is certain that they will be more actively involved in the learning process, leading their teachers from more structured experimentation approaches to open ones

3. **Teachers‘ monitoring:**

It is very important for teachers to keep monitoring the class, while going through their experimentations. Undoubtedly, they should be present throughout the whole learning process, not only to assist pupils but also in order to get feedback concerning the knowledge they are to teach and the teaching method selected.

4. **Definition of Learning Objectives:**

Another aspect of great importance is to define from the very beginning of the experimentations (as we did in teacher-led experimentations) the goals of our teaching. A learning objective is an explicit statement that clearly expresses what the student will be able to do after taking a course. It is an observable and measurable student outcome statement. A learning objective identifies what behavior(s) a student must demonstrate, in order for the instructor to know that the planned learning took place. Learning objectives also benefit students by helping them clarify their personal goals for a course 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.

Students are supposed to be familiar with certain notions and have certain abilities, such as basic knowledge and competences in technical drawing, basic computer knowledge and competences, knowledge of mathematics, physics, science and technology. Furthermore, it is significant to define in detail the knowledge and competences that the pupils will acquire through the building of the object, the preparation of the drawing and finally the 3D printing.

5. Precise evaluation of the conditions given for the experimentation:

Given the students' vast imagination and enthusiasm prevailing in adolescence, combined with the excitement they share for creating something by themselves, it is very important for teachers to be careful about the following:

- define the phases through which the pupil-led experimentations will go through, so that students will be able to follow the steps
- define the duration of the pupil-led experimentations, so that they do not fall off-schedule, leading their students to incomplete results, running the risk of their disappointment and erosion of self-esteem.
- evaluate overall resources (equipment, materials, technical support) and assess students' competences, so that the pupil-led experimentations are finally successful, leading to attracting students back to STEM subjects and achieve the whole project's general pedagogical goal, which is to introduce the use of 3D printing in the ordinary scholar/didactic curriculum, as a method of learning based on practice and active teaching, with the effect of demonstrating the relevance of scientific disciplines for practical purposes and raising motivation,
- design in advance and make consistent use of monitoring tools, so that feedback is received and assistance is up-to-date and effective.
- stay in touch and continuous consultation by business partners, in order to receive technical support and enhance their role in the whole coordination of the activities.
- meet the standards of the IT supports required by the experimentation and make use of 3D CAD files, pre-selected drawing libraries and conversion programmes for 3D printing format.
- make use of the platform, in order to share photos and videos of the pupil-led experimentations, exchange ideas and troubleshooting strategies, eliminating the distance and making optimal use of all participants' knowledge and involvement.
- keep a daily calendar of all activities carried out during the pupil-led experimentations (create documentation), so that it is verified that the set standards are met, that monitoring is effective and that we will eventually come up with an open, replicable teaching resource.

6. Suggestions on what to follow during pupil-led experimentations:

1. Let students discover knowledge themselves and restrain your role in providing constant encouragement.
2. Assist students in establishing collaboration in class, in order to achieve the desired goal.
3. Define the steps of the process the students should take, to prevent misorientation.
4. Assure public recognition, to enhance the feeling of achievement.
5. Avoid academic speech and presentation of plain encyclopaedic knowledge.
6. Be impulsive and dare follow the students' intuition.
7. Keep your presence discreet but solid.

1.4 PROJECT WORK FORMAT TO BE COMPLETED BY STUDENT(S) ABOUT OWN PROJECT WORK

This format can be used for final presentation in class by each working group

PROJECT WORK TITLE	
NAMES OF STUDENT(S) PARTICIPATING	
FOCUS OF PROJECT WORK	□ Mathematical learning □ Scientific learning □ Interdisciplinary learning
SUBJECTS INVOLVED	
LEARNING OBJECTIVES	List of learning objectives (referred both to STME subjects and self-development General objective: Specific objectives:
CHRONOLOGY	Programme of the implementation phases. Working period on the different project work phases (example): Idea: Self-study: Project design: Revision/fine tuning: Printing:
OBJECT PRINTED	
REASONS WHY / RATIONALE	Description of reasons why the specific project work and object have been chosen (background interests for the student(s) to focus on own specific project
PROJECT WORK ELEMENTS	Teachers involved: Tools: Materials: Technologies:
DESCRIPTION OF THE PROJECT WORK PROCESS	Description of phases, activities carried out and how for the completion of the project work. Report of the activities
ISSUES ENCOUNTERED AND HOW THEY'VE BEEN SOLVED	
TEACHERS SUPPORT NEEDED	
RESULTS	Description of results in terms of: Object successfully printed (or not) Meeting the learning objectives and at which level All kind of learning that students feel to be achived through the project work

1.5 QUESTIONNAIRE FOR FINAL EVALUATION OF STUDENTS' LEVELS OF SATISFACTION AND MOTIVATIONS

In order to enable teachers to evaluate the level of satisfaction of students in relation to the new didactic methodology of 3D printing application to STEM subkects learning through pupil-led activities (project work), the following questionnaire will be submitted to each participant student.

The survey will allow to finetune throughout time the methodology, by leveraging the more and more and better on motivation towards study, that the 3D printing technology can stimulate.

	QUESTIONNAIRE	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 STEM-related contents?				
4	Have the pupil-led exercise with use of the 3D printer been useful to improve your knowledge and understanding of STEM rules/concepts related to the object that you designed and printed?				
5	Did you appreciate the use of the 3D printer in learning theoretical rules and STEM 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 STEM subjects? Why? Please write here to explain your opinion:				
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?				
12	Would you have preferred a longer experimentation in order to improve even more your knowledge/understanding of the STEM 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 scientific and/or mathematical 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. Educational experimentations carried out by 5 Secondary Schools: Learning objectives - Printed objects - Lessons Learnt - Recommendations

2.1 BALANCE (IISS A. BERENINI – Italy)

PUPIL-LED APPROACH

Through a dialogue between teachers and students, students propose a series of objects that wish to print. Teachers provide support to the choice evaluate the feasibility and consistency with the course of study, identify additional modules to assure the necessary theoretical basis. Through this process of choosing the object to be printed, students identify a discussion on topics that may be of particular interest for them trying to get the printout of an item of their choice. All this should lead to an activity on STEM additional modules characterized by a particular interest from students with a consequent improvement of learning outcomes.

LEARNING OBJECTIVES

Learning Objectives identified by the pupils 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) Calculating areas, volumes and densities.
2) Forces and moment of forces.
3) Equilibrium of rigid bodies.
4) Levers and simple machines.
3) Able to draw and recognizes complex solids.
4) Be able to draw and print 3D solids.

How the Learning Objectives have been identified and why?

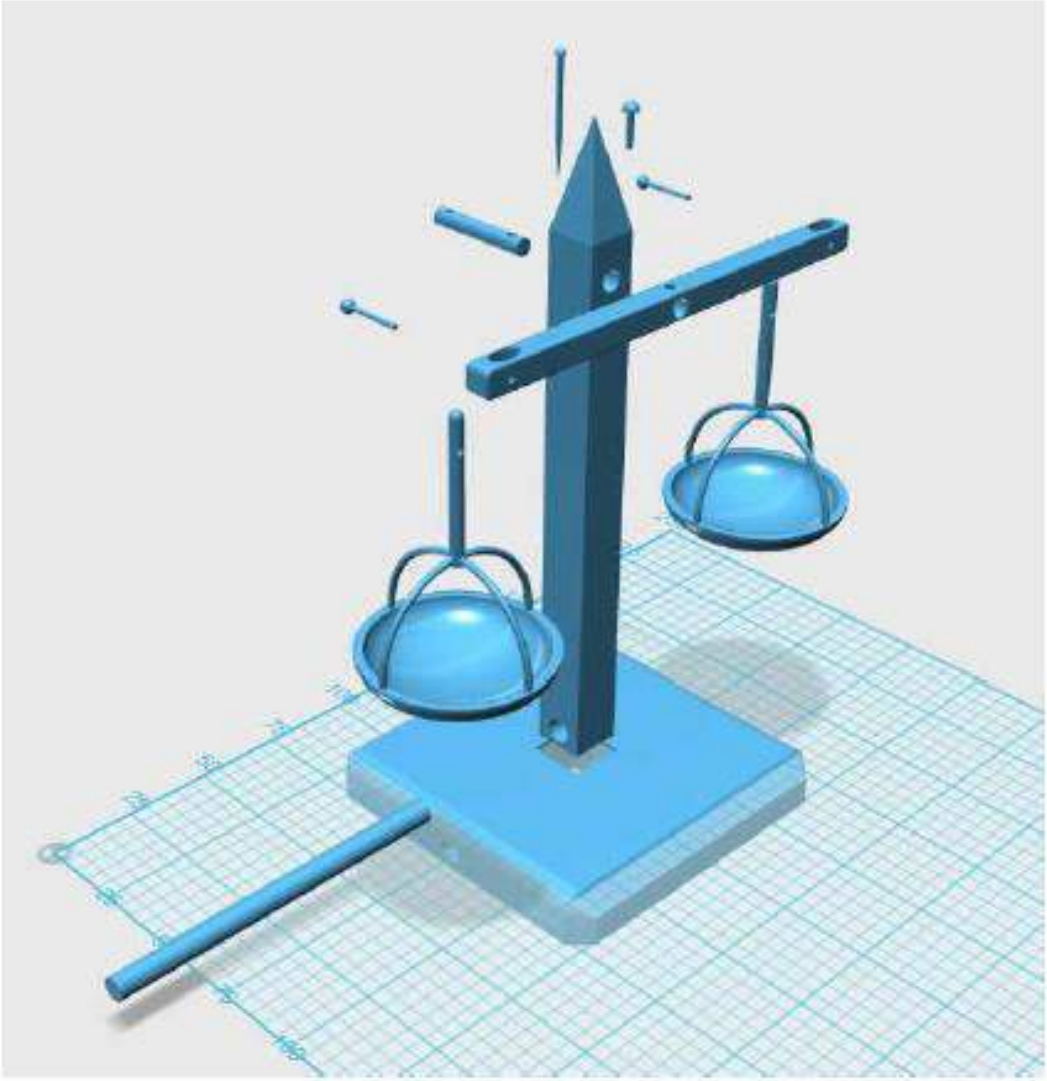
The object has been identified through an interview with the students in a brainstorming process. The teachers, evaluating the feasibility and relevance with their studies, helped to identify the object among those proposed.

PRINTED OBJECT

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

Why this object?

The choice of the structure of DNA model allows excellent connections with the science curriculum and chemistry done in the current year.



PREREQUISITES

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

- ✔ Knowledge of the concepts of force and moments of strength.
- ✔ Balance of rigid bodies, rotation.
- ✔ Levers.

THE TEACHERS TEAM INVOLVED

4 teachers have been involved in the experimentation:

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

Rationale of the Teachers Team
These teachers were chosen as the choice of 3D printing of Balance implied a knowledge of Physics together with those of 2D and 3D graphics.
The teacher of applied sciences has made an important contribution to the 3D printing process.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:
Number of pupils: 24
Type of group: single class
Number of classes: 1
Scholar curriculum specialization of the class(es) involved: Electronics
"Special needs" students: 5 (dyslexia, dyscalculia)
Entry level assessment: written test.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN STEM SUBJECT	PHYSICS
Topics related to the Learning Objectives of experimentation	Calculation of areas, volumes, density, equilibrium of rigid bodies, moment of forces, levers, simple machines.
Total number of hours dedicated to completion of the experimentation	10 hours theory in the classroom 2 hour verification

OTHER RELATED SUBJECT	TECHNICAL DESIGN
Didactic Topics related to the Learning Objectives of experimentation	use of CAD 3D 123D
Total number of hours dedicated to completion of the experimentation	2 hours theory in the classroom 10 hours computer lab

OTHER RELATED SUBJECT	APPLIED SCIENCES
Didactic Topics related to the Learning Objectives of experimentation	Software for printing and 3D printing
Total number of hours dedicated to completion of the experimentation	10 hours to file and print 3D conversion

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** 123D Design 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

- **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.

€2.370,00(VAT excluded)

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

1° - Definition of Learning Objectives and object to be printed
Number of hours dedicated: 2 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 or pupils self-study on Physics Subject:
Number of hours dedicated: 10
People involved: science teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work

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

°6 - Transfer of the object designed to 3D printing software:
Number of hours dedicated: 4
People involved: teacher of applied sciences
Didactic methodology used: laboratory work.

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

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

Marks of Entry Test show that:
· 9 students got bad marks (lower than 5/10)
· 5 students got good marks (6/10 and above)
· the average of the marks is 5.18 (not enough)

Marks of Final Test show that:
· 4 students got bad marks (lower than 5/10)
· 12 students got good marks (6/10 and above)
· the average of the marks is 6.34 (sufficient)

evident improvement in terms of average rating, reduction of students seriously insufficient and improvement of sufficient students.

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) Good collaboration between the groups of students
2) They have actively participated in the development of the problems
3) The boys have shown some interest in printing an object designed by them.
3) They knew how to work in groups, dividing tasks according to their interests and abilities
4) In general we have met their learning goals.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ developing the ability to solve problems independently;
- ✓ work in a group by sharing the skills;
- ✓ continuation of design work at home as a demonstration of interest.

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ students' difficulties in conducting the project, the need to have the support of the teacher;
- ✓ temporal scanning does not always adaptable to the normal school activity;
- ✓ availability of laboratory equipment (overlapping with other curricular activities and projects).

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 independently, for each specific problem he can always ask to the competent teacher.
- ✓ 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.

2.2 DNA (IISS A. BERENINI – Italy)

PUPIL-LED APPROACH

Through a dialogue between teachers and students, students propose a series of objects that wish to print. Teachers provide support to the choice evaluate the feasibility and consistency with the course of study, identify additional modules to assure the necessary theoretical basis. Through this process of choosing the object to be printed, students identify a discussion on topics that may be of particular interest for them trying to get the printout of an item of their choice. All this should lead to an activity on STEM additional modules characterized by a particular interest from students with a consequent improvement of learning outcomes.

LEARNING OBJECTIVES

Learning Objectives identified by the pupils 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) DNA structure.
2) Chemical structure of the nitrogenous bases and D-2-deoxyribose DNA.
3) Complementary base pairing.
4) Role of DNA in the cell's functionality.
3) Able to draw and recognizes complex solids.
4) Be able to draw and print 3D solids.

How the Learning Objectives have been identified and why?

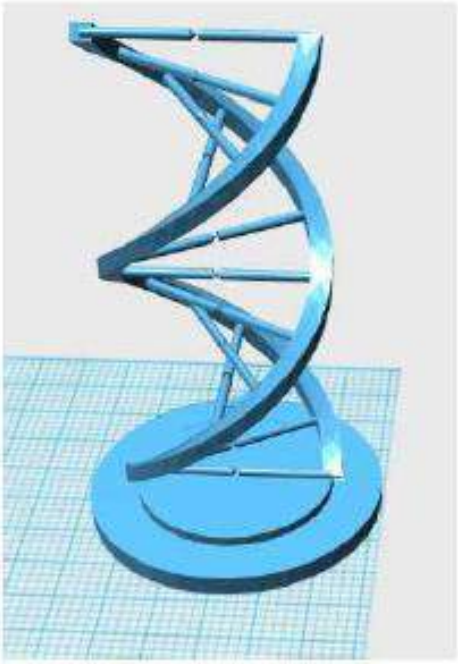
The object has been identified through an interview with the students in a brainstorming process. The teachers, evaluating the feasibility and relevance with their studies, helped to identify the object among those proposed.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing a structure of DNA model.

Why this object?

The choice of the structure of DNA model allows excellent connections with the science curriculum and chemistry done in the current year.



PREREQUISITES

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

- ✔ geometric construction of the spiral
- ✔ Realization of a spiral and cylindrical propeller in orthogonal projections and axonometric
- ✔ CAD2D use
- ✔ Knowledge of covalent bonding and hydrogen bonding bridge

THE TEACHERS TEAM INVOLVED

5 teachers have been involved in the experimentation:

List each teacher' subject/domaine:
1 teacher of Chemistry
1 teacher of Sciences
2 teacher of Technical design
1 teacher of Applied sciences

Rationale of the Teachers Team
These teachers were chosen as the choice of 3D printing of DNA structure implied a greater knowledge of biochemistry together with those of 2D and 3D graphics.
The teacher of applied sciences has made an important contribution to the 3D printing process.

THE PUPILS GROUP INVOLVED

The targeted group of pupils undergoing the experimentation have been the following:
Number of pupils: 26
Type of group: single class
Number of classes: 1
Scholar curriculum specialization of the class(es) involved: Chemistry and Mechanics
"Special needs" students: no
Entry level assessment: written test.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN STEM SUBJECT	BIOLOGY
Topics related to the Learning Objectives of experimentation	DNA role in the functionality of the cell DNA structure
Total number of hours dedicated to completion of the experimentation	4 hours theory in the classroom 1 hour verification 3 hours computer lab

MAIN STEM SUBJECT	CHEMISTRY
Didactic Topics related to the Learning Objectives of experimentation	chemical structure of the nitrogenous bases and D-2-deoxyriboseDNA Complementary base pairing
Total number of hours dedicated to	2 hours of theory in the classroom

completion of the experimentation	1 hour verification 3 hours computer lab

OTHER RELATED SUBJECT	TECHNICAL DESIGN
Didactic Topics related to the Learning Objectives of experimentation	geometric construction of the spiral in the orthogonal projection and axonometry cylindrical propeller geometric construction in orthogonal projection and axonometry
Total number of hours dedicated to completion of the experimentation	6 hours theory in the classroom 10 hours computer lab

OTHER RELATED SUBJECT	APPLIED SCIENCES
Didactic Topics related to the Learning Objectives of experimentation	Software for printing and 3D printing
Total number of hours dedicated to completion of the experimentation	10 hours to file and print 3D conversion

II) PRINT STEM LAB: THE TECHNOLOGIES

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

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

- **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.


Delta 20 40
wasp

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 or pupils self-study on Sciences Subject:
Number of hours dedicated: 8
People involved: science teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work

5° - Training Unit on Chemistry Subject:
Number of hours dedicated: 2
People involved: chemistry teacher
Didactic methodology used to teach the contents: front lesson, laboratory work and group work.

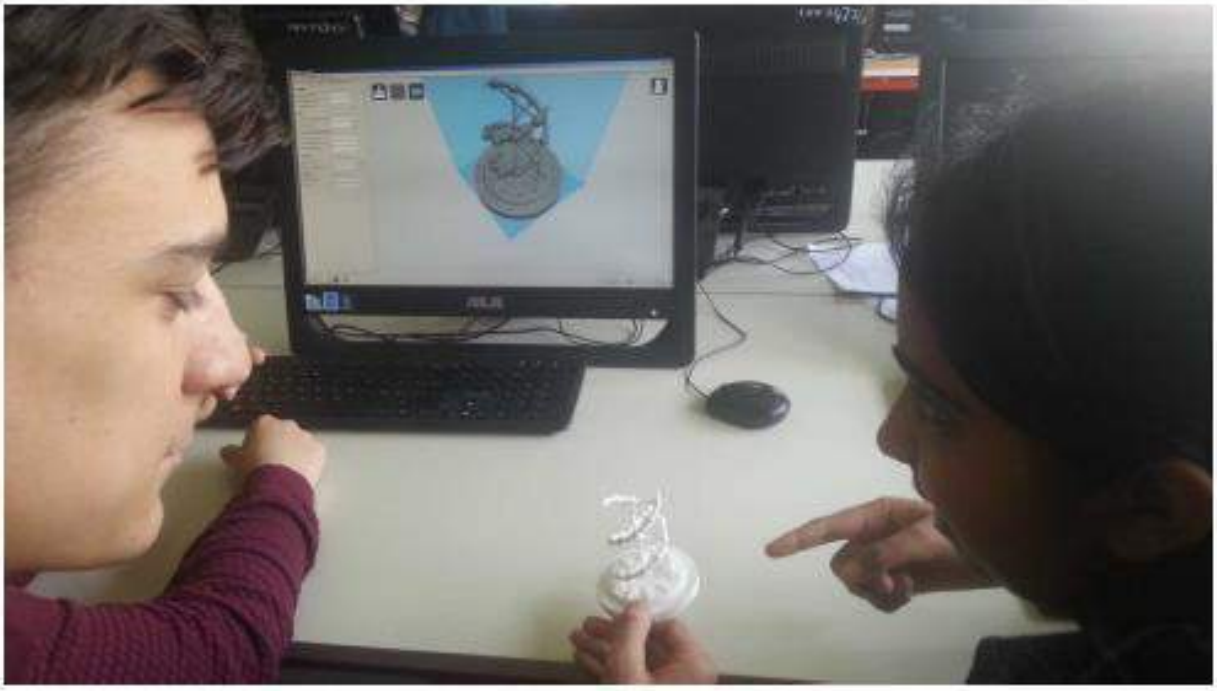
6° - Training Unit on Chemistry Subject:
Number of hours dedicated: 4
People involved: chemistry teacher
Didactic methodology used to teach the contents: front lesson and group work.

°7 - CAD Design of the object:
Number of hours dedicated:16
People involved: drawing teacher
Didactic methodology used: laboratory work and group work.

°8 - Transfer of the object designed to 3D printing software:
Number of hours dedicated: 4
People involved: teacher of applied sciences
Didactic methodology used: laboratory work.

