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PRINTSTEM

Pedagogical Resources IN Teaching Science, Technology, Engineering, Mathematics

METHODOLOGY AND GUIDELINES FOR THE INTRODUCTION OF 3D PRINTERS AS A TOOL IN TEACHING EXPERIMENTATIONS IN SECONDARY SCHOOLS

Intellectual Output N. 2

Release of final validated Intellectual Output: September 2015

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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 the present Intellectual Output: Kirkby Stephen Grammar School

List of Partners

PARTNERSHIP	COUNTRY
Project Coordinator: Istituto d'Istruzione Secondaria Superiore "A.Berenini"	Italy
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Chapter 1. What is 3D Printing?

The inkjet printer was invented in 1976. Charles Hull adapted inkjet printing technology to create stereo-lithography, a printing process which is able to turn 3D software models into 3D products.
3D printing is the common name for Additive Manufacture. This is where a model is built up layer by layer. A wide range of materials can be used, including: plastics, metals and rubber.
Source : DATA Key Resources

1.1 Time Line for Additive Manufacture:

1976 The inkjet printer is invented
1983 The start of 3D Printing using Stereo lithography
1988 The first 3D Printer using Fused Deposition Modelling invented
1993 Powder bed 3D Printing invented
2005 Open Source collaboration on line
2006 Selective Laser Sintering used for customising products
2008 Thingy Verse starts
2009 DIY kits start being sold.
2011 3D Printing in gold and silver
2012 3D-Printed prosthetic jaw.
2014 Patients jaw rebuilt using 3D Printing.
Source: Infographics.com and BBC

3D printing is a new way of producing products. The general term used to describe 3D Printing in all its guises is Additive Manufacturing. As mentioned previously a product is built by adding layers. The definition and quality of the product is dependant on the size of the extruder or layering height as well as the resolution of the design software.

To contrast Additive Manufacturing with predominantly Subtractive Manufacturing techniques: More traditional school processes have relied upon taking blocks of material and cutting parts of them down to required sizes and shapes etc. Even casting for example usually requires a pattern to be made using subtractive methods first and even if the casting process is seen as a genuine additive process casting has a number of limitations which make 3D Printing more advantageous.

These advantages usually come down to manufacture of more complex forms, the potential to reduce waste and the manufacture of components which would be virtually impossible to make in any other way.

However for the first time ever 3D printing offers the ability to have products manufactured anywhere in the world. No longer would it be necessary to have industrialised centres distributing products around the world. This could now be done by sending 3D "virtual designs" through the internet and having these manufactured at the point of need. These designs could also be customised or modified for more specific or needs within its operating environment.

Manufacturing could be transformed from Just In Time Logistics to Just in Time Manufacturing as suggested by © Big Innovation Centre (The Work Foundation and Lancaster University). This would also have an impact on the quality of life. The carbon footprint of products could be significantly reduced as products could now be manufactured where needed or within the locality. Busy transportation network and infrastructure would be reduced too. By providing students with the opportunities to realise the potential of this manufacturing process we are supporting future generations in improving the quality of life for themselves and future generations.
Source: Three Dimensional Policy: Why Britain needs a policy framework for 3D printing

1.2 Benefits for 3D Manufacturing

Customisation
This is where a product can be partially re-designed to specifically suit a new environment or new needs.

Reduced Stocks
Manufactures and retailers would operate with less stock producing only when needed. Other components or raw materials for the printing would still be required. Just in Time Manufacturing would now be much more immediate.

Reduced Capital Costs

Large scale capital investment in factories and machinery would be reduced. However investment in the printer itself would still need to be accounted for, as would the raw materials for each print.

Reduced Transport Costs

Distribution of the products and the components, which make up the products, would be significantly reduced.

Environmental Benefits –

3D printing should enable companies to reduce the carbon footprint of themselves and their products due to the reduced transport costs.

1.3 Weaknesses of 3D Manufacturing

Can Be a Slow Process

At the moment large components can take significant amounts of time to produce. This will be an area where print development engineers are already focusing.

Responsibility

If 3D printed products go wrong who will be responsible for the fault. Will this lie at the hands of the designer, print manufacturer or the person who is actually responsible for down loading the print

Real World Proofing

So far a lot of the expected impacts on manufacture are conjecture. Finding out if the process works practically will be the next step in assessing if the technology is practical if at all possible.

Assembly.

Depending on the sort of products to be manufactured will mean what other components will be needed. Some of these will not be practical to be manufactured totally using 3D Printing.

