Pedagogical Resources IN Teaching Science, Technology, Engineering, Mathematics

REPORT OF PUPIL-LED S.T.E.M SUBJECTS EXPERIMENTATIONS
Intellectual Output N. 3

Project partner responsible for the Intellectual Output

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

2 teachers have been involved in the experimentation:

List each teacher's subject/domain:

Kevin Gough              Teacher of Design & Technology    Responsible for the 3D Printer.
Michelle Thwaites        Teacher of Chemistry             Responsible for STEM theory.
Ben Hayes                Teacher of Maths                 Supporting Michelle Thwaites

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:

1) **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)

<table>
<thead>
<tr>
<th>MAIN MATHEMATICAL SUBJECT</th>
<th>Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topics related to the Learning Objectives of experimentation</td>
<td>Measuring X,Y,Z axis Scaling Volume</td>
</tr>
<tr>
<td>Total number of hours dedicated to completion of the experimentation</td>
<td>4 hours</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER RELATED SUBJECT</th>
<th>CAD Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Didactic Topics related to the</td>
<td>Learning 3D Modeling skills</td>
</tr>
<tr>
<td>Learning Objectives of experimentation</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>--</td>
</tr>
<tr>
<td>Total number of hours dedicated to completion of the experimentation</td>
<td>5 hours</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER RELATED SUBJECT</th>
<th>3D Modeling conversion to G Code.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Didactic Topics related to the Learning Objectives of experimentation</td>
<td>Practice and discussion of how to set manufacturing parameters.</td>
</tr>
<tr>
<td>Total number of hours dedicated to completion of the experimentation</td>
<td>5 hours</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER RELATED SUBJECT</th>
<th>Operation of 3D Printer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Didactic Topics related to the Learning Objectives of experimentation</td>
<td>How to load consumables, level build plate and operate.</td>
</tr>
<tr>
<td>Total number of hours dedicated to completion of the experimentation</td>
<td>5 hours.</td>
</tr>
</tbody>
</table>

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.

Add technical and pupils pictures + link to files + videos

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 parameters 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.

Importantlly 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.

Add technical and pupils pictures + link to files + videos

**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.

Add pictures + link to videos

**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.

**MEDIUM TERM IMPACTS:**

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

The scores and results obtained by the pupils revealed that 100% of pupils had an increase ability to use the 3D Design software, use the file conversion software and operate the 3D Printer.

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**PUPILS FINAL SELF-EVALUATION**

Each of the (total number) participating pupils have been asked to answer a self-evaluation questionnaire after completion of the experimentation. Following, the cumulative feedback obtained:

<table>
<thead>
<tr>
<th>(fill in the total cumulative number of answers for each item in the respective type of answer)</th>
<th>YES, VERY MUCH</th>
<th>YES</th>
<th>ONLY IN PART</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Did you have high expectations of your future experience with the 3D printer before the start of the exercises?</td>
<td>10</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Did you understand clearly the learning objectives before the start of the 3D printing exercises?</td>
<td>33</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Are you satisfied with the experience of using the 3D printer in terms of learning STEM contents?</td>
<td>5</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Were the exercises with use of the 3D printer useful to improve your knowledge and understanding of STEM rules/concepts related to the object that you designed and printed?</td>
<td>22</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Did you appreciate the use of the 3D printer in learning theoretical rules and didactic contents instead of a traditional style lesson?</td>
<td>8</td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>Do you think that the 3D printer is an effective method to learn theoretical/abstract concepts, otherwise difficult to understand?</td>
<td>18</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Did you find the software in 3D printing easy to use?</td>
<td>5</td>
<td>34</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Can you suggest any changes to the software? Please, specify:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Booklets helped with the work. Using Sketchup was easy and fun. Some found it a little tricky at first</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Question</td>
<td>Answer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<td></td>
</tr>
<tr>
<td>9</td>
<td>Did the use of the 3D printer increase your interest and motivation towards learning STEM subjects? Why? Please write here to explain your opinion:</td>
<td>It was a fun and eventful experience and good to express yourself. It was a different learning experience which I enjoyed. Fun way to learn which improved my learning and meant that I learnt more.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Do you think that the use of 3D printer exercises can improve the practical understanding of links among different STEM subjects?</td>
<td>31 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Was the duration of the learning exercise through the 3D printer satisfactory to you?</td>
<td>2 10 28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Would you have preferred a longer experimentation in order to improve your knowledge/understanding of STEM contents?</td>
<td>36 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Would you like to repeat the experience in other subjects and/or with other objects to be printed? Please, write here which ones:</td>
<td>27 11 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Definitely yes. Better facilities and more 3D Printers please. We need to do more exciting projects.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Would you suggest to your school that it makes regular use of the 3D printer to teach STEM topics?</td>
<td>33 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>What would you suggest to your teachers in order to improve and develop new exercises with the 3D printer in order to teach your class theoretical subjects, rules, or formulas etc? Write here:</td>
<td>Makes science more fun. The use of the booklets helped us. I’d like to see more 3D Printing done in school.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>What did you appreciate most of the exercise? Write here:</td>
<td>Working in groups, the buzz of the activity. Young pupils like new technology. It engages you more.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>What have been the difficulties you encountered and how overcame them to complete the job? Write here:</td>
<td>I did need the teacher sometimes to help me. However I worked mostly on my own and teaching somebody else definitely improved my learning.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>What would you improve in a next exercise with the same “pupil-led” approach? Write here:</td>
<td>We need to design different products. Design more complex products / artifacts Use it more to improve our learning in Physics.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
On the basis of the above overall data gathered, ...% of the participating pupils reported satisfaction and increase in motivation towards mathematic subjects thanks to the use of 3D printer for learning purposes

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 choose 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.