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


INV. 2475/N



TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

Marks of Entry Test show that:
· 6 students got bad marks (lower than 5/10)
· 13 students got good marks (6/10 and above)
· the average of the marks is 5.97 (almost enough)

Marks of Final Test show that:
· 2 students got bad marks (lower than 5/10)
· 17 students got good marks (6/10 and above)
· the average of the marks is 6.30 (sufficient)

evident improvement in terms of average rating, reduction of students seriously insufficient and improvement of sufficient students.

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) The boys have shown some interest in printing an object designed by them.
2) They have shown good creativity, also supported by a spirit of inquiry
3) They knew how to work in groups, dividing tasks according to their interests and abilities
4) In general we have met their learning goals.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✔ Independent choice of the boys on the subject to be studied
- ✔ Ability to use their skills across the board.

WEAK POINTS OF THE EXPERIMENTATION:

- ✔ Temporal scanning does not always adaptable to the normal school activity
- ✔ availability of laboratory equipment (overlapping with other curricular activities and projects).

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 independently, for each specific problem he can always ask to the competent teacher.
- ✔ 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.

2.3 SLIDING TROLLEY (IISS A. BERENINI – Italy)

PUPIL-LED APPROACH

- Pupils are asked to choose an object to design and to print, connected with their STEM subjects.
- Pupils meet together and discuss about the objects.
- Pupils discuss with teachers involved (STEM teachers), who notice as the chosen objects have only an end at itselves and don't give the opportunity to do an experiment or to use them for whichever project related to their subjects.
- Teachers help them to choose the most suitable object/s satisfying the requirements both of the planned experiments and of the print.
- The teacher of the relevant subject oversees the project and decides what basic knowledge it needs.
- Once pupils have chosen the objects split themselves into groups.
- Each group defines better the object, decides its size, shape, and weight.
- Technical drawing teacher teaches them how to use the CAD software and how to Print.
- Pupils print the objects.
- Pupils and the Physics Teacher test the printed objects carrying out the planned experiments.
- Pupils face final tests concerning the activity just done, some topics of the involved subject and their satisfaction of the whole project.

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) To work in groups improving communication and creativity.

2)To use creativity keeping in touch with the reality.

3)To make accurate measurement.

4)To observe and describe natural phenomena removing unnecessary aspects.

5)To plan a work in almost complete autonomy following the right steps.

SPECIFIC Learning Objectives

1)To understand the behavior of moving objects

2)To study the effects of the drag on different bodies with different shapes

3)To learn and use CAD 3D software

How the Learning Objectives have been identified and why?

Pupils were asked to meet together and choose an object, or a series of objects, related to one of the topic that they have studied this year or that they would like to study or to get more in depth of.

They suggested a lot of ideas, among with the teacher helped them to choose the most suitable to be printed, but also the most useful for applications.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing:

At last they decided to print a "trolley", sliding on the frictionless rail used in the scholastic Physics laboratory to study the motion, but actually a "sailing trolley".

Why this object?

The purpose was to study the air resistance, i.e. drag. For this reason the "Sailing trolley" had to carry something shaped in order to offer resistance while moving on the rail but through the air. So they drew sails, but also a sphere to put on the trolley, or an airplane, a car, and so on. Their creativity has been really great, too great to use all this objects in a scientific research, and, most of all, in a short-term research, but Physics laboratory has undoubtedly gained matter to work for a lot of time.

The trolley has to fit with the rail, so they had to take very accurate measures of dimensions and of weight, because if the trolley is too heavy the air pillow on which it moves can't support it and if it is too light its motion can't be regular

PREREQUISITES

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

Basic knowledge and competences in technical drawing (CAD 2D),

Basic computer knowledge and competences,

Physics knowledge about frictionless motion.

- ✓ Use of the frictionless rail
- ✓ Use of the timer and measurements

THE TEACHERS TEAM INVOLVED

3 teachers have been involved in the experimentation:

List each teacher' subject/domaine:

1 Physics teacher

2 Mathematics teacher

1 Technical drawing teacher

1 Computer sciences teacher

Rationale of the Teachers Team

Involved teachers were chosen because four of them are STEM teachers in the class (1 Physics, 2 Mathematics and 1 Computer Science teachers), the fifth one is an expert in 3D printer and has more freedom from the daily classes because he usually works together another colleague. Other teachers have lent their hours for the activities.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 23

Type of group: one single class

Number of classes: 1

Scholar curriculum specialisation of the class involved: 2nd class of Liceo Scientifico Opzione Scienze Applicate

"Special needs" students: 1 "special needs" student (dyslexic)

Entry level assessment: The last topic studied was motion, at first with constant speed and then with constant acceleration. The teacher added the laws of dynamics and the effects of friction and drag on the motion. A test about these topics was done before the beginning of the planning and drawing activity.

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 by pupils)

MAIN PHYSICS SUBJECT	
Topics related to the Learning Objectives of experimentation	Air drag on moving bodies, theory, use of the frictionless rail with electronic gates, measures of time and experimental calculation of speed and acceleration
Total number of hours dedicated to completion of the experimentation	14

OTHER RELATED SUBJECT	MATHEMATICS
Didactic Topics related to the Learning Objectives of experimentation	Analysis of the mathematical features of the motion equations, particularly of the equation describing the influence of air drag, depending on speed, on motion (of course at a basic level because it would need the knowledge of differential calculus). Furthermore, parabola and exponential curve in the cartesian coordinate system.
Total number of hours dedicated to completion of the experimentation	6

OTHER RELATED SUBJECT	TECHNICAL DRAWING
Didactic Topics related to the Learning Objectives of experimentation	CAD 3D "INVENTOR"
Total number of hours dedicated to	8

completion of the experimentation	

OTHER RELATED SUBJECT	SOFTWARE 3D
Didactic Topics related to the Learning Objectives of experimentation	Software "CURA 15.04.4"
Total number of hours dedicated to completion of the experimentation	3

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN: For CAD design a very simple professional software was used: "Inventor 2009" (Autodesk).**

- **SOFTWARE(S) for object PRINTING: The software used for 3D printing was CURA 15.04.4 (by Ultimaker, but this is a software open source) while the 3D printer was "Delta2040". The software "CURA" is necessary to obtain the "gcode file", to use with the 3D printer**

- **3D PRINTER: Ø The our 3D printer is the "DELTA 2040", made in Italy by WASP. Easy to use, it can print objects with these important dimensions: 200 x 200 x 400 mm. The connectivity is possible with SD card. Printing area is closed and the printing speed is very high: 300 mm/s.**

IMPORTANT: How many time is necessary to print the objects of this experimentation with our 3D printer? We built 3 objects. Object A: 600 minutes. Object B: 90 minutes. Object C: 15 minutes.

- **PLASTIC MATERIAL:** Ø PLA. What is PLA? It's a biodegradable thermoplastic material, derived from renewable resources. Its creation starts with a starchy grain like corn starch, potatoes, or tapioca. The grain is then milled and a simple sugar is extracted. The solution is fermented in bacteria, which turn the simple sugar into lactic acid. Once purified via the removal of extra water, the lactic acid forms a compound called lactide. A catalyst is added allowing the lactide molecules to form a long polymer strand. This is PLA in raw form.
  Cost: 700 gr. PLA 3D printing are available at a price of around 24 euros.

  Suggested printing temperature: 190°-220°C.

  Where is it possible to buy? Internet.

IMPORTANT: How many quantities of PLA material are necessary to print the objects of this experimentation? Object A: 100 gr. Object B: 12 gr. Object C: 2 gr.

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 3h

People involved: pupils and STEM teachers, mainly Physics teacher when defined the subject.

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

Number of hours dedicated: 3h

People involved: Maths, Physics, Technical Drawing, Computer Sciences teachers

3° - Entry level assessment

Number of hours dedicated: 5h

People involved: Physics teacher

4° - Training Unit on Physics Subject:

Number of hours dedicated: 5h

People involved: Physics teacher

Didactic methodology used to teach the contents: front lesson, laboratory work.

5° - Training Unit on Mathematics Subject:,

Number of hours dedicated: 6

People involved: Mathematics teachers

Didactic methodology used to teach the contents: front lesson, group work, computer laboratory work with *Geogebra* software.

6° - CAD Design of the object:

Number of hours dedicated: 3

People involved: **Technical Drawing teacher**

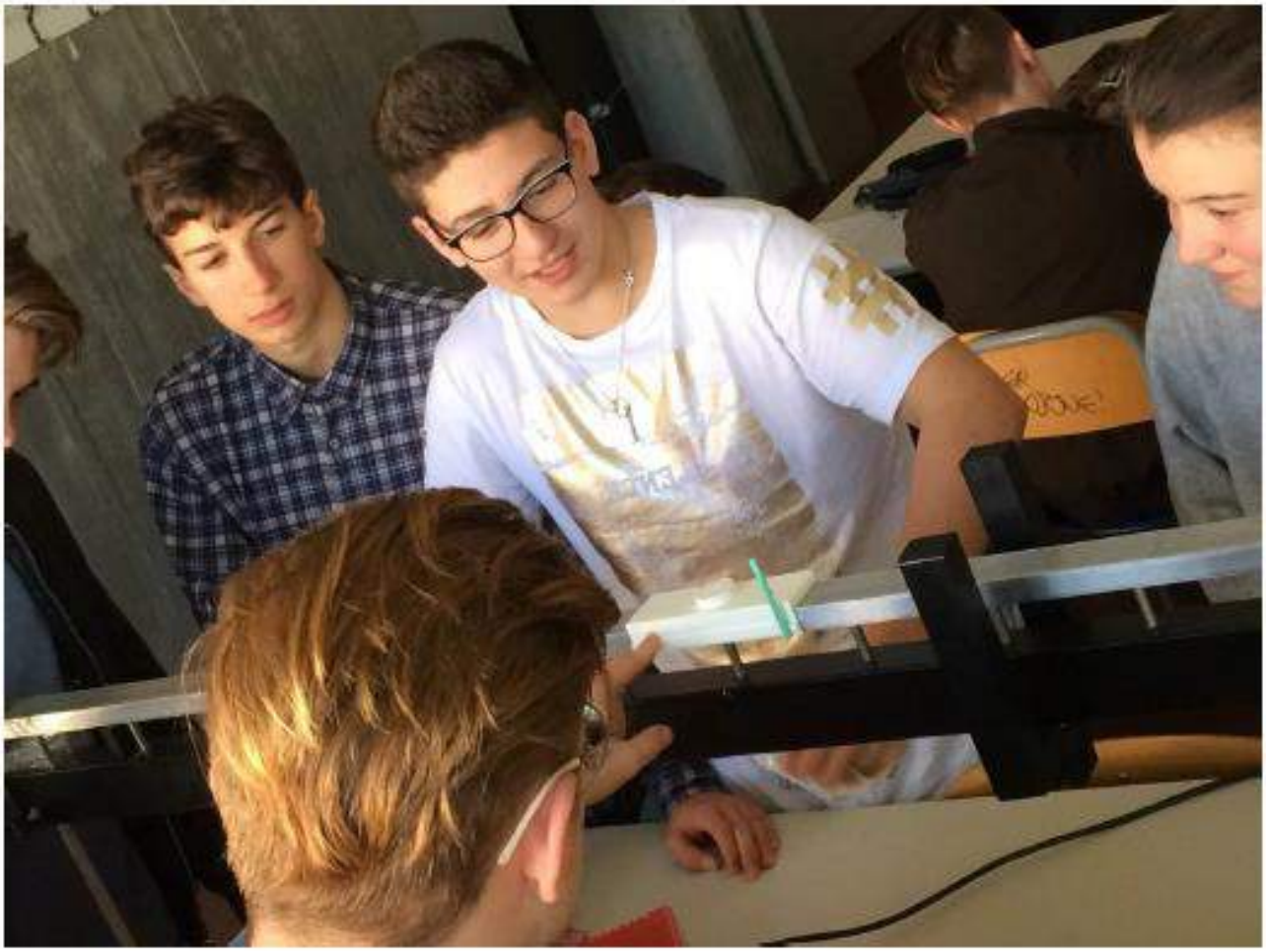
Didactic methodology used: front lesson and laboratory workfront lesson and laboratory work

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

Number of hours dedicated: 8

People involved: **Technical Drawing teachers from "Forma Futuro" Institute.**

Didactic methodology used: front lesson and group work

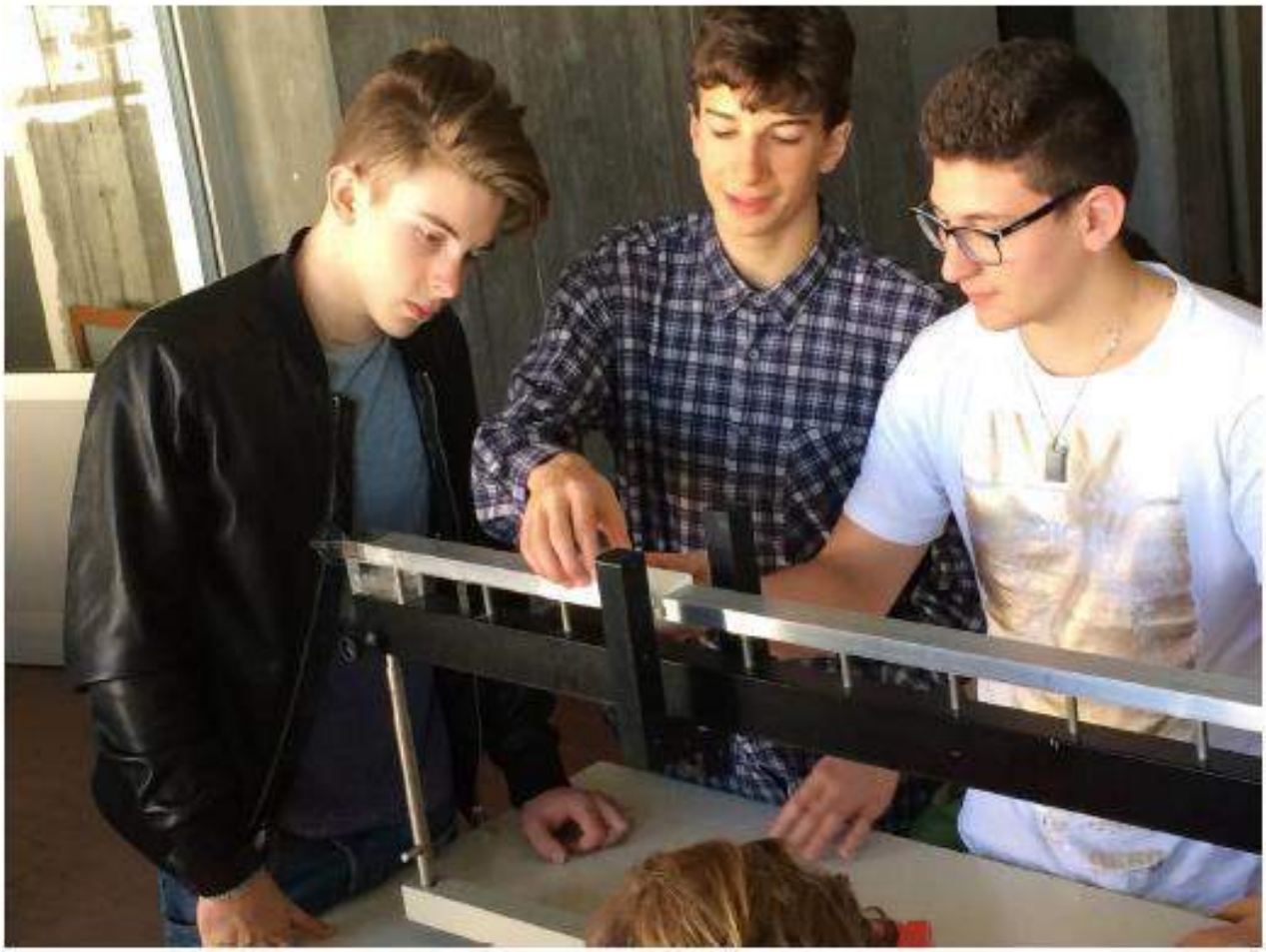


8° - Object printing:

Number of hours dedicated: **13 hours**

People involved: **Technical Drawing teacher**

Didactic methodology used: After a brief introduction about WASP 3D printer, it was necessary to start with the print without direct observation because of the long printing period. It was also necessary to repeat two 3D prints.



n° - End of experimentation

Number of hours dedicated: 4h Physics

People involved: Physics teacher

Didactic methodology used:

Pupils have been asked to give their technical evaluation of the experience, filling in the "Pupils final self-evaluation" attached to this report.

TEACHER'S FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of a test like the initial one, in order to measure their increased knowledge of the topic.

Entry level test (20/23 pupils did the test):

3/10	4/10	5/10	5,5/10	6/10	7/10	7,5/10	8/10
1	2	3	2	6	4	1	1

Final test (18/23 pupils did the test):

4/10	5,5/10	6/10	7/10	8/10	8,5/10	9/10	10/10
1	1	1	2	4	7	1	1

Each working group was supposed to write a report about their experience and the results of the experimental work, but, as the whole project has taken more time than we expected, it has been postponed.

Hereafter we list the test learning results:

1)Increased working in group skill.

2)Increased interest in the scholastic work by the opportunity to show their creativity.

3)Increased knowledge of CAD design.

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) Facilitated relationship among pupils due to the less strict environment.

2) Greater involvement of the less motivated students.

LESSONS LEARNT

The project would have needed more time. In fact we had to share the Computer Labs with other projects. The best choice would be to stop usual lessons and to concentrate the activities in a few days, but for this reason it was impossible. In our project the laboratory experiments to test the trolley are a part of utmost importance and for the time being we haven't had time enough to complete our experiments.

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increased student's leading role
- ✓ Development of creativity
- ✓ Increased student's self confidence
- ✓ More interdisciplinary teaching

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ Few time
- ✓ Shared laboratories
- ✓ Stiff lessons plan, no scholastic activities in the afternoon

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ Find a subject and a topic that pupils really like (it's not so easy).
- ✓ Define clearly with your colleagues tasks and timing.
- ✓ Stop ordinary activities for a few days, the project works better if you strike while the iron is hot.

2.4 MOBILE PHONE PROTECTIVE CASES and ONE-STOREY BUILDING (1 Epalchanion – Greece)

Mobile phone protective cases, with several decorative geometrical patterns

LEARNING OBJECTIVES

GENERAL Learning Objectives

1) observe products around them and realize the connections among them and the knowledge they have been taught throughout their school life, focusing on STEM subjects.

2) understand clearly the steps taken and the process followed, in order for such products to be made. This could be envisaged only if they were personally involved in the process in an absolutely active way.

3) come up with a clever idea, associated to the knowledge needed for its actualisation and experience the creative procedure up to its completion.

4) use the experience they had gained by participating in IO4 experimentations, in order to face problematic situations (developing their problem-solving strategies) or even better be able to predict them.

SPECIFIC Learning Objectives

1) take advantage of the world around them and their everyday life (interests / hobbies) in order to come up with ideas for objects they could print, using the 3D printer. By doing so, they could actually prove that it is easier for anyone to learn something if he/she really likes it and acknowledges the need for such knowledge in order to turn his/her ideas into reality.

2) realize the properties of products around them and decide which prerequisites are considered to be essential, in order for a quality product to be constructed, based on its usefulness, durability, ease of use, aesthetic quality and other important features.

3) put their theoretical knowledge on Mathematics and especially Geometry into practice, in order to achieve their goals.

4) carry out online research, proceed with 3D printing of open .stl files of their selected objects but most importantly, go through a self-evaluation process and try to realize which of these objects are feasible, depending on their knowledge and the software and hardware's potential.

How the Learning Objectives have been identified and why?

It is a fact that during their first brainstorming attempts, our students were greatly influenced by the excitement they were feeling, when they realized that they could freely proceed into downloading ready-to-use .stl files and print their favourite objects, or at least objects which had attracted their attention. It was a great relief for them to be able to create something, working outside any framework

including theoretical knowledge on abstract notions, axioms, principles and other rules. It was at this point, that teachers' intervention was regarded to be absolutely necessary, in order for students to understand that their creations should be associated to the already acquired knowledge. If this was not probable, they should at least attempt to spot the knowledge necessary for the completion of their objects and then restrict their options in the range of objects that could be 3D designed and printed, based on the existing knowledge.

One-storey building, including all basic parts of a construction

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were mainly oriented into developing the ability to:

GENERAL Learning Objectives

1) develop their critical observation of nature and several structures around them, in order to be able to realize the value of 3D printing process in goods production.

2) develop their skill to come up with an idea, based on several parameters, which are considered to be quality factors for a functional construction. To achieve this, they need to understand clearly the steps taken and the process followed, in order for such products to be made. This could be envisaged only if they were personally involved in the process in an absolutely active way.

3) feel useful and at the same time improve their knowledge on Engineering by making use of 3D design and printing process, even if they had to use ready-to-use .stl files at times, which was equally intriguing.

4) use the experience they had gained by participating in IO5 experimentations, in order to face problematic situations (developing their problem-solving strategies) or even better be able to predict them.

SPECIFIC Learning Objectives

1) be able to identify the several parts of a construction (floors, beams, columns), transfer them into draft design, then proceed with 3D design and come to actual 3D printing of what they had captured in the real world, as a 3D model in scale.

2) take advantage of the world around them, including open spaces, buildings, monuments, special constructions, etc. in order to transfer pictures of these into paper and come up with ideas for objects they could print, using the 3D printer. By doing so, they could actually prove that it is easier for anyone to learn something if he/she really likes it and acknowledges the need for such knowledge in order to turn his/her ideas into reality.