Chapter 2. 3D Print Stem Logistical Accessibility

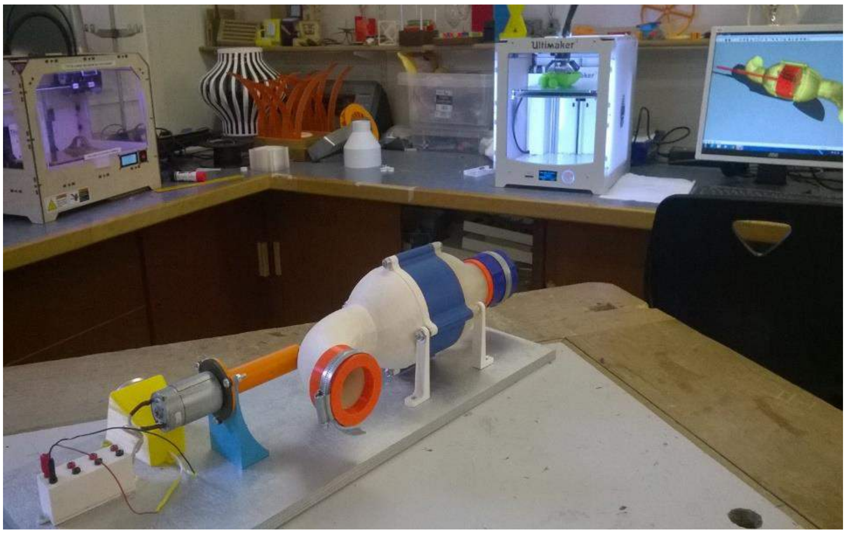
In order to deliver an effective STEM programme using the 3D print technology it is crucial that organisations consider the logistical accessibility. Failure to do this could impact on the quality of lesson delivery and the creative learning process, thus leading too the lowering in standard of learning outcomes and ultimately a failure to meet the original project objectives.

However it is clear that organisations have many differences that must be considered before logistical decisions are made. Differences in size, culture (International and nationally), legal requirements, staff resourcing, building infrastructure, student background, behaviour and dynamics will all dictate the ultimate accessibility of the 3D print technology. Institutions must try to overcome any constraints or threats caused by these dynamics, in order to access the practical impact of 3D printing on pupil performance in STEM.

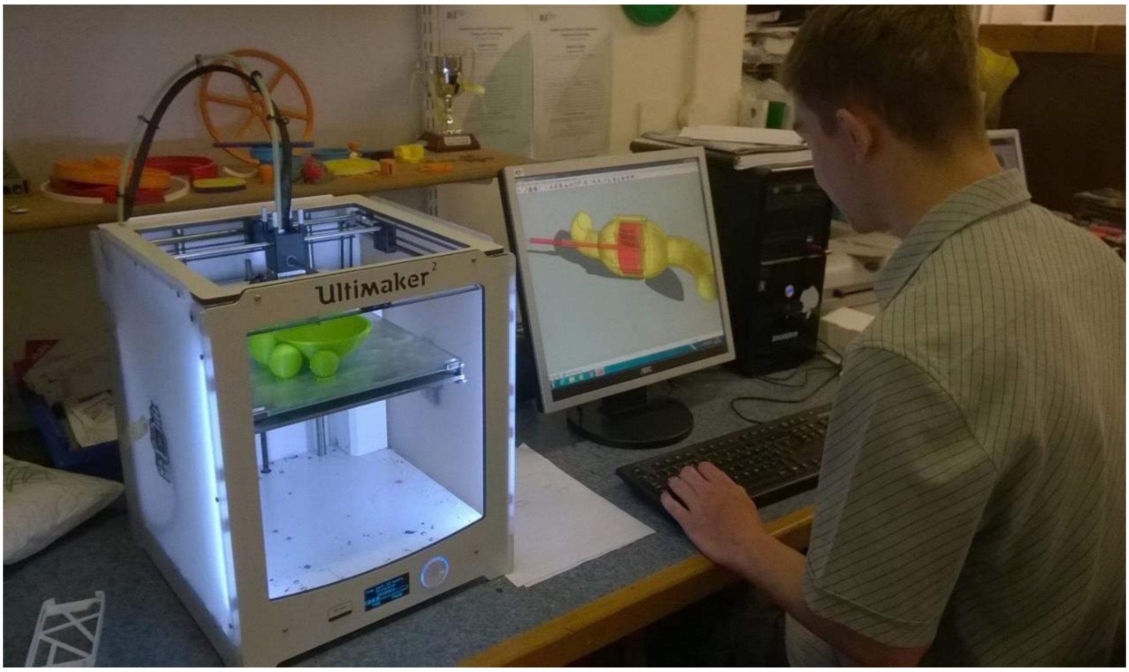
Within each institution, all staff and parties involved in the project must be consulted and all practical scenarios considered. However, in making decisions, learning objectives must drive the logistic; if logistics drive learning then there is a danger of watering down the pedagogical approach.