2) realize the several parts of buildings around them and decide which prerequisites are considered to be essential, in order for a quality building to be constructed, based on its usefulness, durability, ease of use, aesthetic quality and other important features.

3) put their theoretical knowledge on Engineering, Technical Drawing and Geometry into practice, in order to achieve their goals.

4) carry out online research and proceed with 3D printing of open .stl files in order to enhance their object to be printed. By doing so, they wanted to feel the freedom of downloading ready-to-use .stl files, so that they would no more feel restricted and let their creativity flourish, despite the fact that they really enjoyed and learned a lot using the 3D design software.

How the Learning Objectives have been identified and why?

It is a fact that during their first brainstorming attempts, our students were greatly influenced by the excitement they were feeling, when they realized that they could freely proceed into downloading ready-to-use .stl files and print their favourite objects, or at least objects which had attracted their attention. It was a great relief for them to be able to create something, working out of any framework including theoretical knowledge on abstract notions, axioms, principles and other rules. It was at this point, that teachers' intervention was regarded to be absolutely necessary, in order for students to understand that their creations should be associated to the already acquired knowledge. If this was not probable, they should at least attempt to discover the knowledge necessary for the completion of their objects and then restrict their options in the range of objects that could be 3D designed and printed, based on the existing knowledge.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing

a. Mobile phone protective cases, with several decorative geometrical patterns
b. One-storey building, including all basic parts of a construction

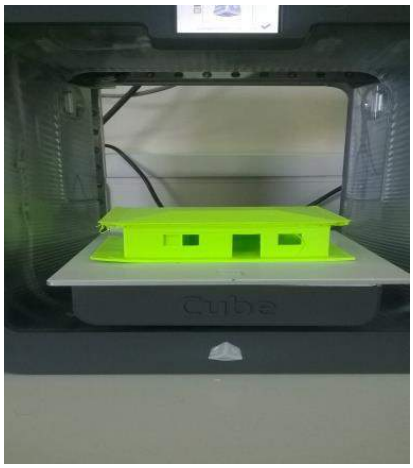
Why these objects?

These objects would enable pupils to put their theoretical knowledge into practice. To start with, in order to design and print the protective case for mobile phones, as well as the several parts of the building they photographed, they would:

- realize in depth the connections among shapes and solids, go on with accurate measurements, revising their knowledge of areas, volumes, circumference, etc.

- put into practice their skills of technical drawing on paper, as well as their knowledge of the commands and the whole function of the CAD software, which is considered as a major prerequisite in order to achieve successful 3D printing results.

- revising dimensions, areas and volumes of several shapes and solids, such as square, rectangle, circle, ellipse, polygon, cone, cube, cylinder, pyramid, etc.



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
- ✓ Ability for collaboration in-class
- ✓ Development of brainstorming and problem-solving techniques

THE TEACHERS TEAM INVOLVED

Two (2) teachers have been involved in the experimentation:

One teacher of Mathematics

One teacher of Technical drawing / CAD

Rationale of the Teachers Team

The teachers involved in the team were chosen because they had been teaching during the IO4 and IO5 experimentations, so they were more familiar to the whole philosophy of 3D printing technology. However, most importantly, their choice was based on the fact that it had been obvious though teacher-led experimentations that teaching of Mathematics and especially Geometry is a crucial parameter to be taken into consideration, when designing objects oriented to 3D printing. At the same time, even when downloading from Open Libraries, knowledge of CAD is equally significant, for students to be able to understand the distinguished parameters and the special way though which their design will eventually turn into something tangible; not to mention, how important CAD teaching is, when getting students to actually design their objects by using the software's commands. Last but not least, both teachers are

familiar to up-to-date IT, so it was easier for them to cope with malfunctions, breakdowns, defective materials, etc.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 68

Type of group: single classes

Number of classes: 4

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: The final written exam that had been used after the completion of the IO4 and IO5 teacher-led experimentations was taken into consideration, in order to assess the entry level of students.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	GEOMETRY
Topics related to the Learning Objectives of experimentation	Dimensions, areas and volumes of several shapes and solids, such as square, rectangle, circle, ellipse, trapezium, polygon, cone, cube, cylinder, pyramid, etc. Connections among shapes and solids Carrying out accurate measurements
Total number of hours dedicated to completion of the experimentation	16

OTHER RELATED SUBJECT	TECHNICAL DRAWING / CAD
Didactic Topics related to the Learning Objectives of experimentation	Basic skills of technical drawing on paper Using the commands and the whole function of the CAD software
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**
- **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

a. One protective mobile phone case with this 3D printer is 1,5 hour, at standard mode (200 microns)
b. One one-storey building 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 :

a. One protective mobile phone case with this 3D printer is 3% of this material
b. One one-storey building is 8% of this material

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 4

People involved: 2 teachers + 68 students

A different process was followed in order to help our students define what exactly they would like to learn out of pupil-led experimentations.
More specifically, two groups of 17 students each, were assigned to carry out online research about the fields of everyday life, in which 3D printing can be applied. They were advised to work in groups and create presentations in Google Drive Presentation, about their research results. The last stage was to browse in Open Libraries, in order to spot designs of objects they had decided to print, based on the parameters mentioned above

The other two groups of 17 students each, visited a neighboring site in order to measure real-life dimensions of a certain construction (columns, stairs, roof, walls, windows, doors) and take pictures.

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

Number of hours dedicated: 2

People involved: 2 teachers + 68 students

The first two groups working under Mr. Bichakis's surveillance and guidance got involved into actually 3D print each sub-group's desired object, after they had followed the whole process as it had been taught during teacher-led experimentations. A round-table discussion on objects printed followed, in order to examine the conditions necessary in order for each of them to be printed. Although it didn't seem to be a students' need, the teacher's aim was to make them go through a self-evaluation process before setting for their final experimentation.

The other two groups of students, working under the surveillance and guidance of Mr. Petrakis, went on with drawing on paper using scale, as they had been taught. It seemed a rather familiar procedure for them. What followed was a general discussion, in order to make students come up with one particular choice for an object to work on for each of four sub-groups and succeed in seeing it printed eventually.

3rd - Training Unit or pupils self-study on Geometry:

Number of hours dedicated: 4

People involved: 2 teachers + 68 students

A certain theoretical background in Geometry was considered as a prerequisite for the completion of both objects selected to be printed.

Didactic methodology used to teach the contents:

- Having students acknowledge the specific geometrical notions needed, in order to have successful experimentations.
- Revising certain knowledge, such as area of shapes and volumes. The majority of students appeared to be familiar to notions such as:

- identifying most well-known parallelograms and curved shapes, polygons and their properties
- circumference, area of most shapes and scaling
- parallel lines, levels
- solids and their properties

Nevertheless, we had to go over notions, such as:

- the theorem of three perpendicular lines
- properties of angles
- axons, axonometric projection, parallel projection
- Cartesian coordinates
- Sections in cones (hyperbolic, parabolic, circle, ellipse)

Students worked in groups, in order to identify the knowledge that had to be taught again and front lesson followed.

4th - Training Unit on Technical Drawing:

Number of hours dedicated: 2

People involved: 2 teachers + 68 students

A certain theoretical background in Technical Drawing was considered as a prerequisite for the completion of both objects selected to be printed.

Didactic methodology used to teach the contents:

- Students needed no more explanation on the use of drawing instruments, although we felt we had to revise grid and its use.
- Drawing lines, geometrical shapes, scaling were well – acquired skills. Nevertheless, we revised notions, such as dimensions, projection, plan, section and elevation.

5th – 123D Design of the object:

Number of hours dedicated: 4

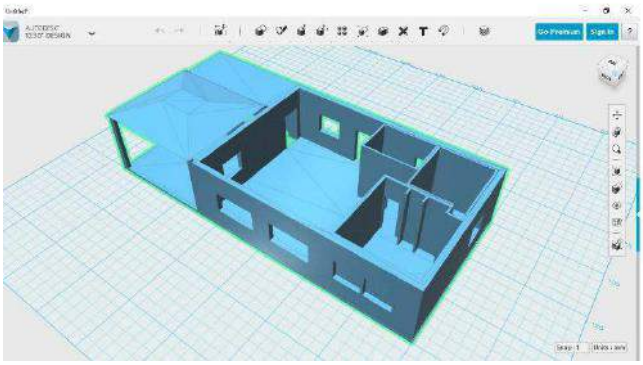
People involved: 2 teachers + 68 students

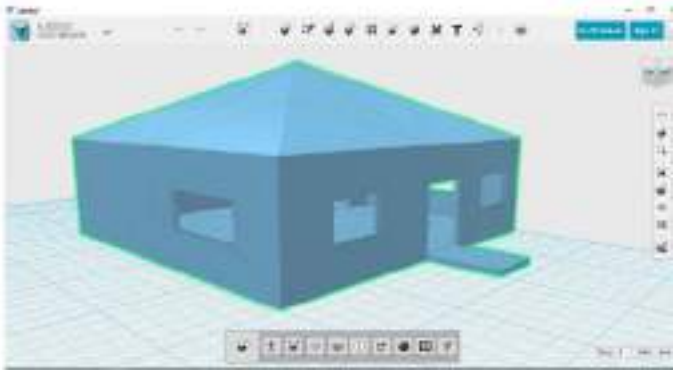
Front lesson was used in order to help all students get accustomed to basic notions of 3D design. To be more specific, we went through:

- Creation of 3D geometrical models
- Solids (sphere, cone, etc.)
- 2D Commands – Extrusion, Rotation, Lofting, etc.
- Surfaces
- Transformation of 3D models (Copy, Rotation, Reflect, etc.)
- Reasoning acts (Boolean) among solids (Unite, Section, Subtract)
- Special Tools of the software (Theory of Dimensions, etc.)

The first two groups downloaded free .stl files from open libraries, but proceeded into editing them, making any necessary alterations, in order to adjust the appropriate settings for the production of a design of a mobile phone protective case. By doing this, students were able to realise which knowledge was used in order for these designs to be created (reverse learning).

The other two groups transferred their designs into 123D Design software. Each sub-group designed the partitions, without any limitations imposed to each individual student. They were allowed to form openings, keeping in mind that the final result should be functional.



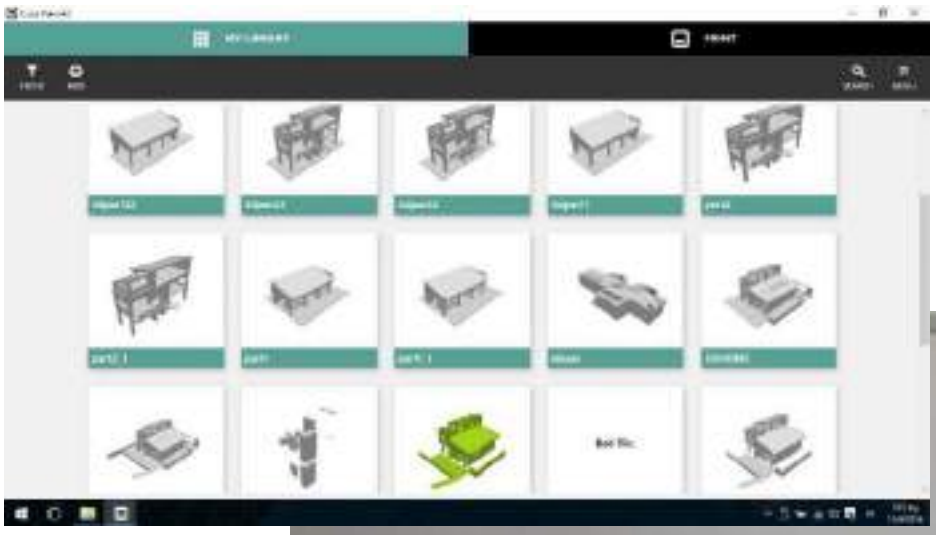


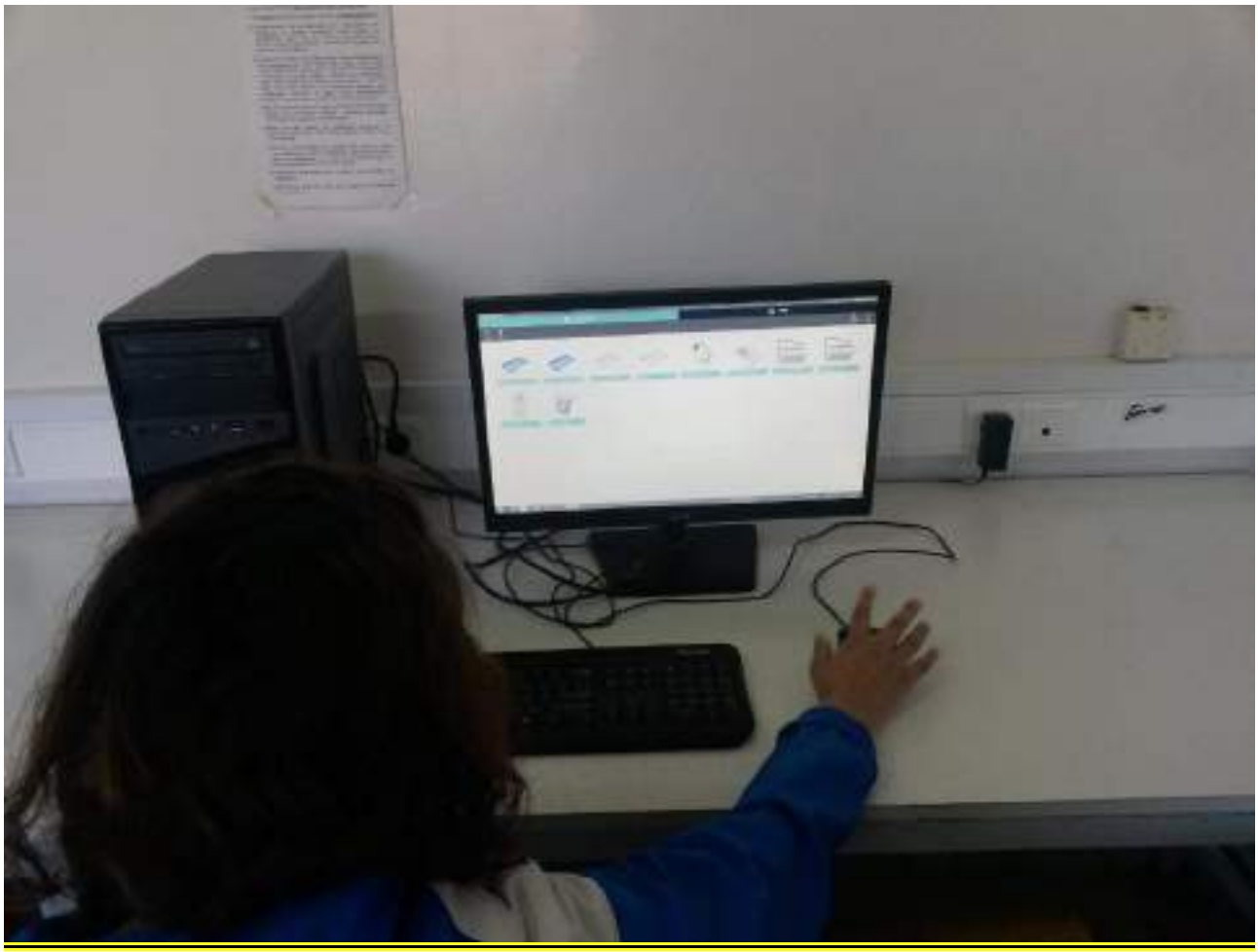
6th - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 2

People involved: 2 teachers + 68 students

It was very important for teachers to help students realise that a lot of factors should be taken into account before actually proceeding with 3D printing. Students' analysing skill, as well as problem-solving techniques evolved during their work in the laboratory. For example, students had to decide if they had to use supportive material or not, as well as determining other parameters. Such decisions were made through group discussion and previous experience from teacher-led experimentations proved valuable. However, first attempts were not successful.





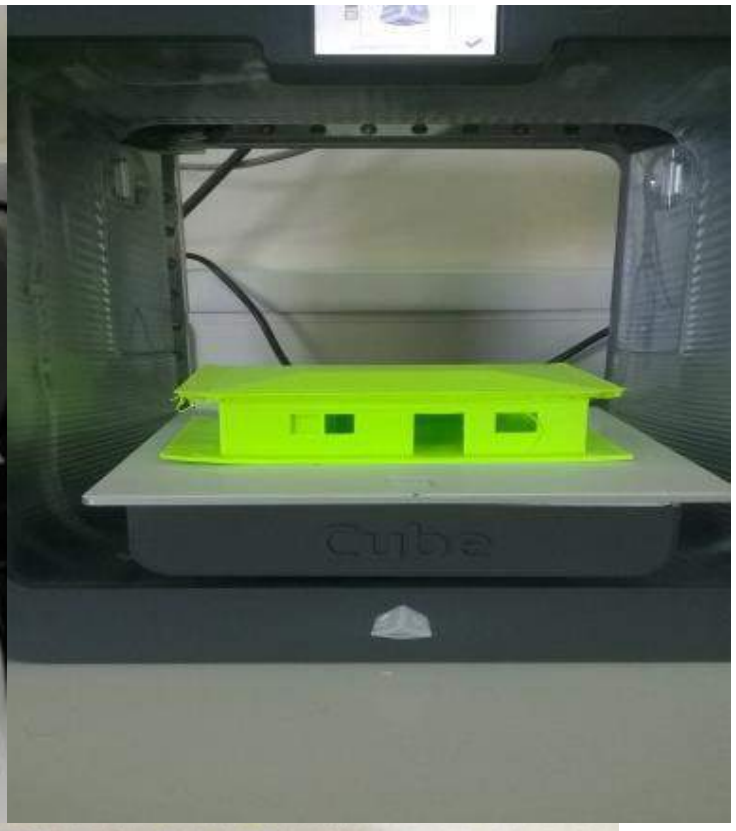
7th - Object printing:

Number of hours dedicated: 4

People involved: 2 teachers + 68 students

Didactic methodology used:

- Teachers divided the classes to several sub-groups, assigning different roles and responsibilities to each of them. There were some cases that objects had to be re-printed.



8th - End of experimentation

Number of hours dedicated: 2

People involved: 2 teachers + 68 students

Didactic methodology used:

We asked students to choose between the following: either, create descriptive essays of their impressions on pupil-led experimentations, as if their essays were to be published in the school's newspaper. Or, write instructions for the construction/production of the 3D model, as if these instructions were to be published in a manual, accompanying the model. Since the whole concept of pupil-led experimentations was based on a freer way of learning, dependent on self-initiative, self-centred learning and learning by doing methods, we thought that the formats mentioned above, would be the most appropriate in order to help them express themselves, without feeling that they had to answer traditionally structured questions once more.

Presentation of items manufactured by the students.

Discussion about the difficulties encountered by several students to design software 3D objects, and attempt to find a solution.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teachers of the main subjects interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives mainly by means of direct observation. However, we also went through an assessment process of the final model. We discussed the differences between the original model and the one printed eventually and tried to spot differenced and the reason why we came up with them. Afterwards, we asked students to suggest ways these models could be released into market and whether they would be attractive to buyers. During this stage, we focused on defects of the final product, sought reasons and proposed possible solutions, in order to prevent such possibilities in a second printing attempt. Finally, we asked students to create a portfolio, describing all steps for this model to be produced, including cost of materials, time consumed, personnel needed, possible price, purchase power, etc. Students were assigned roles of salesmen and consumers, with a view to proving if their model would be powerful in real marketplace terms or not and why.

LESSONS LEARNT

Students seemed to really enjoy the whole process of pupil-led experimentations. We suppose that the most important reason for this was the fact that they felt free to create. Nevertheless, we would like to comment on the following aspects of the experimentations:

It seems to us that it would have been better if IO3 had taken place before IO4 and IO5, as it had been initially planned. Students' dealing with open libraries and downloading .stl files would have enabled them to familiarise with the use of 3D printer through constant practice. Furthermore, we wouldn't have had to devote so much time teaching the basic skills of Technical Drawing and especially 3D Design, since it would have been easier for everyone to use ready-to-use files. Using these open sources, we would have had the chance to analyse the method used for them to be created, taking the opportunity to teach STEM subjects, without having to cope with the really tiresome process of teaching beginners how to use such an advanced designing tool, like CAD software. It is true that there is a percentage of students who are really keen and capable of learning how to use CAD software, but the majority of them seemed awkward about it. Last but not least, if IO3 had been completed before teacher-led experimentations, we would have had the chance to identify which STEM subjects really interested the majority of our students and planned the IO4 and IO5 on these particular likes, instead of devoting so much time working on one particular notion of Mathematics or Engineering.

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 two teachers 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.

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. There is the necessity for a Teachers' training course on the use of 3D Drawing software, before the beginning of experimentations and the choice of Drawing 3D software for beginners. Otherwise, if the STEM subject experimentation is not Engineering, then the solution may be the galleries with preset .stl files.

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. The shortage of financial resources of schools resulted in a great delay as far as the purchase of the 3D printer is concerned, but also restricted our options in one of the most economical ones, which inevitably caused great problems regarding its function and handling its printing materials (PLA and ABS).