2.1 Motivation for Students

The original reasoning behind the application of this technology in the classroom was to improve the learning outcomes of underachieving 15 year old children in the STEM subject. A hypothesis behind this reasoning is that they cannot access the STEM curriculum due to the teaching strategies imposed on their learning, that does not suit their learning style (In many cases teachers who by definition achieved academic success during their own time at school, may have suited a particular learning, such as an auditory approach and therefore perpetuate this in their own teaching, possibly disadvantaging their cohort.). Kinaesthetic learners who often underachieve in conventional, 'chalk and talk', lessons need to be physically active, visually stimulated and doing jobs to access the curriculum. For this reason, in order for 3D printers to impact on this style of learner the 3D printer whenever possible must be accessible and operated by the learner. By having ownership of the hardware the student controls their own learning, becomes more motivated to achieve physical outcomes through seeing the impact of their theoretical work building into a physical tactile object. By being able to constantly move between the workstation, the printer and other learning resources allows for the growth of a creative and stimulating classroom environment. Without this accessibility and ownership of the process, learners may lose track of the learning objectives, leading to a reduction in motivation. Allowing student access is an uncomfortable prospect for some teachers, particularly in institutions where pupil behaviour can be challenging and unpredictable, but if managed and supported effectively may well improve the performance of the target group of underachievers.



A suitable classroom environment enhances the creative process.



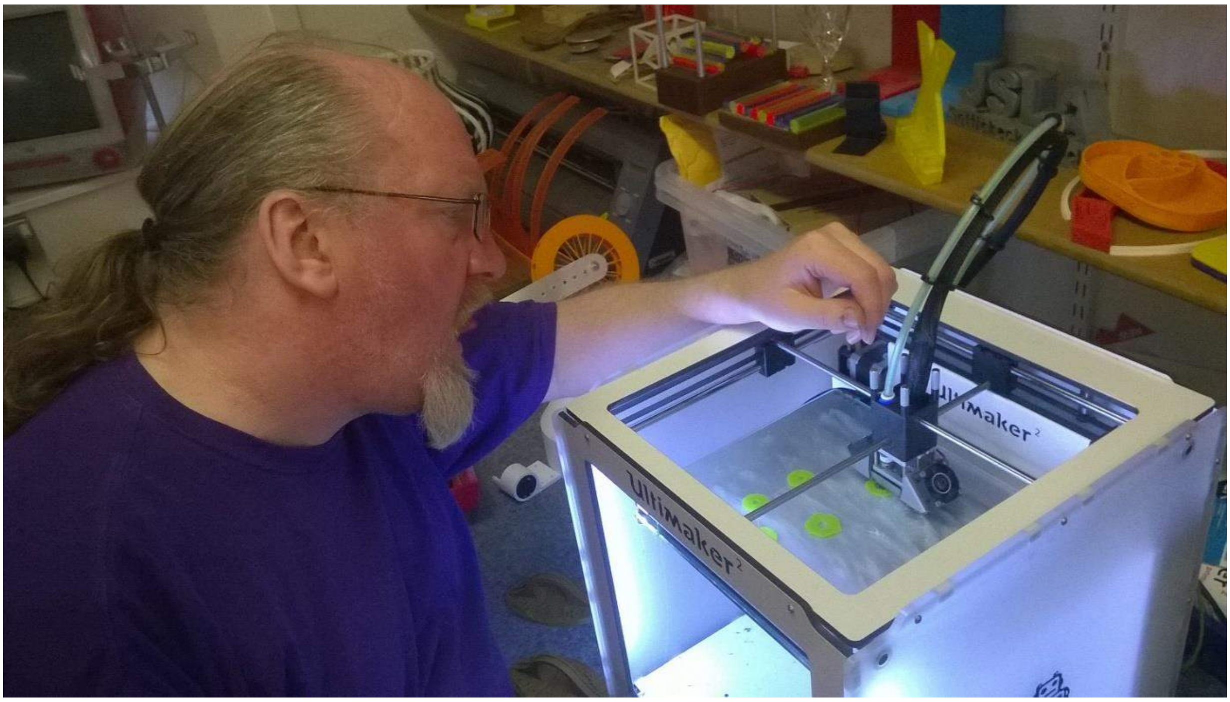
Ownership of the process is a strong motivational factor for the student.