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ It is a great motive for students to feel useful and at the same time improve their theoretical background on STEM subjects, through the introduction of such an innovative technique, such as 3D printing technology. Students can feel the satisfaction of creating models from scratch or by downloading ready-to-use files from open libraries, which also arouses their interest in a different way.
- ✓ Learning difficulties are overcome and students' interest rises, following a step-by-step process, which makes students make a move towards knowledge acquisition. It is extremely important for students to realise why they need to learn something, especially when the reason is to be enabled to complete their designs, achieving their goal.
- ✓ Abstract notions, eternally misunderstood by students, turned into valuable knowledge absolutely necessary for the completion of their ideas. It is really astonishing to observe students, who had always been negative towards STEM subjects, realise that they want to learn and seek ways to do so.
- ✓ Students get more responsible and participate consciously in the whole learning process. A very important point to be made is the delicate balance kept when students had to analyse the essential parameters for their object to be printed. If they lacked suitable knowledge, they voluntarily excluded their choice, demonstrating a surprisingly mature behaviour, just because there were convincing arguments for such a decision.
- ✓ The relationship between teacher and students gets more qualitative, since teachers keep a discreet assisting role, instead of just transmitting bare knowledge, which can easily be found in any book or online. At the same time, students acknowledge and seek their teacher's assistance, leading their relation to an advanced level.
- ✓ The learning by doing method is really appealing to students, who feel that their ideas are taken into consideration seriously. 3D printing technology 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.
- ✓ Students are able to learn from their mistakes, which will be an invaluable experience going into their futures. In this way, they discover a new way of approaching and conquering knowledge.

WEAK POINTS OF THE EXPERIMENTATION:

It is a fact that through pupil-led experimentations, both teachers and students learned how to be more optimistic and try to find solutions and face any problematic situation. However, we feel obliged to mention that there may be certain complaints and disappointment when certain objects cannot be selected for printing, basically because of lack of knowledge on behalf of the students. Apart from that, technical malfunctions, either of the printer or the materials used – as they have been discussed and commented on in formal reports for IO4 and IO5 – kept torturing both teachers and students as a whole.

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. 3D Drawing Software selection should be as simple to use, appropriate for young learners at a beginner's level, as well for teachers who may have never dealt with such software before.
- ✓ Make sure that no Interdisciplinary Team consists of fewer than 5 teachers in each School partner's institution, with fluency in English
- ✓ Besides teaching STEM subjects, the use of 3D printers can also be applied and taken advantage of in an Interdisciplinary project studying local history, architecture, etc through printing significant local monuments, in which Language Teachers, Computer Science teachers and Civil Engineering teachers can get involved.
- ✓ Encourage the use of open source, free to use libraries on the Internet, with pre-set .stl files that have already been used for teaching a great number of different subjects. In this way, we can focus only in the process of 3D printing and the use of printed objects in teaching, overcoming the potential obstacle of teaching 3D Drawing.
- ✓ Make sure that constant technical support is available, since it is a vital for the successful completion of all experimentations and the project as a whole.
- ✓ We strongly encourage that students initially deal with pre-set files, working on objects which are of great interest for them, so that the transition to teaching more complex notions, such as these of Mathematics or Engineering, is smoother.

2.5 GEOMETRIC SOLIDS (SABANCI KIZ TEKNIK VE MESLEK LISESI – Turkey)

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) To arouse pupils' interest and motivation by using different methodologies

2) Creating awareness among pupils towards 3D technology

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

4) To promote project based learning and develop team working skills among the pupils.

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 mathematics are a down-to-earth science which they can use in their daily lives

4) To be able to identify the distinctive features of geometric shapes

5) To be able to make simple calculations regarding measurements, mass, weigh, force, area and pressure in mathematics and physics

How the Learning Objectives have been identified and why?

During the discussions before the experiment pupils' main point was to carry out an experiment which would contribute to their daily life, strengthen their creativity and support their learning in core subjects at school. The experiment was anticipated to include team work and collaboration. The only intervene of the teachers was that the subject to be chosen should be part of the school curriculum.

PRINTED OBJECTS

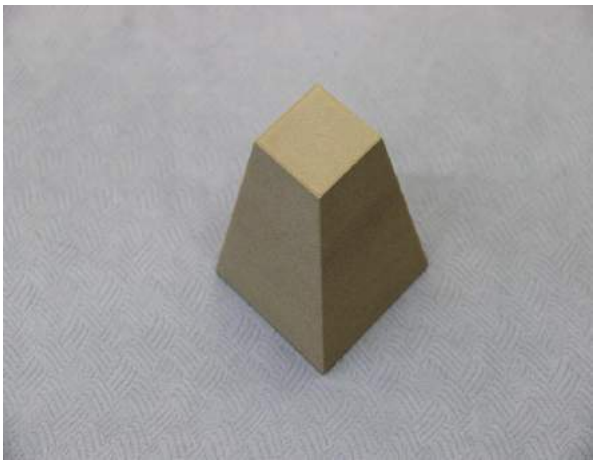
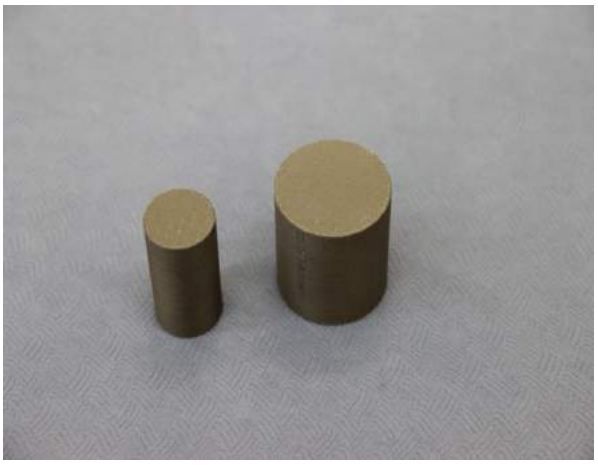
In order to reach the general and specific learning objectives above mentioned, pupils agreed on printing different geometric shapes of different sizes such as:

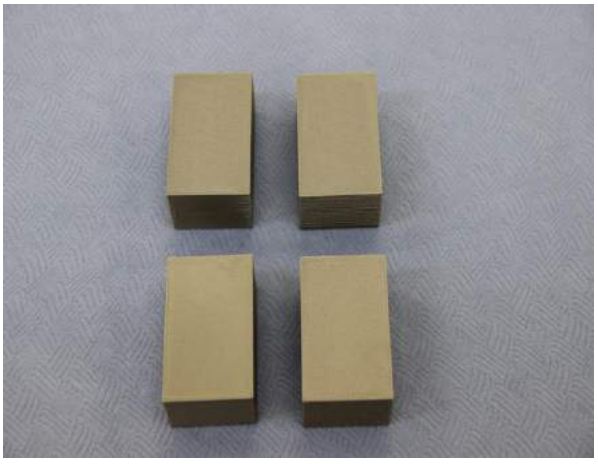
1) Truncated Square Pyramid,

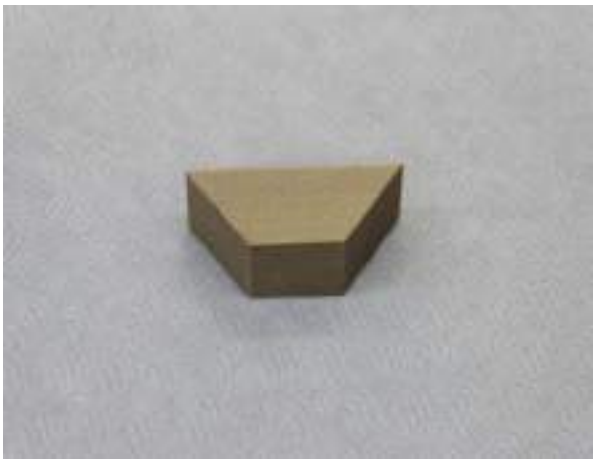
2) Cylinder,
3) Cone,
4) Rectangular Prizm,
5) Trapezoidal Prizm,
6) Triangular Prizm

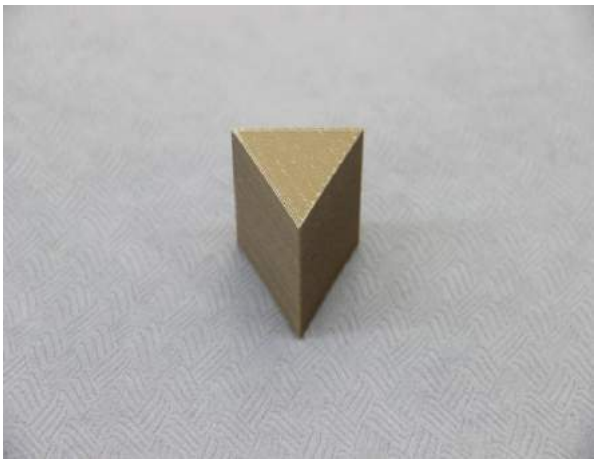
Why this object?

The object would enable pupils to use and enhance their core knowledge in STEM subjects as regards to the subject of geometrical objects within the compulsory curriculum. The objects for this experiment have been chosen in accordance to the curriculum of 9th grade classes. These objects having different areas were decided to be suitable for the successful implementation of the experiment.







PREREQUISITES

In order to reach the defined learning objectives of the experimentation, specific prerequisites were required to pupils:

- ✓ basic computer knowledge and competences
- ✓ basic knowledge in mathematics and physics
- ✓ being able to use basic lab materials like lab weights, digital scales, millimetre rulers etc.

THE TEACHERS TEAM INVOLVED

3 teachers have been involved in the experimentation:

- ➢ 1 teacher of Physics, (Aysegül Ince)
- ➢ 1 teacher of Art and Design, (Ömer Faruk Karslıoğlu)
- ➢ 1 technical teacher (Rıfat Arıkan)

Rationale of the Teachers Team

The teachers involved in the team were chosen in order to successfully carry out the project. A teacher of Physics was chosen in order to give the pupils the continuous supervision and support the pupils need during the experimentation.

To this regard the role of the physics teacher was;

- defining the learning objectives in Physics and providing pupils with basic knowledge,
- helping to define the subjects for the experimentations,
- selecting the pupils
- evaluating the progress of pupils

The Art and Design teacher and 1 teacher for technical/computer support were chosen in order to help the pupils in using the computer and 3D software so that they can 3D print their models.

The role of Art and Design teacher was;

- providing software trainings to the pupils
- supporting the pupils in using the software
- selecting the pupils
- evaluating the progress of pupils

The role of the technical teacher was;

- providing hardware trainings to the pupils
- technically supporting the pupils in using the 3D printer
- maintenance of the printer

THE PUPILS GROUP INVOLVED

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

Number of pupils: 38

Type of group: inter-classes group which is a 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: A survey has been carried out in order to assess the entry level of the pupils. It aimed to assess the pupils' capabilities in mathematics, their skills in computer and designing and also assessed the level of their motivation and interest. Also their previous school records were put into consideration.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	Geometric shapes
Topics related to the Learning Objectives of experimentation	Measurements, calculations, scaling and mathematical modeling
Total number of hours dedicated to completion of the experimentation	10

OTHER RELATED SUBJECT	Physics

Didactic Topics related to the Learning Objectives of experimentation	Pressure, mass and force
Total number of hours dedicated to completion of the experimentation	10

OTHER RELATED SUBJECT	3D Modeling
Didactic Topics related to the Learning Objectives of experimentation	Sketchup-pro software trainings for pupils
Total number of hours dedicated to completion of the experimentation	6

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** Sketchup-Pro was used due to its friendlier interface and ease of use

- **SOFTWARE(S) for object PRINTING:** Zortrax Z-Suite is the software that supports our printer

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

Technical details:

PHYSICAL DIMENSIONS
Without Spool 345 x 360 x 430 mm [13.6 x 14 x 17 in]
With Spool 345 x 430 x 430 mm [13.6 x 17 x 17 in]
Shipping Box 460 x 470 x 570 mm [18 x 18.5 x 22.4 in]
Weight 13 kg [28.7 lbs] Shipping weight 20 kg [44 lbs]

TEMPERATURE
Ambient Operation Temperature 15°-35° C [60°-95° F]
Storage Temperature 0°-35° C [32°-95° F]

ELECTRICAL
AC input 110/240V ~ 2 A 50/60 Hz
Power requirements 24 V DC @ 11 A Power consumption ~ 190W
Connectivity SD card [included], WiFi*

SOFTWARE

Software bundle Z-Suite®
File types .stl, .obj, .dxf
Supports Mac OS X / Windows XP, Windows Vista, Windows 7, Windows 8

PRINTING
Print technology LPD - Layer Plastic Deposition
Build volume 200 x 200 x 185 mm [7.87 x 7.87 x 7.28 in]
Layer resolution settings Advanced: 25-50* microns [0.000984-0.0019685 in] Standard: 90-400 microns [0.003543-0.015748 in]
Wall thickness Minimal: 400 microns Optimal: 800+ microns
Resolution of single printable point 400+ microns
Filament Diameter 1.75 mm [0.069 in]
Filament Type Z-Filament Series
Nozzle diameter 0.4 mm [0.015 in]
Minimum single positioning 1.5 microns Positioning precision X/Y 1.5 microns Z single step 1.25 microns
Extruder maximum temperature 380° C [716° F]
Heated platform maximum temperature 110° C [230° F]

IMPORTANT: Time necessary to print 1 geometric shape with this 3D printer depending on the size of the object was approximately between 2-3 hours.

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

IMPORTANT: Quantity of this material necessary to print 1 object is: approximately 35 gr

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%)

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 2 hours per group

People involved: pupils and physics teacher

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

Number of hours dedicated:2 hours per group

People involved: Pupils and physics teacher



3° - Entry level assessment

Number of hours dedicated: 2 hours per group

People involved: Pupils, physics and Art & Design teacher

4° - Pupils self-study on subject:

Number of hours dedicated: 2 hours per group

People involved: pupils

Didactic methodology used to teach the contents: visual presentation, work sheets,

5° - Training Unit on subject:

Number of hours dedicated:2 hours per group

People involved: Physics teacher and pupils

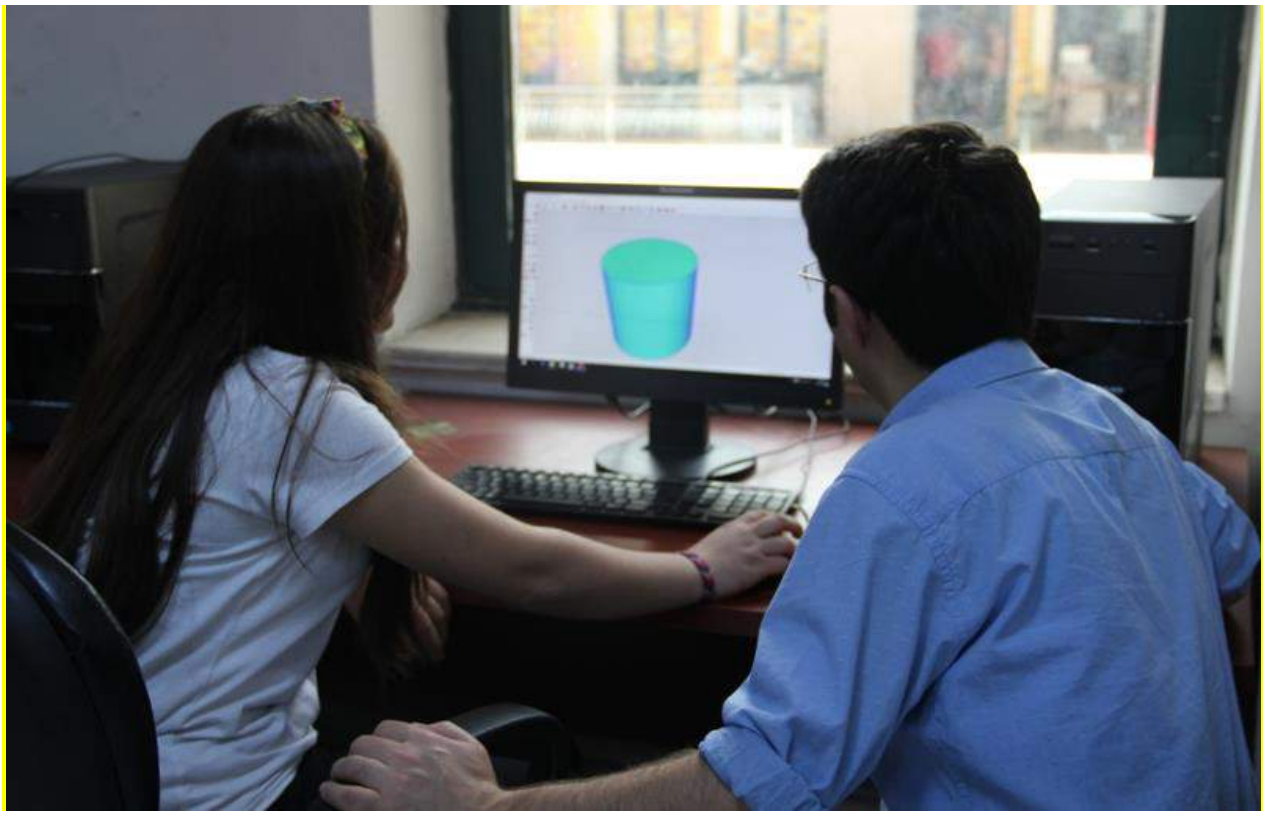
Didactic methodology used to teach the contents: front lesson, pupils self-study, laboratory work, group work, conventional teaching methodology in the classroom

6° - CAD Design of the object:

Number of hours dedicated: 6 hours per group

People involved: art & design teacher and pupils

Didactic methodology used: front lesson, visual tutorials,



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

Number of hours dedicated:2 hours per group

People involved: art & design teacher and pupils

Didactic methodology used: laboratory work, group work

8° - Object printing:

Number of hours dedicated: 3 hours per group

People involved: Technical teacher and pupils

Didactic methodology used: personal printing by each student under the supervision of the technical teacher.

9° - End of experimentation

Number of hours dedicated:2 + 1 hours per group

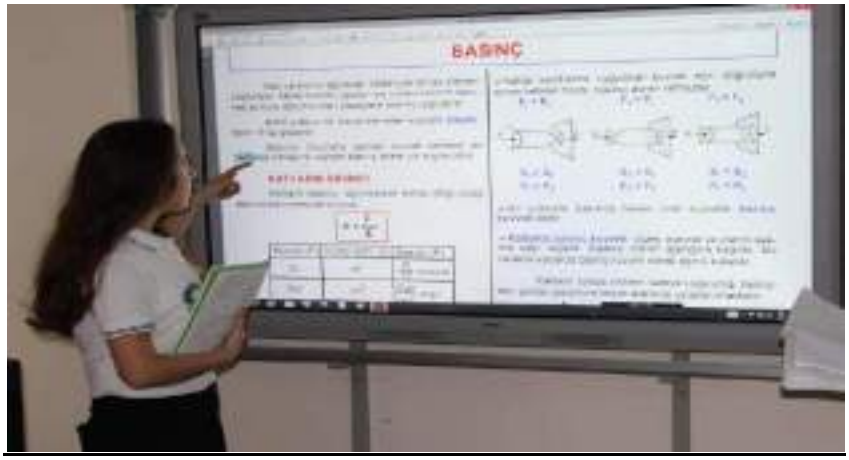
People involved: teacher of physics and pupils

Didactic methodology used: There were two rounds during the experiment:

1) We use two rectangular prisms of equal weight but place them on the surface differently, the first one standing on a smaller area of contact with the surface and the second on a larger area of contact. The aim of this round is, as will be shown to pupils via the measurement of the depth on the surface, to prove that the first one applies more pressure than the second.

2) We use two truncated square pyramid of different weight but both have the equal area of contact with the surface. The aim of this round is, as will be shown to pupils via the measurement of the depth on the surface, to prove that the heavier cube applies more pressure than the lighter one.

The experiments were carried out in the physics lab of the school. Each group was given 2 hours to complete their experiment. After completing their experiment pupils were asked to report on their experiments via preparing final papers and explaining with a visual presentation on the smart board. One hour was dedicated for this activity.



TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of pupils' reports, visual presentations and oral exams recorded the following learning results:

1) The results show that the pupils' level of comprehending the subject is more advanced than traditional teaching results,

2) They can easier correlate real life situations,

3) Pupils find the aesthetic qualities of the experimentation motivating, but usability of the software and hardware still poses problems. In case of a more complicated design then pupils will certainly need to spend more time on the software and also with the printer.

4) Experimenting with the solid object of their own shows interest towards the lesson.

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 in particular answers from the pupils questionnaire to detect lessons learnt

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

STRENGTH POINTS OF THE EXPERIMENTATION:

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

WEAK POINTS OF THE EXPERIMENTATION:

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

RECOMMENDATIONS 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

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

2.6 KSGS BADGE (KIRBY STEPHEN GRAMMAR SCHOOL – UK)

PUPIL-LED APPROACH

The pupil lead project, right from the beginning, was seen as the most difficult part of the Erasmus + project. This was due to the open ended nature of the task. It would be necessary to provide topic areas or to focus pupils attention to a limited number of scientific or mathematical areas which could be developed by pupils.

Time constrictions within the British Education system meant that pupils could not be given open ended design tasks. In the end it was decided that the pupil lead approach would centre around the actual pupils becoming individual teachers. The topic itself would be set out by the teacher who would then allow the pupils to develop their own skills and knowledge and pass these skills and knowledge on to other pupils. The pupils, in effect, would become "teachers".

The Science and Technology departments at Kirkby Stephen Grammar School decided that a simple motif / badge project would be designed and manufactured. Kirkby Stephen Grammar School (KSGS) has strong links with it's feeder primary schools, ie schools who send their pupils to KSGS. It was therefore decided to work on a collaborative project with some year 6 pupils who would be moving into our school in September.

The focus of the project was to teach pupils simple mathematical concepts such as measuring, what the radius and diameter of a circle is, estimating sizes, learning how to use 3D CAD software and turning this into a 3D object. Pupils would also be given a brief introduction into thermoplastics and their properties.

The object of the exercise was initially to allow KSGS pupils to teach the younger pupils basic mathematical and science skills. However this had a number of more unexpected positive consequences.

The KSGS pupils who were going to teach the project had to become very proficient in the use of Sketch-up so that they were capable of not just directing the younger primary school pupils but were also able to trouble shoot problems as and when they arose. This is quite a complex process as it required not just a straight forward ability to be able to use the software programme but also the ability to "unravel" mistakes. This required a deeper understanding of how the software programme worked.

Another positive unexpected outcome was the introduction to the school and in particular the Design & Technology department. During year 6 to year 7 transitions, where pupils move up from out Primary feeder schools to KSGS, pupils can become quite anxious about joining a new school. This project enabled the year 6 pupils to experience the "new" school for a short period of time and have quite a positive experience. As pupils were paired up with the KSGS pupils they would have a familiar face when they eventually joined our school.

The project forces the KSGS pupils into a role as a mentor. The benefit of this is that because the pupil is forced into a role of responsibility they act in a mature manner, which has tremendous impact on the confidence of those pupils.

The final outcome, which is obviously important, is that the project gives the year 6 primary pupils an introduction to 3D modeling software, which will be used in the Design & Technology department.

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) To understand basic geometric principles.

2) To be able to use 3D modeling software

3) To know the properties of a thermoplastic.

4) To be able to name a specific thermoplastic.

SPECIFIC Learning Objectives

1) Pupils will be able to estimate scale sizes.

2) Pupils will be able to visualise and approximate sizes in millimetres.

3) Pupils will be able to describe the difference between radius, diameter and circumference.

4) Pupils will understand why thermoplastics are needed for 3D Printing.

5) x,y and z axis as used on 3D modeling.

5) Pupils will be able to use 3D CAD Software, such as Sketch-up.

6) Pupils will be able to convert 3D Drawing files to G code files.

How the Learning Objectives have been identified and why?

Pupils were guided towards the learning objectives as the whole project was set within limited area. As previously mentioned project parametres were given to the pupils due to limited time frame and the difficult nature of the project, that of being pupil lead.

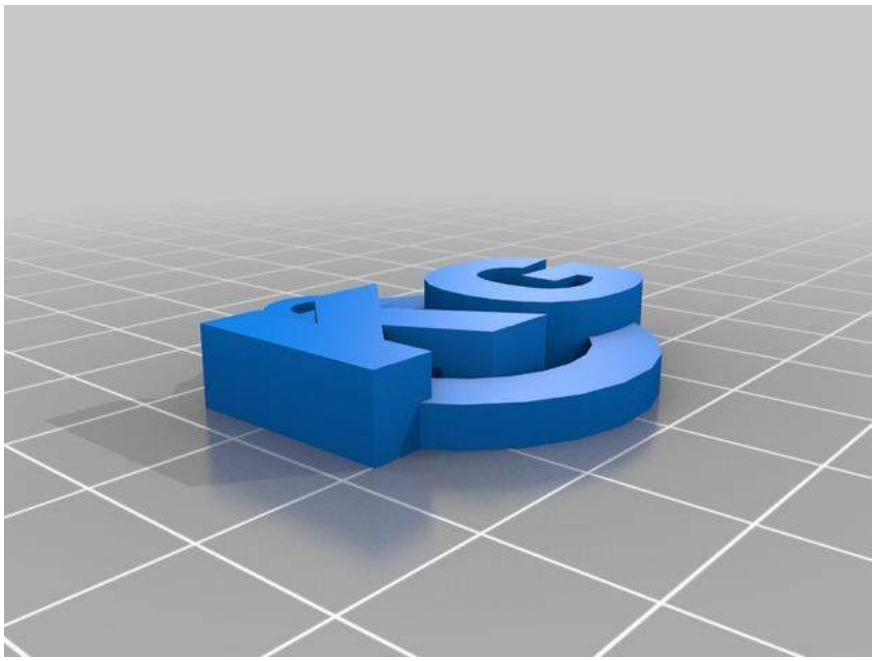
To quite a large extent, despite the project being pupil lead, it is still possible for the teacher to specify Learning Objectives and this could be a starting point for future projects. This will give pupils the focus

for their project and allow them to investigate an area of their choice but still allow the teacher some control of the project and the learning outcomes.

The learning objectives were arrived at by the teacher marking existing pupils work and examining trends where pupils were either struggling with their understanding or failing to understand the concept at all.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing a simple badge or motif.



Why this object?

The object was a simple badge or motif, which would give a high rate of success. This was important for both groups of pupils for them to have a positive experience.

The reasoning behind the choice of project was because it was already resourced and a number of pupils were familiar with the basic concepts. As the students would be teaching the project to younger pupils it was felt that they would be more motivated due to them being under more pressure from "their" pupils.

This increased motivation was to ensure that they were able to fully understand the concepts as they would be required to "teach" them to the younger pupils. This increased motivation was seen as a way of making them take responsibility for their own education, something which is being seen in the UK as a major driver in improving learning within the classroom.

Due to the nature of the project, ie teaching younger pupils, the STEM skills learnt were less demanding than had been hoped. However a number of the younger pupils found the introduction to STEM by other pupils a positive experience and as result were more interested or more likely to take up STEM subjects when they moved to secondary school.

The difficulties mainly centred around some pupils being more confident socially then less introverted pupils. This lead to a difference in the success rate or speed with which pupils completed the task. By this I mean that the younger pupils were more likely to make mistakes and fall behind before intervention by the pupil mentors.

PREREQUISITES

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

(Examples: basic knowledge and competences in technical drawing, basic computer knowledge and competences, mathematics knowledge, etc.)

1) Basic knowledge of 3D Software.

2) Basic knowledge of geometry.

3) Knowledge of how to measure.

4) Understanding of the properties of thermoplastics.

5) How to use conversion software.

6) How to download and operate the 3D Printer.

THE TEACHERS TEAM INVOLVED

2 teachers have been involved in the experimentation:

List each teacher' subject/domaine:

Kevin Gough Teacher of Design & Technology Responsible for the 3D Printer.

Michelle Thwaites Teacher of Chemistry Responsible for STEM theory.

Rationale of the Teachers Team

The teachers involved in the team were chosen because of their area of specialism and ability to plan and work together. The teachers involved were able to examine key aspects of knowledge that would be required for the lower years of secondary school and plan these into a simple project.

Michelle Thwaites discussed the polymer aspects of the project and use the correct terms and concepts which would be required.

Kevin Gough was able to work with the pupils organizing them so that they had an understanding of the processes which would be involved, in effect training them on how and what to deliver.

Skills required for the project included: understanding of polymer science, use of 3D Software and use of 3D Printer.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 40

Type of group: The group was of mixed sex and ability.

Number of classes: 2

Scholar curriculum specialisation of the class(es) involved: Design & Technology and Engineering

"Special needs" students: 3 pupils had very low target grades, below C at GCSE. In previous years they had had reading intervention as they had weak literacy skills.

Entry level assessment: Pupils were given a similar set task, that of designing and manufacturing a specific component / components, following some technical terms and measurements.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	Geometry

Topics related to the Learning Objectives of experimentation	Measuring X,Y,Z axis Scaling Volume
Total number of hours dedicated to completion of the experimentation	4 hours

OTHER RELATED SUBJECT	CAD Skills
Didactic Topics related to the Learning Objectives of experimentation	Learning 3D Modeling skills
Total number of hours dedicated to completion of the experimentation	5 hours

OTHER RELATED SUBJECT	3D Modeling conversion to G Code.
Didactic Topics related to the Learning Objectives of experimentation	Practice and discussion of how to set manufacturing parameters.
Total number of hours dedicated to completion of the experimentation	5 hours

OTHER RELATED SUBJECT	Operation of 3D Printer
Didactic Topics related to the Learning Objectives of experimentation	How to load consumables, level build plate and operate.
Total number of hours dedicated to completion of the experimentation	5 hours.

II) PRINT STEM LAB: THE TECHNOLOGIES

- **SOFTWARE(S) for object DESIGN:** Trimble Sketch-up. This was chosen because of the ease with which it can be used but also the speed with which pupils can learn. It is also freely available so pupils can use this at home too as it is open source.

- **SOFTWARE(S) for object PRINTING:** Cura Software was used as it is open source and able to be used by a number of 3D Printers.

- **3D PRINTER:** Ultimaker 2; Euro 1800; plate size 223x223x205; 24mm2/second
  Time necessary to print one: 15mins

- **PLASTIC MATERIAL:** PLA filament was used. ABS has been used before on other projects and seems to suffer from warping more so than PLA. Both are freely available on the internet and varies in price depending upon where it is bought from. Of particular note is the fact that cheaper filament does not appear to reduce the quality of the print. However due to the nature of the polymers PLA and ABS they can absorb water moisture. This is why it is important to keep the filament in the dry sealed polythene bag until needed. It will then be important to use this in a dry dust free environment, as dust too can have an adverse effect on the quality of the print but more importantly how well the machine works.

Quantity of this material necessary to print 1 (object of the experimentation) is: 10mm2

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 1 hour

People involved: Pupils and Teacher. This was discussed with pupils but was mainly teacher lead.

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

Number of hours dedicated: 4 hours

People involved: Mainly pupils but worksheets had been produced by the teacher.

3° - Entry level assessment

Number of hours dedicated: 1 hour. Testing pupils CAD skills.

People involved: K. Gough and pupils

4° - Training Unit or Pupils Self-study on Polymers and Basic Geometry

Number of hours dedicated: 5 hours

People involved: Michelle Thwaites, Pete Wareham and K. Gough

Didactic methodology used: front lesson and pupils self-study with some experimentation.

5° - Training Unit on CAD CAM Skills:

Number of hours dedicated: 5 hours

People involved: K. Gough

Didactic methodology used: Front lesson, pupils self-study and group work.

6° - CAD Design of the object:

Number of hours dedicated: 2 hours for pupils

People involved: K. Gough

Didactic methodology used: A work booklet had been devised to take pupils through the necessary skills, which would be needed for the project. This required a lot of work to produce the booklet as we wanted the pupils to self study or progress at their own pace. Something we thought would be important for the depth of learning required.

Very often lessons can be very much teacher orientated. By this I mean teachers giving out information then pupils doing set tasks. This was far more pupil orientated as they had to learn for themselves, with only a little support from the teacher. It was recognised that sometimes pupils teaching pupils can be more effective.

What we did was provide pupils with booklets which they could follow at their own pace and allowed them to work collaboratively or help one another if required.

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

Number of hours dedicated: 1 hour

People involved: 2 K. Gough and Technician

Didactic methodology used: Pupils were allowed to transfer their design to Cura software. Print parametres were covered in a booklet and were very basic. We used factory settings apart from the print speed where we used the fastest possible print speed. This worked well as the models printed out did not have any fine detail.

Initially we saved the files to a single pen drive, which was slow and caused pupils to shout out "where's the Pen Drive!" To stop this we created a folder on the school intranet where we allowed pupils to save their work so it could be transferred in one go.

Importantly this allowed any mistakes to be rectified. We had a number of issues where projects had not been properly designed or parts were misaligned. This gave the Technician time to rectify any problems or highlight any pupils who were finding the project difficult.

I would strongly advise teachers to adopt a similar method as this serves a number of purposes. It speeds up the process of printing; allows for smoother task transitions between different aspects of the design and manufacturing process; allows work to be checked so both time and filament are saved and means any modifications / alterations can be done by the teacher if necessary.

8° - Object printing:

Number of hours dedicated: The print can be started at the end of the school day and checked to see that the print has started correctly. It can then be left on overnight.

People involved: Technician

Although pupils were allowed to add their own files in the end to speed the process up we used the technician to collect each file ready for printing to operate the machine and allow multiple prints to be completed in one go. This was done overnight as whilst one print took 15mins multiple prints took a lot longer.

Didactic methodology used: Although pupils were allowed to add their own files in the end to speed the process up we used the technician to collect each file ready for printing to operate the machine and allow multiple prints to be completed in one go. This was done overnight as whilst one print took 15mins multiple prints took a lot longer.

n° - End of experimentation

Number of hours dedicated: 2 hours

People involved: K. Gough

Didactic methodology used: Pupils were given a similar task to produce their own simple design.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The teacher of the main subject interested by the experimentation assessed after experimentation pupils achievement of Learning Objectives by means of observation of current work and discussion with pupils about their understanding of their work and recorded the following learning results:

1) Greater pupil engagement.

2) Increased motivation from disaffected pupils

3) Improved confidence with the subject matter.

4) Pupils saying that they enjoyed the experience whilst learning.

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) Use of these skills in aspects of their coursework.

2) Ability to produce more complex ideas.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

1) Can focus the pupils attention.

2) Pupils given responsibility for own learning (this increases pupil participation and learning)

3) Can be a motivational factor.

4) Can be fun and engage more pupils than the teacher standing at the front of the class.

5) Pupils can learn different skills

6) Pupils can learn to become more self-reliant.

7) Pupils can have different learning experiences

8) Fun.

WEAK POINTS OF THE EXPERIMENTATION:

1) Can be very time consuming.

2) Needs a lot of preparation.

3) Can go horribly wrong.

4) Possibility of pupils not learning.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

I have covered a lot of this in the introduction to the project evaluation. However I intend running a number of similar courses next year. These following points will be the focus of my attention:

The biggest problem by far is the speed of the print out and how to complete the print ready for next lesson. This problem can, to some extent, be alleviated by having a number of printers available for use. However this is not always possible. I may chose to use another schools printers but this may still not be enough. Staggering the printing of components will be necessary in order that all print outs are completed for the next lesson or a number of lessons.

I am considering specifying time limits on the print or size limitations as this is available when Cura converts the print. This could be a time restriction that is imposed on the design and pupils will need to meet this time restriction if they want the print to be completed. This is in actual fact a typical restriction that a production engineer may find in a manufacturing specification.

Another way of getting around slow print speeds is by having groups or cells of students who will produce one 3D Print only. This will aid cooperative learning but could end up in arguments. It may be appropriate for each pupil to contribute a certain aspect to a single design / 3D Print. So for example an air pressure lock for a lunar base could be designed. Then the design is passed onto the next pupil who adds their own component or modifies the design.

As D&T teacher who is required to teach aspects of STEM, I intend to incorporate more science and maths within my subject. This may only be basic but could build on work done in the science and Maths department. One such project I am thinking about is a Mars Project. As aspects of gravity, mass and weight are covered in science it would be worthwhile using pupil's understanding of these concepts and some how apply it to a Design and Make project.

Having work booklets that pupils can follow is a good way of using self directed study time or making pupils independent learners. The work booklet could be given out at the start of the academic year and pupils could progress at their own rate. This would also allow time between each print and prevent all

pupils wanting their print to be printed out in one go. Another possibility is to get pupils to design something for themselves. This would extend the more gifted and talented pupils and gain their interest.

My main worry is that of wasting time and not having quantifiable learning outcomes or having learning outcomes, which are varied between different students and groups of students then marking them. What would that marking criteria look like? Students would need to be given a format in which they are required to demonstrate their learning. This could be in the form of a Power Point presentation where pupils need to show specific pieces of work. For example in a Mars Project they could calculate the weigh of an object they design. They could demonstrate the 3D Design they have actually designed and annotate the key parts of that design saying why they have designed it like this.

Supporting the science of polymers, smart materials and new composite materials would be an excellent way of gaining the interest of pupils. Showing pupils how these can be applied and how to apply this could be a new way of teaching.

Finally it will be important to discuss, in detail, any cross curricular stuff that is taught so you, as a teacher get it right.

Key considerations:

1) Set certain parameters for the project.

2) Try to remain partly in control.

3) Break tasks down into multiple small stages.

4) Put time limits on tasks.

5) Get pupils to write down briefly what they have learnt at each stage.

6) Be very clear about what is required.

7) A Technician is very useful.

8) Some times things go wrong. This is a learning experience, not a failure.

2.8 KEYRINGS (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) Perform and apply a study about the e-commerce of 3D-printed objects.

2) Offer a didactic context to other students, so they could freely create objects.

SPECIFIC Learning Objectives

1) Cost f production.

2) Patent.

3) Formal procedures for granting the patent.

How the Learning Objectives have been identified and why?

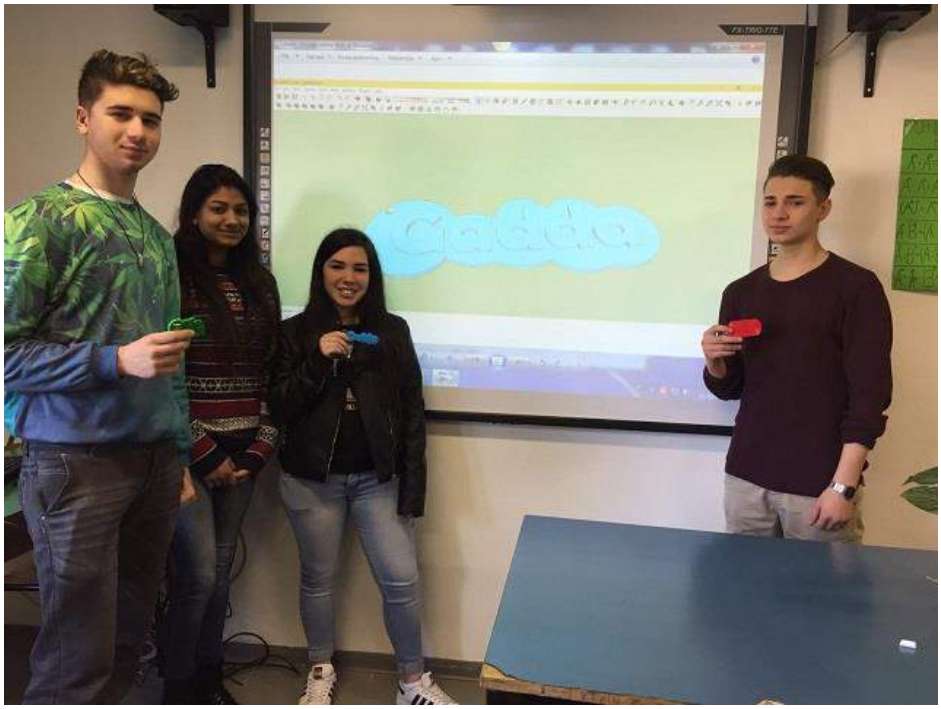
The computation of cost of production was part of the program. The teachers exposed the possibility to insert it in the experimentation and the pupils accepted.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing **keyrings**.

Why this objects?

The object would enable pupils to perform and apply a study about the e-commerce of 3D-printed objects. Our Headmaster suggested to create a gadget for the new students of our school.



PREREQUISITES

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

- ✓ Measurements.
- ✓ 3D basic Geometry.
- ✓ Economic functions.
- ✓ Basic computer knowledge and competences.
- ✓ Basic knowledge and competences in technical drawing.

THE TEACHERS TEAM INVOLVED

3 teachers have been involved in the experimentation:

1 teacher of Mathematics.

1 teacher of Economy.

1 teacher of the enhancement staff.

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I03 implementation and they expressed their interest.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 12

Type of group: single class.

Number of classes: 1

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

"Special needs" students: 2 Pupils. Everyone took part to the job on the basis of their own capabilities.

Entry level assessment: Standard tests.

SETTING UP THE EXPERIMENTATION

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	
Topics related to the Learning Objectives of experimentation	✓ Cost of production. ✓ Measurements. ✓ 3D basic Geometry. ✓ Basic computer knowledge and competences . ✓ Basic knowledge and competences in technical drawing (Sketchup).
Total number of hours dedicated to completion of the experimentation	5

OTHER RELATED SUBJECT	**Economy**
Didactic Topics related to the Learning Objectives of experimentation	✓ Economic functions. ✓ E-commerce. ✓ The patent laws.
Total number of hours dedicated to completion of the experimentation	5

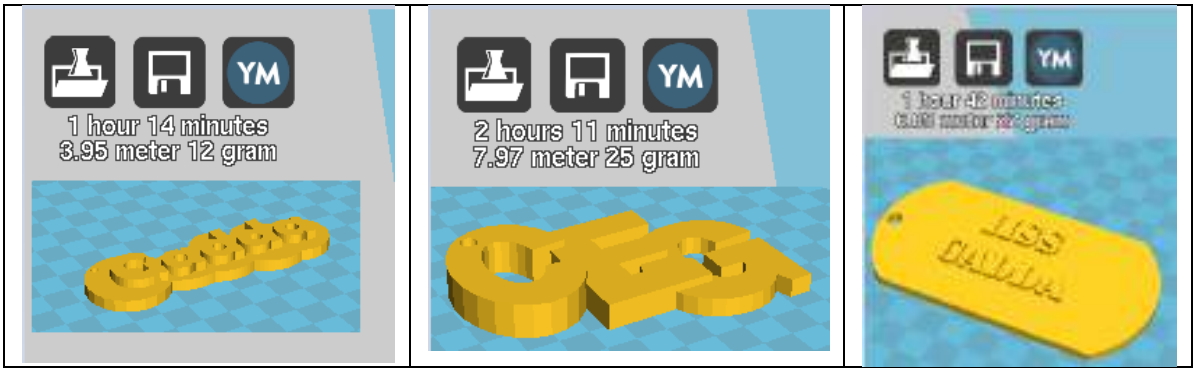
II) PRINT STEM LAB: THE TECHNOLOGIES

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

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

- **3D PRINTER:** WASP

IMPORTANT: Time necessary to print and quantity of material with this 3D printer is:



- **PLASTIC MATERIAL:** PLA.

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

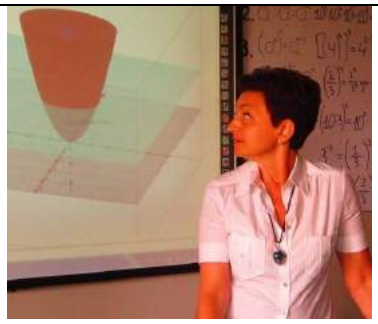
Number of hours dedicated: 1

People involved: 3 Teachers.

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

Number of hours dedicated: 1

3 Teachers.

		
Prof. M. Bertocchi - Mathematics	Prof. G. Zanin - Economy	Prof. R. Rossi - Enhancement Staff.

3° - Entry level assessment

Number of hours dedicated: 1

3 Teachers.

4° - Training Unit or pupils self-study on involved Subjects:

Number of hours dedicated: 5

People involved: three stem-teachers.

Didactic methodology used to teach the contents:

- Frontal lessons.
- Pupils self-study.
- Laboratory work.
- Teamwork.

5° - CAD Design of the object:

Number of hours dedicated: 3

People involved: Prof. R Rossi – Enhancement Staff.

Didactic methodology used: Prof. Rossi helped pupils in drawing with Sketchup.

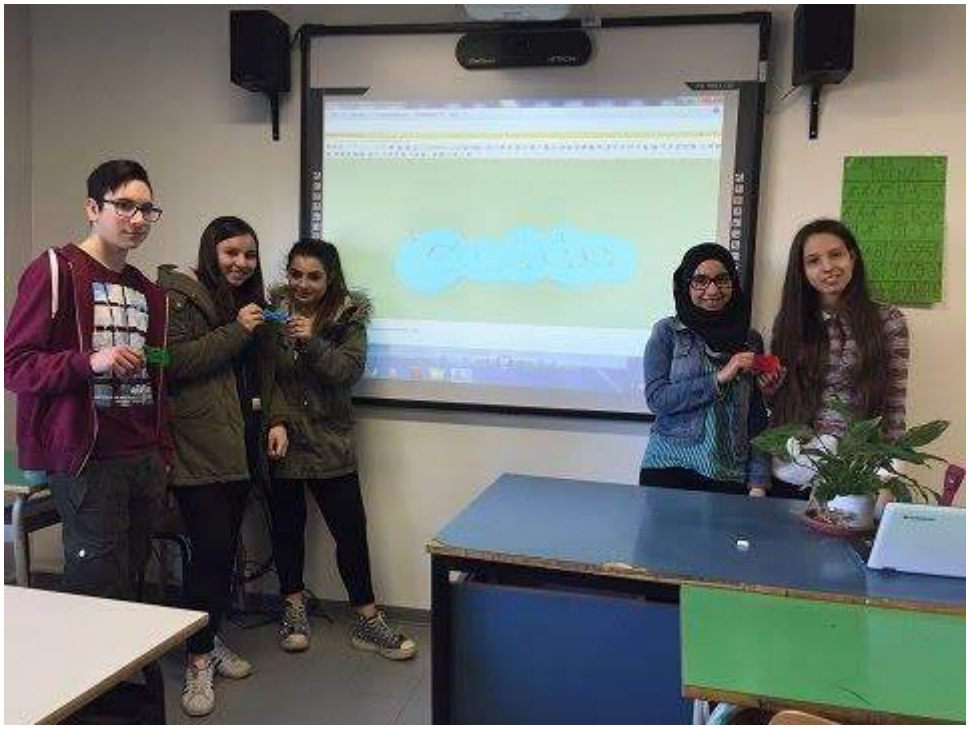
6° - Transfer of the object designed to 3D printing software:

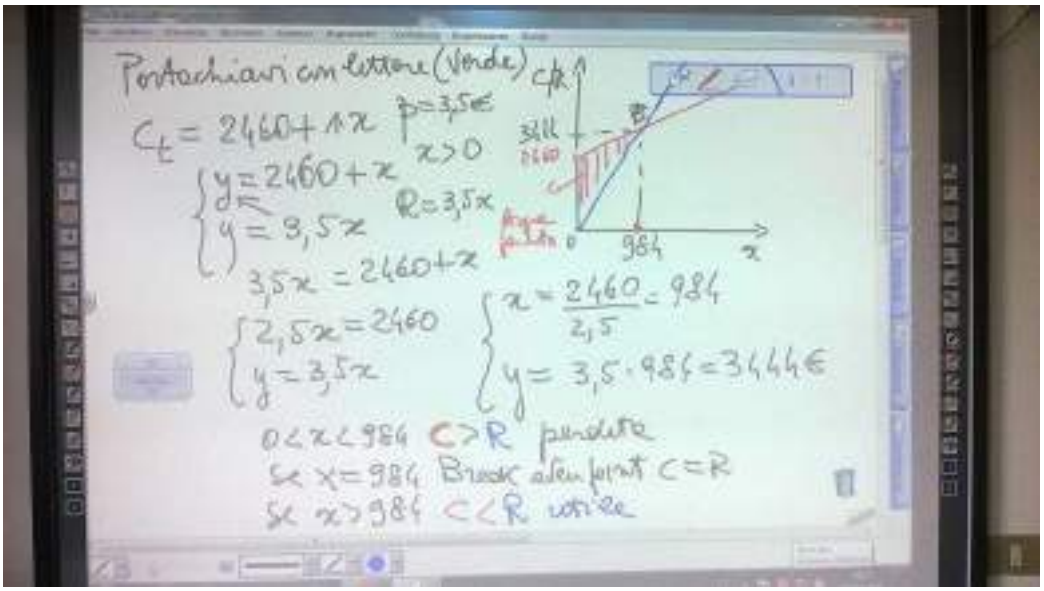
Number of hours dedicated: 1

People involved: Prof Rossi.

Didactic methodology used:

The students were already informed about the main line of the setting of the files with slicer during the previous experimentation; they simply had the opportunity to see once again the choice of the printing parameters.





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

6° - Object printing:

Number of hours dedicated: 1

People involved: Prof. Rossi.

Didactic methodology used:

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

7° - End of experimentation

Number of hours dedicated: 3

People involved: 2 teachers involved.

Didactic methodology used:

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

A final test named "prova esperta" is going to be submitted to pupils.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

1) Better degree of competence in dealing with economic subject.

3) Competence in applying mathematical topics to Economy.

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) Improvement in skills teamwork.

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

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

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation.
- ✓ Learning of new software and technical devices.
- ✓ The 3D-printer allowed the realization of theoretical concepts.
- ✓ Teamwork.

- ✓ 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.
- ✓ The bureaucratic aspect of the experimentation: too repetitive.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ The 3d printer is going to be a new didactical tool but it isn't a new distinct subject.
- ✓ 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.

2.8 ADDING MACHINE (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) Apply the theory of the binary number system to a simple practical device.

2) Realize why every modern computer exchanges and processes information in the ones and zeros of binary numbers.

SPECIFIC Learning Objectives

1) Adding algorithm of the sum of binary numbers.

How the Learning Objectives have been identified and why?

The binary numbers system was part of the program of Computer Science.
The teacher presented the tutorial: https://www.youtube.com/watch?v=md0TlSjIags

The pupils decided to collaborate all together and to make an adding machine.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing an **adding machine**.

Why this object?

The object would enable pupils to connect the sum of binary numbers with a mechanical device.

The further step consisted in connecting it with an electronic circuit.

PREREQUISITES

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

- ✓ Measurements.
- ✓ 3D basic Geometry.
- ✓ Binary numbers system.

- ✓ Basic computer knowledge and competences.
- ✓ Basic knowledge and competences in technical drawing.

THE TEACHERS TEAM INVOLVED

- ✓ 3 teachers have been involved in the experimentation:
- ✓ 1 teacher of Mathematics.
- ✓ 1 teacher of Economy.
- ✓ 1 teacher of the enhancement staff.

Rationale of the Teachers Team
The teachers involved in the team were chosen because their subjects were strictly connected with I03 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.

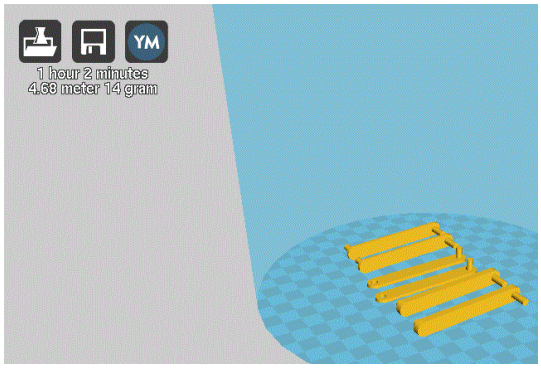
SETTING UP THE EXPERIMENTATION

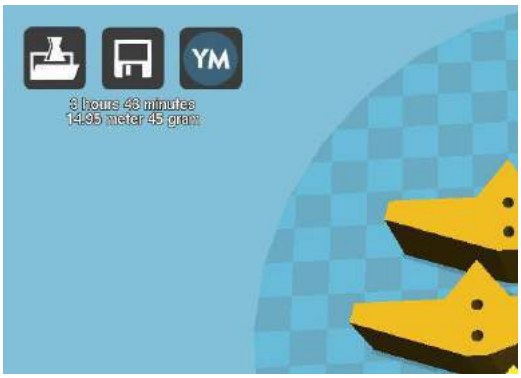
I) SUBJECTS INVOLVED

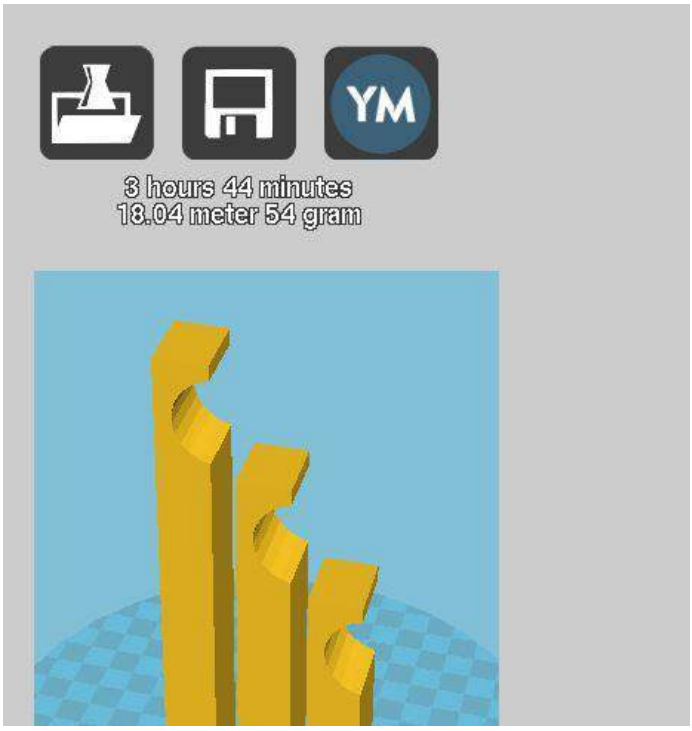
MAIN MATHEMATICAL SUBJECT	
Topics related to the Learning Objectives of experimentation	✓ Binary numbers system.
Total number of hours dedicated to completion of the experimentation	5
OTHER RELATED SUBJECT	**Graphics**
Didactic Topics related to the Learning Objectives of experimentation	✓ Measurements. ✓ 3D basic Geometry. ✓ Basic computer knowledge and competences .

	✓ Basic knowledge and competences in technical drawing (Sketchup).
Total number of hours dedicated to completion of the experimentation	5

II) PRINT STEM LAB: THE TECHNOLOGIES







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. S. Saccani – Computer Science

Prof. R. Rossi - Enhancement Staff.

3° - Entry level assessment

Number of hours dedicated: 1

2 Teachers.

4° - Training Unit or pupils self-study on involved Subjects:

Number of hours dedicated: 5

People involved: three stem-teachers.

Didactic methodology used to teach the contents:

- Frontal lessons.
- Pupils self-study.

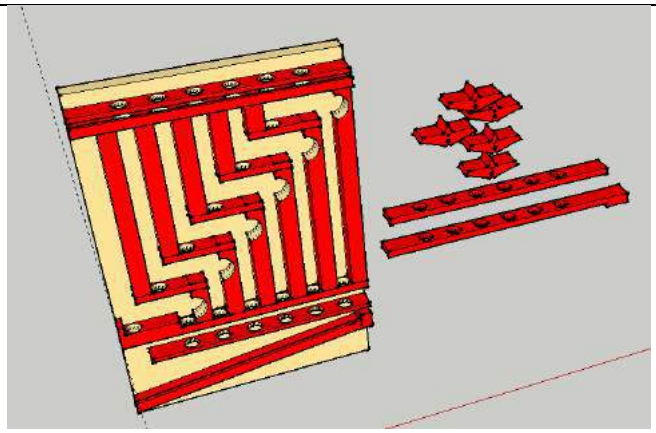
- Laboratory work.
- Teamwork.

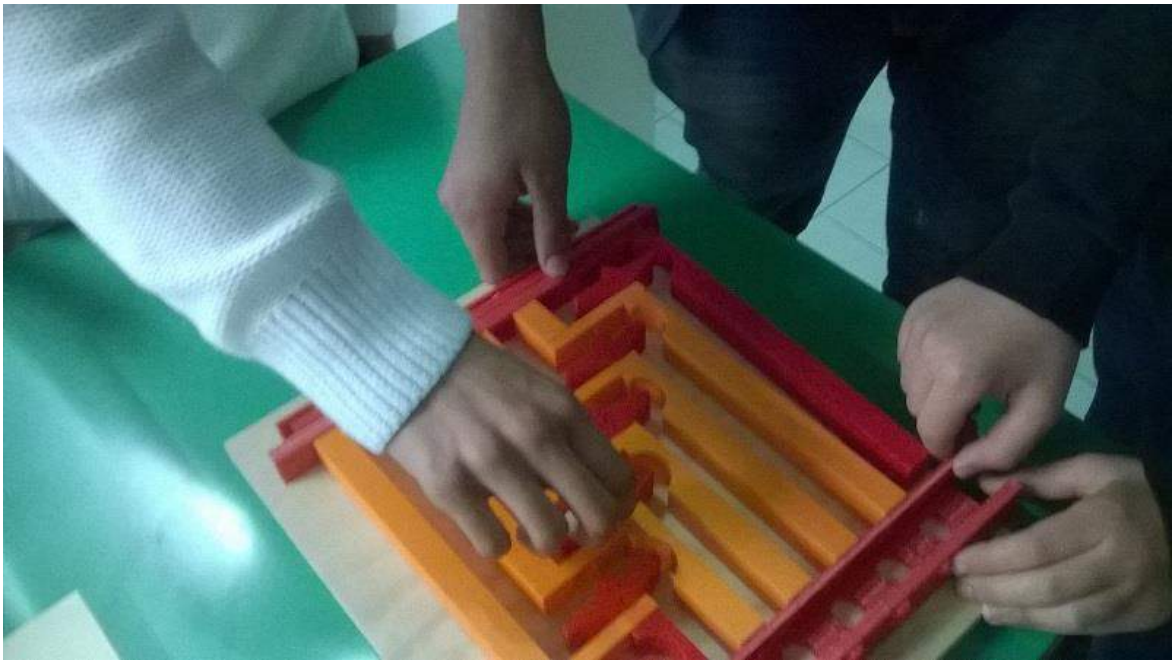
5° - CAD Design of the object:

Number of hours dedicated: 3

People involved: Prof. R Rossi – Enhancement Staff.

Didactic methodology used: Prof. Rossi helped pupils in drawing with Sketchup.





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

Number of hours dedicated: 1

People involved: Prof Rossi.

Didactic methodology used:

The students were already informed about the main line of the setting of the files with slicer during the previous experimentation; they simply could see once again the choice of the printing parameters.

8° - End of experimentation

Number of hours dedicated: 3

People involved: 2 teachers involved.

Didactic methodology used:

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

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

1) Better degree of competence in dealing with binary numbers.

3) Competence in applying mathematical topics to Computer Science.

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) Improvement in skills teamwork.

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

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

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation.
- ✓ Learning of new software and technical devices.
- ✓ The 3D-printer allowed the realization of theoretical concepts.
- ✓ Teamwork.
- ✓ 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.
- ✓ The bureaucratic aspect of the experimentation: too repetitive.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ The 3d printer is going to be a new didactical tool but it isn't a new distinct subject.
- ✓ 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.

2.9 WINGS (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) Printing an object suitable to a physical investigation.

SPECIFIC Learning Objectives

1) Learn how to measure the lift of a wing.

How the Learning Objectives have been identified and why?

The Physics teacher was explaining the properties of the airfoils in a non-rotational flux of air.
He proposed a competition between groups: each group was asked to print a wing.
The winner was the wing with greater vertical strength in an equal flux of air.
The class accepted.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing some **wings**.

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.

PREREQUISITES

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

- ✓ Strength measurements.
- ✓ Basic physics concepts.
- ✓ 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 I03 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

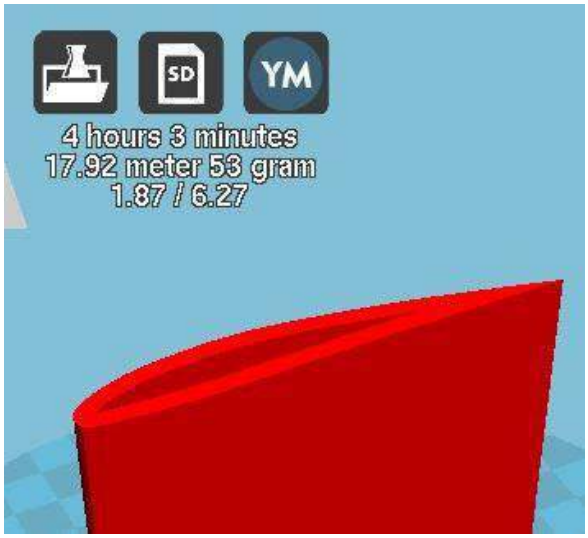
I) SUBJECTS INVOLVED

MAIN SUBJECT	
Topics related to the Learning Objectives of experimentation	✓ Flux of air. ✓ Lift of a wing or of an aileron.
Total number of hours dedicated to completion of the experimentation	5

OTHER RELATED SUBJECT	Graphics
Didactic Topics related to the Learning Objectives of experimentation	✓ Measurements. ✓ 3D basic Geometry.

	✓ Basic computer knowledge and competences . ✓ Basic knowledge and competences in technical drawing (AUTOCAD).
Total number of hours dedicated to completion of the experimentation	5

II) PRINT STEM LAB: THE TECHNOLOGIES



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: 2

2 Teachers.  Prof. L. Quarantelli – Physics.	 Prof. V. Mangione - Graphics.

3° - Entry level assessment

Number of hours dedicated: 1

2 Teachers.

4° - Training Unit or pupils self-study on involved Subjects:

Number of hours dedicated: 5

People involved: two stem-teachers.

Didactic methodology used to teach the contents:

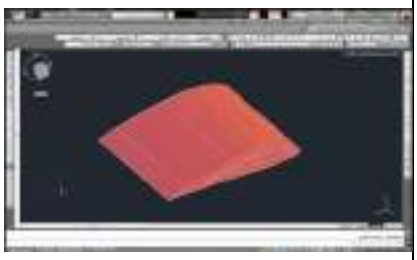
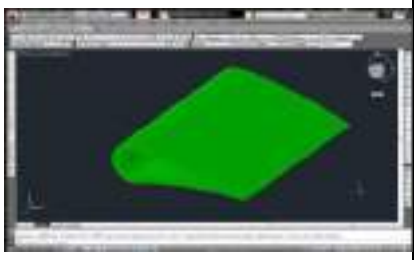
- Frontal lessons.
- Pupils self-study.
- Laboratory work.
- Teamwork.

5° - CAD Design of the object:

Number of hours dedicated: 2

People involved: Prof. V. Mangione - Graphics.

Didactic methodology used: standard lesson on AUTOCAD.

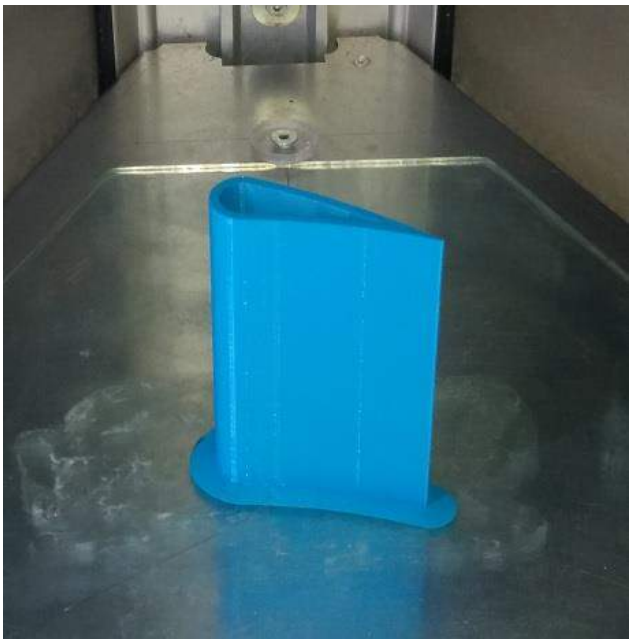

6° - Transfer of the object designed to 3D printing software:

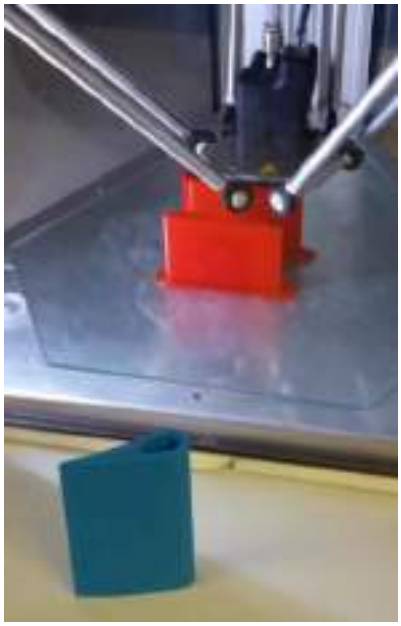
Number of hours dedicated: 1

People involved: Prof . Mangione.

Didactic methodology used:

The students were already informed about the main line of the setting of the files with slicer during the previous experimentation; they simply could see once again the choice of the printing parameters.





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

7° - End of experimentation

Number of hours dedicated: 3

People involved: 2 teachers involved.

Didactic methodology used:

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

A further step can be the analysis of the lift in function of the speed of the air.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

1) Better degree of competence in dealing with Physics lab .

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) Improvement in skills teamwork.

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

3) Ability to use the software AUTOCAD .

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation.
- ✓ Learning of new software and technical devices.
- ✓ Apply the students to perform an original and unusual lab experiment.
- ✓ Teamwork.
- ✓ 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.
- ✓ The bureaucratic aspect of the experimentation: too repetitive.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ The 3d printer is going to be a new didactical tool but it isn't a new distinct subject.
- ✓ 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.

2.10 PIE GRAPH AND OTHER OBJECTS (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) Increase the interest in a difficult class.
2) Allow pupils to express themselves.
3) Allow pupils to feel active part of the school.
4) Increase the self-esteem in low level unmotivated students

SPECIFIC Learning Objectives

1) Statistics.
2) 3D Geometry.
3) E-commerce.

How the Learning Objectives have been identified and why?
The Mathematics teacher was explaining some statistics.
Dealing with pie graphs and histograms, a student proposed to print some of them with the 3D printer.
The teacher added the idea of making a mixture of the two objects.
The subjects of the statistical survey were the birth place of the students and their rating of mathematics.
This was done by the whole class.
Each student was also allowed to draw and print in a free way its own object.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing a **pie graph and many free objects**.

Why this object?

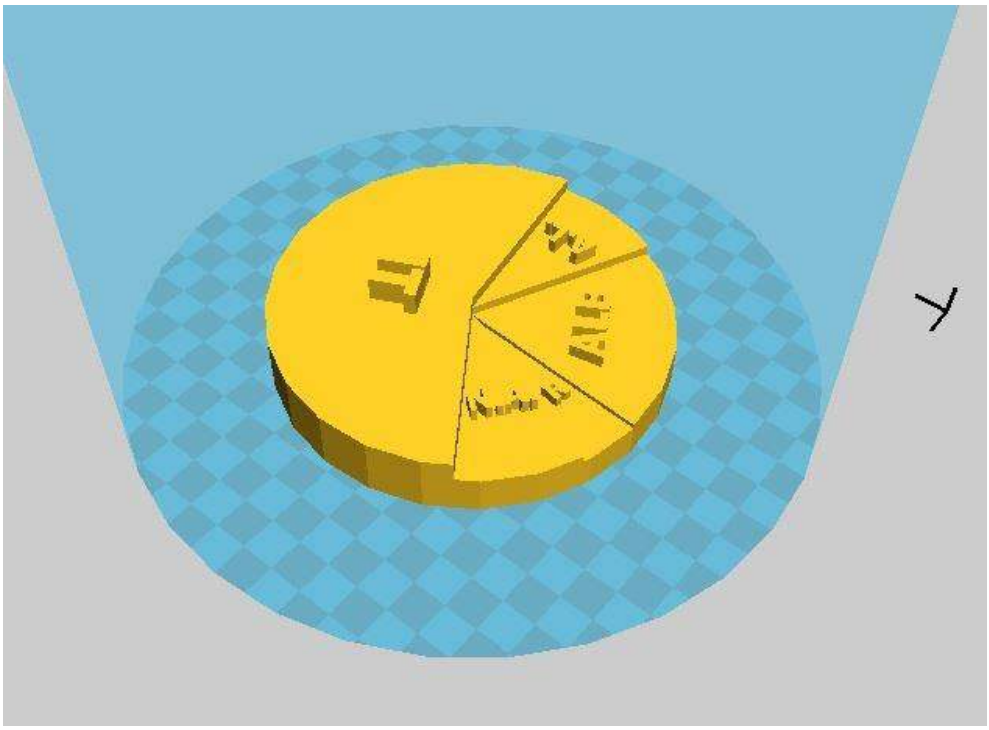
Because a student proposed it.
It was an amazingly precise application of the pupil-led experimentation.

PREREQUISITES

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

- ✓ Statistical ratios.

- ✓ Basic statistics concepts.
- ✓ 3D basic Geometry.
- ✓ Basic computer knowledge and competences.
- ✓ Basic knowledge and competences in technical drawing.



The angles represent the birth place of the pupils while the heights represent the average mark in Mathematics.

THE TEACHERS TEAM INVOLVED

2 teachers have been involved in the experimentation:

- ✓ 1 teacher of Mathematics.
- ✓ 1 teacher of the enhancement staff.

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I03 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: 21

Type of group: single class.

Number of classes: 1

Scholar curriculum specialization of the class involved: M.A.T.

"Special needs" students: none.

Entry level assessment: Standard tests.

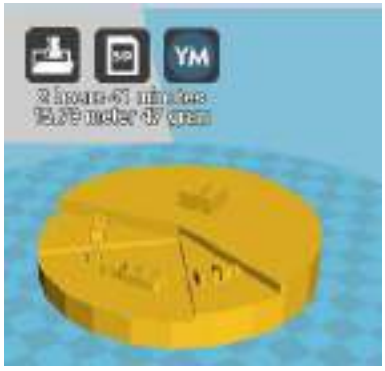
SETTING UP THE EXPERIMENTATION

I) SUBJECTS INVOLVED

MAIN SUBJECT	
Topics related to the Learning Objectives of experimentation	✓ Statistics
Total number of hours dedicated to completion of the experimentation	5

OTHER RELATED SUBJECT	Graphics
Didactic Topics related to the Learning Objectives of experimentation	✓ Measurements. ✓ 3D basic Geometry. ✓ Basic computer knowledge and competences . ✓ Basic knowledge and competences in technical drawing (Sketchup).
Total number of hours dedicated to completion of the experimentation	5

II) PRINT STEM LAB: THE TECHNOLOGIES



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: 2

2 Teachers.

	
Prof. L. Amadasi - Mathematics.	Prof. R. Rossi - Enhancement Staff.

3° - Entry level assessment

Number of hours dedicated: 1

2 Teachers.

4° - Training Unit or pupils self-study on involved Subjects:

Number of hours dedicated: 5

People involved: two stem-teachers.

Didactic methodology used:

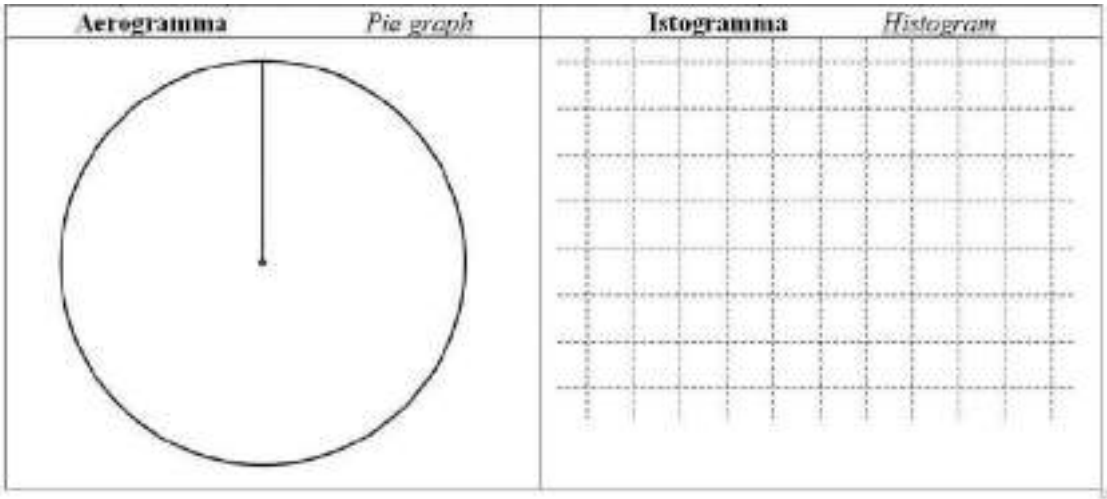
- Filling-in of forms
- Pupils self-study.
- Laboratory work.
- Teamwork.

Scheda di lavoro n°... Data..... Alunno..... consegna ore.....

La classe 2° D è composta da 21 alunni. Nella tabella sono riportati il paese di origine e i voti in matematica. Completa la tabella e realizza i grafici statistici relativi.	*The 2°C class is composed of 21 pupils.* *The chart gives information about the birth place of the pupils and about their rating of mathematics.* *Complete the table and make the statistical graphics.*					
Origine *Country*	**N°**	**%**	**Voti** *Marks*	**Voto medio** *Average mark*	**Istogramma** *Histogram*	**Aerogramma** *Pie graph*

Data collection.

...



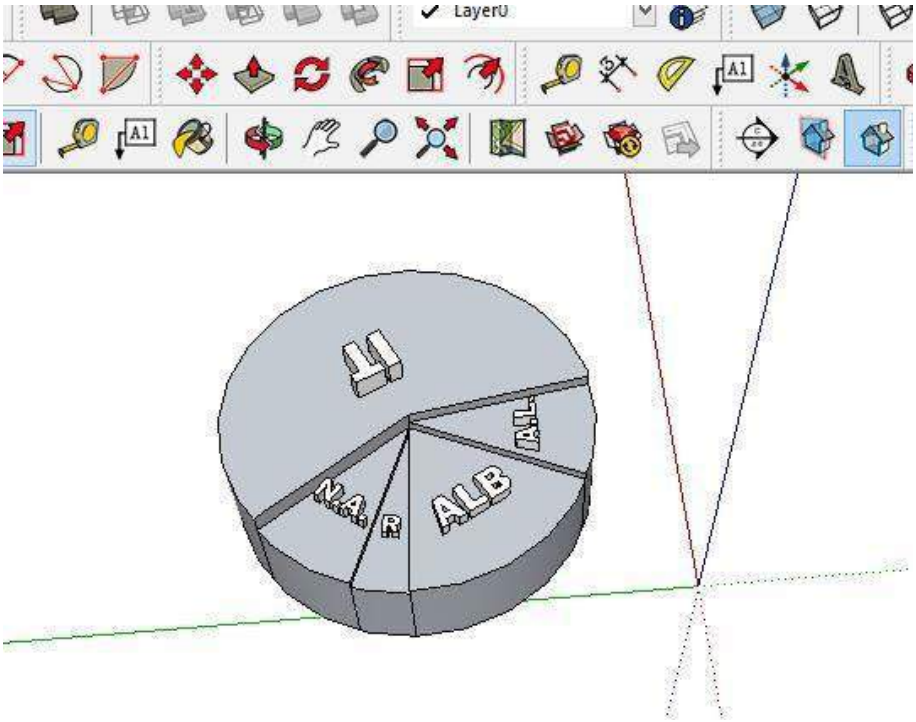
Histogram and pie graph to be joined

5° - CAD Design of the object:

Number of hours dedicated: 2

People involved: Prof. R. Rossi.

Didactic methodology used: Prof. Rossi helped pupils in drawing with Sketchup.



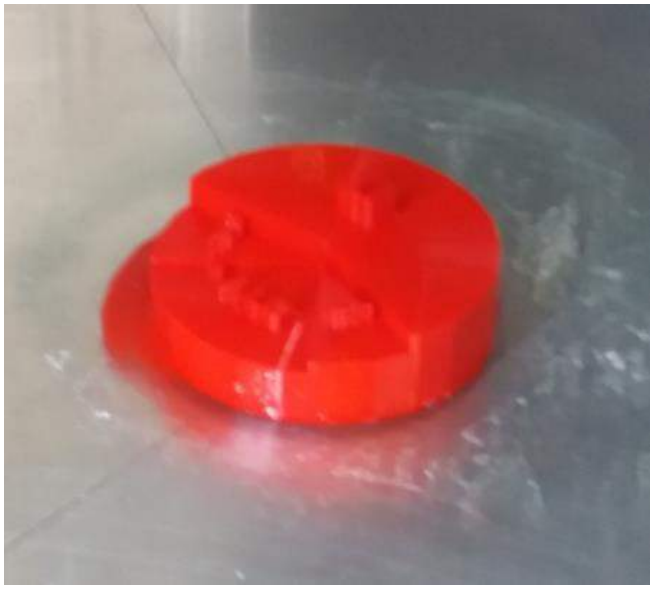
6° - Transfer of the object designed to 3D printing software:

Number of hours dedicated: 1

People involved: Prof . Rossi.

Didactic methodology used:

The students were already informed about the main line of the setting of the files with slicer during the previous experimentation; they simply could see once again the choice of the printing parameters.

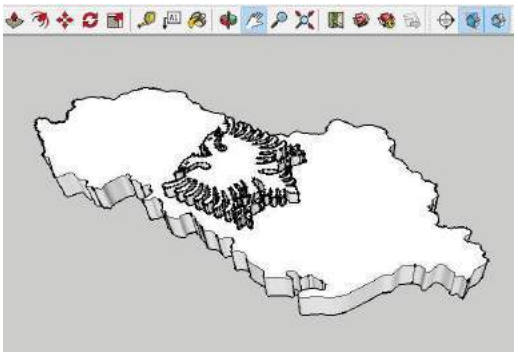


See also: https://sites.google.com/a/fr.itsosgadda.it/print-stem/experimentations/c-d

7° - Some other object printed

Our distant homeland

Albany: a 3D map

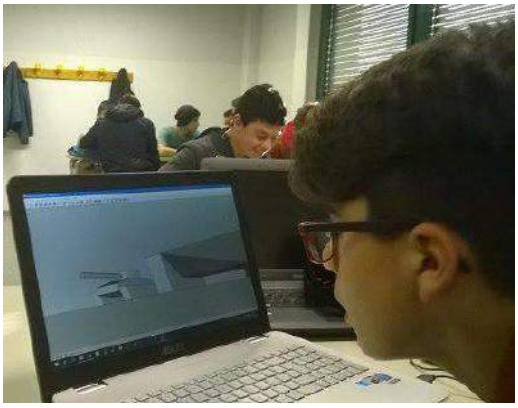


Albanian football team T-shirt

They're building my new house

A private event

A tank	**A mobile support**
	
	

Each object is the result of a little personal experience or of a passion for sport; of some kind of affection

8° - End of experimentation

Number of hours dedicated: 3

People involved: 2 teachers involved.

Didactic methodology used:

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

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

1) Better degree of competence in dealing with statistics.
2) Slightly better behaviour of the class, as the class council observed.

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) Improvement in skills teamwork.

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

3) Ability to use the software Sketchup .

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation.
- ✓ Learning of new software and technical devices.
- ✓ Apply the students to perform an original and unusual lab experiment.
- ✓ Teamwork.
- ✓ 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.
- ✓ The bureaucratic aspect of the experimentation: too repetitive.

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ The 3d printer is going to be a new didactical tool but it isn't a new distinct subject.

- ✓ 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.

2.11 PENCIL BOX (IISS GADDA – Italy)

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

Knowing 3D modeling software SketchUp:

Using interface design tools, visualization tools, settings and models of management, file export.

SPECIFIC Learning Objectives

We felt that, with the participation in this project, the pupil could improve his integration process and strengthen his self-esteem.

How the Learning Objectives have been identified and why?

We decided to participate in this project a pupil certified according to 104/92 law, attending the third class of Computer Science.

The class council decided to include the study of the general aspects of Robotics (definition, historical evolution) and, in particular, the study of the 3D printer in the curriculum, taking into account the personal interest of the pupil.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing a **pencil box**.

Why this objects? A simple and useful object.

Prof. L Lombardi and Fabio (third class).

PREREQUISITES

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

- ✓ Measurements.
- ✓ 3D basic Geometry.
- ✓ Basic computer knowledge and competences.

- ✓ Basic knowledge and competences in technical drawing.
- ✓ Knowing how to work with integer numbers and decimals;
- ✓ Using software for data sharing;
- ✓ Using Sway.

THE TEACHERS TEAM INVOLVED

2 teachers have been involved in the experimentation:

1 Support teacher of Mathematics.

1 teacher of the enhancement staff.

Rationale of the Teachers Team

The teachers involved in the team were chosen because their subjects were strictly connected with I03 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: 1

SETTING UP THE EXPERIMENTATION

I) SUBJECTS INVOLVED

MAIN SUBJECT	
Topics related to the Learning Objectives of experimentation	✓ Measurements. ✓ 3D basic Geometry. ✓ Basic computer knowledge and competences . ✓ Basic knowledge and competences in technical drawing (Sketchup).
Total number of hours dedicated to completion of the experimentation	3

OTHER RELATED SUBJECT	
Didactic Topics related to the Learning Objectives of experimentation	✓ Ability to understand the various languages; ✓ Ability to produce multimedia texts (Sway and ppt): information search, ability to analyze, correct writing

	of the text and the approach ability of verbal language.
Total number of hours dedicated to completion of the experimentation	2

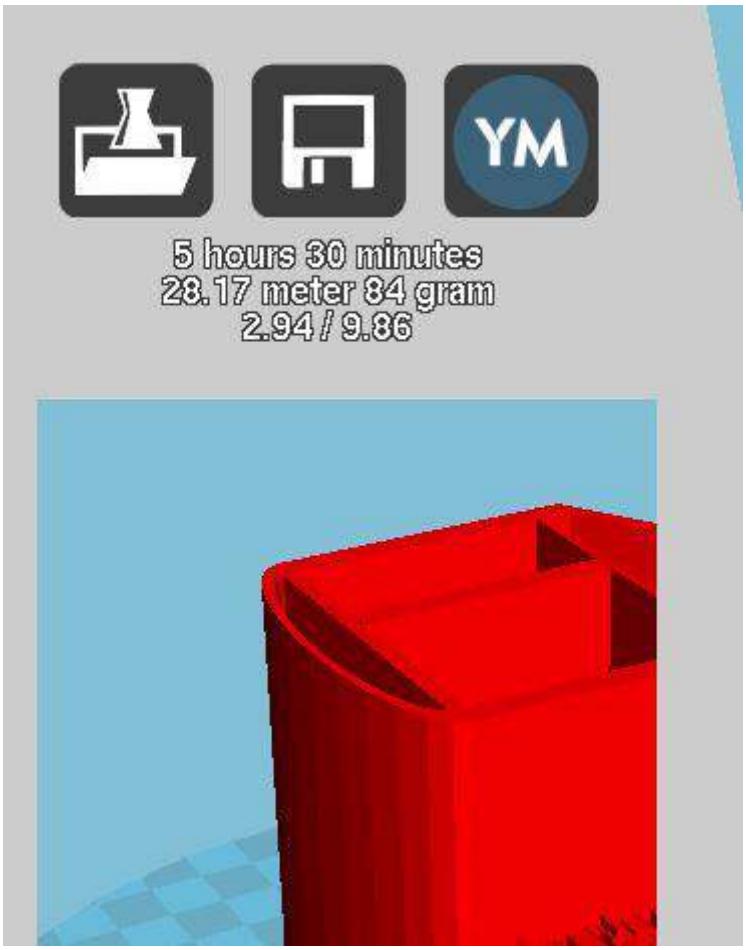
II) PRINT STEM LAB: THE TECHNOLOGIES

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

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

- **3D PRINTER:** WASP

IMPORTANT: Time necessary to print and quantity of material with this 3D printer is:



- **PLASTIC MATERIAL:** PLA.

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 1

People involved: 3 Teachers.

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

2 Teachers.

Prof. R. Rossi, Prof: L Lombardi, Fabio

3° - Entry level assessment

Number of hours dedicated: 1

4° - Training Unit or pupils self-study on involved Subjects:

Number of hours dedicated: 5

People involved: three stem-teachers.

Didactic methodology used to teach the contents:

- Frontal lessons.
- Pupil self-study.
- Laboratory work.

5° - CAD Design of the object:

Number of hours dedicated: 3

People involved: Prof. R Rossi – Enhancement Staff.

Didactic methodology used: Prof. Rossi helped pupils in drawing with Sketchup.After creating a 3D object using SketchUp, you must convert the design into a language understandable by the 3D printer.

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

Number of hours dedicated: 1

People involved: Prof Rossi.

Didactic methodology used:

Here comes the Slicer Cura, which, thanks to a series of user-set parameters, processes the 3D model, calculating the most efficient path that the 3D printer has to do to get the best result.

The pupil and the teacher can, at this point, choose the print quality (which will also impact printing time): the object's filling, set the speed and temperature of essential releases for the success of the model.The student can proceed with a personal study of the feasibility of the object through the software, taking into account the calculated execution time and any imperfections emerged.

The object, at this point, can be printed.

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

7° - End of experimentation

At this stage the pupil prepares a Sway and shares it to the students of his class, who did not participate in the project and therefore does not know the 3D printer. Fabio explains them what can be done with

a 3D printer, what is the CAD software, which object he created for the PrintStem project, the route taken to achieve it.

Finally the class is asked to answer a short questionnaire on the 3D printer, prepared by the student himself

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

The preparation of a Sway presentation allows the student to expand its educational path and implements a personal reflection on the work done; it improves his self-assessment.

The presentation of the work, moreover, helps the integration process within the class because the student feels active part of the group.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Increasing of pupils' motivation and self-esteem.
- ✓ Improve the integration process within the class.
- ✓ Learning of new software and technical devices.
- ✓ The 3D-printer allowed the realization of theoretical concepts.
- ✓ Multidisciplinary approach.

WEAK POINTS OF THE EXPERIMENTATION:

None.

2.12 PARMA'S BAPTISTER (IISS GADDA – Italy)

The students were invited to choose and/or propose an object to be printed.

Teachers than find and individuate the didactical connection and prepare the lessons to be submitted to students.

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) understanding polygon

2)knowledge principles of equivalence of equations

3) knowledge two dimensional shape

SPECIFIC Learning Objectives

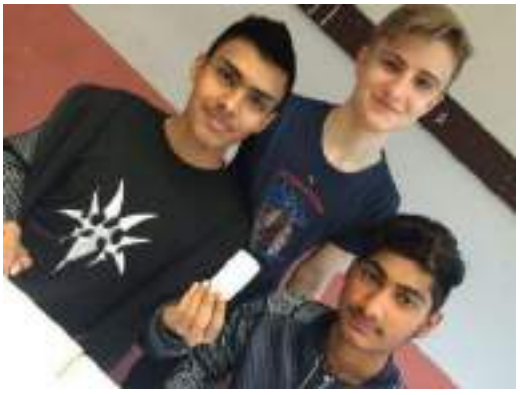
1) Find the area of a regular polygon having one size and vice-versa

2)Use and applicate inverse formulae

How the Learning Objectives have been identified and why?

One of the pupils ask to draw it during cad lessons. The teacher suggest to 3D print the object and students agree. Teacher than find the basic learning objectives.

PRINTED OBJECT



PREREQUISITES

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

- ✓ basic knowledge and competences in technical drawing
- ✓ Understangi plygons
- ✓ Basics of equation

THE TEACHERS TEAM INVOLVED

(2) teachers have been involved in the experimentation:

List each teacher' subject/domaine:

1 teacher of CAD / Architecture

1 teacher of 3D Printer

Rationale of the Teachers Team

The teachers involved in the team were chosen because are the curricular teacher.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 6

Type of group: single class

Number of classes: 1

Scholar curriculum specialisation of the class(es) involved: Computer Science

Entry level assessment: Oral 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 ARCHITECTURAL SUBJECT	Brief history of parma's Baptistery
Topics related to the Learning Objectives of experimentation	Two dimensional shape and polygons
Total number of hours dedicated to completion of the experimentation	10

OTHER RELATED SUBJECT	MATH
Didactic Topics related to the Learning Objectives of experimentation	Formulae and inverse formulae calculation
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 we had at our school
- SOFTWARE(S) for object PRINTING: CURA. The best and maybe the most used free software for slicing
- 3D PRINTER: Wasp DELTA 2040, it cost about 3000 € , it's a ROSTOCK style printer.
- IMPORTANT: Time to print 1 hour; approx 3m or 9g of PLA.
- PLASTIC MATERIAL:
- PLA 1,75 mm diameter
- Cost vary in a wide range (from 19 to 40+ euros/kg);
- - For Italian school only: look at MEPA market
- - For all the other people:
- Take a look on EBAY.COM, AMAZON.COM.
- Suggested site for price and good quality filament (PLA) : www.marwiol.pl
- IMPORTANT: 3 meters or 9 grams

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

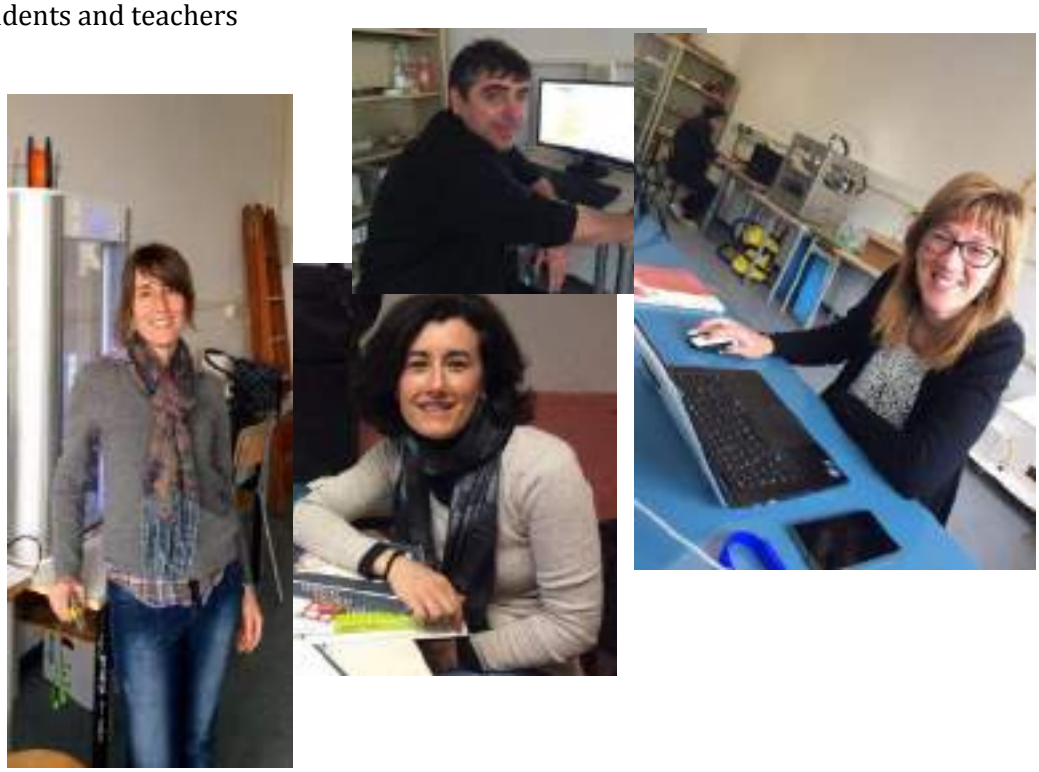
Number of hours dedicated: 5

People involved: students

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

Number of hours dedicated: 4

People involved: students and teachers



3° - Entry level assessment

Number of hours dedicated: 1

People involved: teachers

4° - Training Unit on MATH Subject:

Number of hours dedicated: 4

People involved: pupils and teachers

Didactic methodology used to teach the contents: front lesson, laboratory work, group work

5° - Training Unit on ARCHITECTURAL Subject:

Number of hours dedicated: 5

People involved: pupils and teachers

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

CAD Design of the object:

Number of hours dedicated: 2

People involved: pupils and teachers

Didactic methodology used: laboratory work, group work

Transfer of the object designed to 3D printing software:

Number of hours dedicated: 2

People involved: pupils

Didactic methodology used: group work

Object printing:

Number of hours dedicated: 2

People involved: 1

Didactic methodology used: personal printing by each student.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

1) They are able to calculate and use inverse formulae

2) Knowledge of historical facts on Parma's Baptistery

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) They also know how draw, slice and print an object.

2) One student being involved about architectural topics

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

1) Students have shown more attention, interest and participation towards a generally underappreciated topic

2) Students have improved their ability to work in team

WEAK POINTS OF THE EXPERIMENTATION:

1. Lack of time

2. Teacher's difficult for finding didactical connnection with the object

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

1) All of the activities should be planned in detail at the beginning of the school year

2) Pupils should already have the basics of 3D modeling softwares;

2.13 CLIMATIC ZONES (IISS GADDA – Italy)

The students were invited to choose and/or propose an object to be printed.

Teachers than find and individuate the didactical connection and prepare the lessons to be submitted to students.

LEARNING OBJECTIVES

Learning Objectives identified by the pupils were:

GENERAL Learning Objectives

1) knowledge of astronomical facts of earth

2) knowledge of facts of solar radiaions

3) knowledge of athmosphere facts

SPECIFIC Learning Objectives

1) knowledges of characteristics of biomes, in relation of their position

2) understanig the relationship between all the living beings and the enviroment

How the Learning Objectives have been identified and why?

Students got idea by a lesson from science teachers.

PRINTED OBJECT

In order to reach the general and specific learning Objectives above mentioned, pupils agreed on printing a sphere divided into climatic zone (three zone: equatioral, temperate and pole).

PREREQUISITES

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

- ✓ Basic knowledge of Latitude, Longitude, Earth inclination
- ✓ Basic knowledge of solar radiation
- ✓ Basic knowledge of Temperature, Pressure and humidity

THE TEACHERS TEAM INVOLVED

(3) teachers have been involved in the experimentation:

List each teacher' subject/domaine:

1 teacher of Science.

1 teacher of CAD

1 teacher of 3D Printing

Rationale of the Teachers Team

The teachers involved in the team were chosen because they are the curricular teacher.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 6

Type of group: single class

Number of classes: 1

Scholar curriculum specialisation of the class(es) involved: 1 (Computer Science)

"Special needs" students: 3 with cognitive disease medium gravity

Entry level assessment: oral question.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN SCIENCE SUBJECT	Earth facts
Topics related to the Learning Objectives of experimentation	Longitude, latitude, earth inclination
Total number of hours dedicated to completion of the experimentation	4

OTHER RELATED SUBJECT	Science
Didactic Topics related to the Learning Objectives of experimentation	Temperature, pressure, Humidity
Total number of hours dedicated to completion of the experimentation	5

II) PRINT STEM LAB: THE TECHNOLOGIES

- SOFTWARE(S) for object DESIGN: AUTOCAD as is the software we had at our school

- SOFTWARE(S) for object PRINTING: CURA. The best and maybe the most used free software for slicing

- 3D PRINTER: Wasp DELTA 2040, it cost about 3000 € , it's a ROSTOCK style printer.

  IMPORTANT: Time necessary to print 1 (object of the experimentation) with this 3D printer is 7 hours

  PLASTIC MATERIAL:
  PLA 1,75 mm diameter
  Cost vary in a wide range (from 19 to 40+ euros/kg);

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

  IMPORTANT: Total time is about 36 hours (18 for central piece).
  It needs 332 g of PLA or 114 meters. (diam 1,75)

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

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

Number of hours dedicated: 3

People involved: pupils and teachers

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

Number of hours dedicated: 3

People involved: pupils and teachers

3° - Entry level assessment

Number of hours dedicated:1

People involved: pupils and teachers

4° - Training Unit on Earth facts Subject:

Number of hours dedicated: 4

People involved: pupils and teachers

Didactic methodology used to teach the contents: laboratory work, group work

5° - Training Unit on Earth facts Subject:

Number of hours dedicated: 5

People involved: pupils and teachers

Didactic methodology used to teach the contents: front lesson, laboratory work, group work

CAD Design of the object:

Number of hours dedicated: 2

People involved: pupils and teachers

Didactic methodology used: laboratory work, group work

Transfer of the object designed to 3D printing software:

Number of hours dedicated: 2

People involved: pupils

Didactic methodology used: pupils self-study, laboratory work

Object printing:

Number of hours dedicated: 7

People involved: pupils

Didactic methodology used: personal printing by each student, teachears printing for all the class

Due the long time print the teacher start printing during afternoon and students can "watch" the printing by connecting to a remote webcam. The piece was given them at morning .

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

1) The students can explain to other students about earth and athmospherics fact plus biome.

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:

2) They also know how draw, slice and print an object.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Students have shown more attention, interest and participation towards a generally underappreciated topic
- ✓ Students have improved their ability to work in team

WEAK POINTS OF THE EXPERIMENTATION:

- ✓ Lack of time

- ✓ Teacher's difficult for finding didactical connection with the object

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

- ✓ All of the activities should be planned in detail at the beginning of the school year
- ✓ Pupils should already have the basics of 3D modeling softwares;

2.14 CRIPTEX (IISS GADDA – Italy)

The students were invited to choose and/or propose an object to be printed.

Teachers than find and individuate the didactical connection and prepare the lessons to be submitted to students.

LEARNING OBJECTIVES

Learning Objectives identified by the TEACHER were:

SPECIFIC Learning Objectives

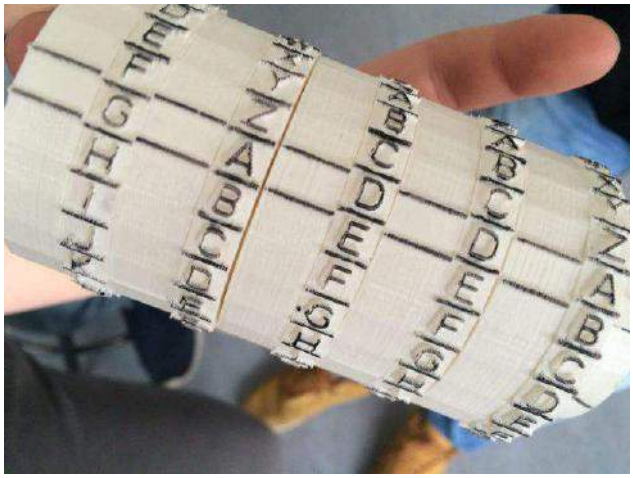
1) calculate permutations with repetition

2) calculate disposition with repetitions

How the Learning Objectives have been identified and why?

Students are interest by reading of "The DaVInci CODE" and ask to print a criptex. Teacher than find the didactical connection with CRIPTEX and Statistical Math (permutation and disposition)

PRINTED OBJECT



PREREQUISITES

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

- ✓ basic knowledge and competences in technical drawing and competences
- ✓ mathematics knowledge
- ✓ Internet searching

THE TEACHERS TEAM INVOLVED

List each teacher' subject/domaine:

1 teacher of Math

1 teacher of CAD

1 teacher of 3D print

Rationale of the Teachers Team

The teachers involved in the team were chosen because are the curricular teacher.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 4.

Type of group: single class

Number of classes: 1

Scholar curriculum specialisation of the class(es) involved: 1

"Special needs" students: None

Entry level assessment: Elementary algebra; understanding and use of FACTORIAL (n!)

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN MATHEMATICAL SUBJECT	Permutations & Dispositions
Total number of hours dedicated to completion of the experimentation	5

II) PRINT STEM LAB: THE TECHNOLOGIES

- SOFTWARE(S) for object DESIGN: AUTOCAD as is the software we had at our school
- SOFTWARE(S) for object PRINTING: CURA. The best and maybe the most used free software for slicing
- 3D PRINTER: Wasp DELTA 2040, it cost about 3000 € , it's a ROSTOCK style printer.

  IMPORTANT: you need to print for 22 hours for a complete object.
- PLASTIC MATERIAL:

  PLA 1,75 mm diameter
  Cost vary in a wide range (from 19 to 40+ euros/kg);

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

  IMPORTANT: you need 66 meters or 194 grams of PLA

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

Brainstorming for choosing object, finding & evaluating design, slicing and printing.

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

Number of hours dedicated: 2

People involved: 2

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

Number of hours dedicated: 4

People involved: 3

3° - Entry level assessment

Number of hours dedicated: 1

People involved: 1

4° - Training Unit on MATH Subject:

Number of hours dedicated: 4

People involved: 2

Didactic methodology used to teach the contents: front lesson, laboratory work, group work

5° - Training Unit on DESIGN STUDY Subject:

Number of hours dedicated: 2

People involved: 1

Didactic methodology used to teach the contents: laboratory work, group work…

Object printing:

Number of hours dedicated: 5

People involved: pupils

Didactic methodology used: printing in small groups and direct observation, teachears printing for all the class No particular trouble for this object. Print slow and with 0.2 slice step.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

1) Now they own the dispositions and permutation calculation.

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:

They also know how draw, slice and print an object.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Students have shown more attention, interest and participation towards a generally underappreciated topic
- ✓ Students have improved their ability to work in team

WEAK POINTS OF THE EXPERIMENTATION:

1) Lack of time
2) Teacher's difficult for finding didactical connnection with the object

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

1) All of the activities should be planned in detail at the beginning of the school year
2) Pupils should already have the basics of 3D modeling softwares;

2.15 SELF-HEATING CUP (IISS GADDA – Italy)

The students were invited to choose and/or propose an object to be printed.

Teachers than find and individuate the didactical connection and prepare the lessons to be submitted to students.

LEARNING OBJECTIVES

Learning Objectives identified by the TEACHER were:

GENERAL Learning Objetives

1) knowledge of chemical reactions

2) knowledge of chemical bonds

SPECIFIC Learning Objectives

1) knowledge of exothermic and endothermic reactions

2) correlating macroscopic aspects of a chemical reaction with structural changes

3) energy analysis of a chemical bonds' formation and breaking

4) knowledge of hydrogen bond

5) knowledge of coordination compounds

6) proposal of a model to improve understanding of the theoretical aspects

How the Learning Objectives have been identified and why?

Students were involved in a multidisciplinar project and decided to use 3D printer to finalize it.

PRINTED OBJECT

PREREQUISITES

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

- ✓ basic knowledge and competences in technical drawing and competences
- ✓ knowledge of inorganic salts' molecular formulas and nomenclature (anhydrous and hydrates salts)
- ✓ recognizing chemical transformings
- ✓ writing and balancing chemical equations
- ✓ knowledge and representation of different chemical bonds
- ✓ Internet searching

THE TEACHERS TEAM INVOLVED

List each teacher' subject/domaine:

2 teacher of Chemistry

1 teacher of CAD

1 teacher of 3D print

Rationale of the Teachers Team

The teachers involved in the team were chosen because are the curricular teacher.

THE PUPILS GROUP INVOLVED

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

Number of pupils: 8.

Type of group: some students of 2B class

Number of classes: 1

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

"Special needs" students: None

Entry level assessment: oral evaluation. Knowledge of inorganic salts' molecular formulas and nomenclature (anhydrous and hydrates salts)**;** recognizing chemical transformings**;** writing and balancing chemical equations**;** knowledge and representation of different chemical bonds.

SETTING UP THE EXPERIMENTATION

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

I) SUBJECTS INVOLVED

MAIN SUBJECT	CHEMISTRY
Topics related to the Learning Objectives of experimentation	-knowledge of exothermic and endothermic reactions -correlating macroscopic aspects of a chemical reaction with structural changes -energy analysis of a chemical bonds' formation and breaking -knowledge of hydrogen bond -knowledge of coordination compounds -proposal of a model to improve understanding of the theoretical aspects
Total number of hours dedicated to completion of the experimentation	10

OTHER RELATED SUBJECT	TECHNICAL DRAWING
Didactic Topics related to the Learning Objectives of experimentation	-AUTOCAD konwledge
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 we had at our school
- SOFTWARE(S) for object PRINTING: CURA. The best and maybe the most used free software for slicing
- 3D PRINTER: Wasp DELTA 2040, it cost about 3000 € , it's a ROSTOCK style printer.

  IMPORTANT: about 18 hours
- PLASTIC MATERIAL:

PLA 1,75 mm diameter
Cost vary in a wide range (from 19 to 40+ euros/kg);

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

IMPORTANT: Quantity of this material necessary to print 1 (object of the experimentation) is:
51 meters or 150 grams of PLA

III) ACTION PLAN AND DURATION OF THE EXPERIMENTATION

Brainstorming for choosing object, finding & evaluating design, slicing and printing.

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

Number of hours dedicated: 4

People involved: 2

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

Number of hours dedicated: 4

People involved: pupils and teachers

3° - Entry level assessment

Number of hours dedicated: 1

People involved: 1

4° - Training Unit on CHEMISTRY Subject:

Number of hours dedicated: 8

People involved: 2

Didactic methodology used to teach the contents: frontal lesson, laboratory work, group work

5° - Training Unit on DESIGN STUDY Subject:

Number of hours dedicated: 1

People involved: pupils

Didactic methodology used to teach the contents: laboratory work, group work

Object printing:

Number of hours dedicated: 1 (23 hours for 3D printing)

People involved: 1

Didactic methodology used: teachears printing for all the class due long time need. No particular trouble for this object. Print slow and with 0.2 slice step.

n° - End of experimentation

Number of hours dedicated: 1

People involved: 1

Didactic methodology used: pupils report to teacher their lab experience, adding the theoretical aspect.

TEACHERS FINAL EVALUATION

IMMEDIATE IMPACTS:

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

1) Now they are able to propose models to improve understanding of chemical theoretical aspects (they would like to challenge for another different 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:

They also know how draw, slice and print an object.

LESSONS LEARNT

STRENGTH POINTS OF THE EXPERIMENTATION:

- ✓ Students have shown more attention, interest and participation towards a generally underappreciated topic
- ✓ Students have improved their ability to work in team

WEAK POINTS OF THE EXPERIMENTATION:

1) Lack of time

RECOMMENDATIONS FOR NEW LEARNING EXPERIENCES

1) All of the activities should be planned in detail at the beginning of the school year
2) Pupils should already have the basics of 3D modeling softwares.