2.2 Teaching and Learning Strategies

When writing programmes of study the teacher will need to consider and plan how and when the printer will be used to improve the learning outcome. In teacher led lessons where the focus is on 'made logic' it may not be necessary to have constant access to the printer. However, during pupil led learning, where experimentation and refinement is a central learning strategy, pupil easy access is crucial. Despite all the recent media publicity indicating, 'the skies the limit' manufacturing, 3D printers ,as is the case with any technology have limiting constraints that need evaluating, and considering at all stages of a project. Through operating, watching, making mistakes and recording information from the process a more informed pupil will be able to develop and refine their own outcomes much more quickly than in a situation where the technology is located remotely.

2.3 Technical Support

It is clear that despite the improving usability of 3D printers these devices need physical maintenance, constant software upgrades and troubleshooting intervention for effective and reliable operation. It is useful for the teacher to understand simple troubleshooting techniques, but within the actual lesson parameters they must not be distracted from their teaching and learning objectives (This is a scenario often observed and recorded in lessons reliant on technology, particularly involving ICT.) If the technical support is not readily available then the teacher must find a solution. This may result in the printer being located remotely in a technician's workshop or office, for ease of monitoring or the arrangement of a regular classroom support and maintenance slot, particularly during the teaching day.



Regular technical support is essential to increase the output of outcomes and allow teachers to teach.

2.4 Classroom layout

If located in the classroom environment the printer should be located in a position for ease of access and demonstration. The size of the printers (The Ultimaker 2 Go for example, is small enough to carry by hand at 258mmx250mmx287mm) does not necessitate the need for specialised trolleys or tables and although generally robust, some form of sturdy carrying case is strongly recommended if required to be moved between different classrooms or departments.

2.5 Group Size

The size of teaching group sizes, clearly impacts on the access to the printers. In group sizes of over 15, the access for individual learners to the hardware would not be possible within the normal lesson context unless multiple devices are utilised. Small sub groups of around 5 students could be formed who would then work independently of the main group, with the support and supervision of a technician or teaching assistant enabling a far more manageable learning environment.

2.6 Student behaviour

From previous experience in operating 3D printers at Kirkby Stephen and Settlebeck the machines are robust and not easily damaged if operated incorrectly, unlike more conventional CNC machinery. However in institutions where student behaviour may cause malicious damage or careless use, staff may need to review the supervision and operating procedures or restrict access to individuals or small groups allowing for a more controlled environment. Any restrictions must be considered very carefully in order not to impact on student motivation and learning outcomes. Indeed a more trusting approach and empowerment of the process to the learner may well improve attitudes and behaviour resulting in improved academic success.

2.7 Hazards / Risk Assessments

The operation of 3D printers involves little hazard or risk and is comparable to using a typical office or domestic appliance. However in order to comply with European or national regulations it is expected that each organisation carries out a full risk assessment using their own protocols and formats. The market for 3D printers is continuing to develop with new models regularly introduced and specifications changing, necessitating the need for regular individual reviews. During process we would recommend that the following possible hazards are assessed, and adequate control measures are put in place.
Heat

Danger of Electrical Shock

The printing devices should comply with current CE regulations, with regards to adequate insulation and 'earth' requirements, correct fusing, accessible power isolation and the implementation of regular PAP (portable appliance testing.) testing is undertaken and documented.

Moving Parts

In our experience our 3printers belt drive systems exert minimal force below a level that would cause any harm or injury and the devices do not need guarding or interlocking for this particular risk. However it is important that the moving parts are not tampered with during operation due to the risk of damage to the printer.

Burn Hazard

As all 3D printing processes involve heat, both on the build plates and extruder nozzle and therefore possible burn hazards, adequate control measures such as warning labels and access to cold running water should be provided to reduce risk of injury.

Inhalation of Harmful Fumes

Although the 3D printing process involves minimal release of harmful fumes, particularly when using material such as PLA, other materials such as ABS are documented with a higher associated risk, when used in a small unventilated space. It is recommended that the machines are placed in reasonably large well ventilated area in order to reduce fume hazard. If only a small unventilated space is available, then a suitable fume extraction system must be installed.

Chapter 3. 3D Printing Technology

The general overarching term for 3-D printing technology is known as additive manufacturing. 3-D printing technology covers a wide variety of processes, materials and technologies. We are perhaps more aware of printers such as Maker Bot which use one sort of technology, call FDM. However industry has a wider variety of technologies, materials and processes which are perhaps lesser known.

Manufacturers who use additive manufacturing will have selected specific printing technology for their specialist areas of manufacture. Some of these will be prohibitively expensive and inappropriate for educational use. However I have listed some below in order to give a more fuller background to the details of additive manufacturing.

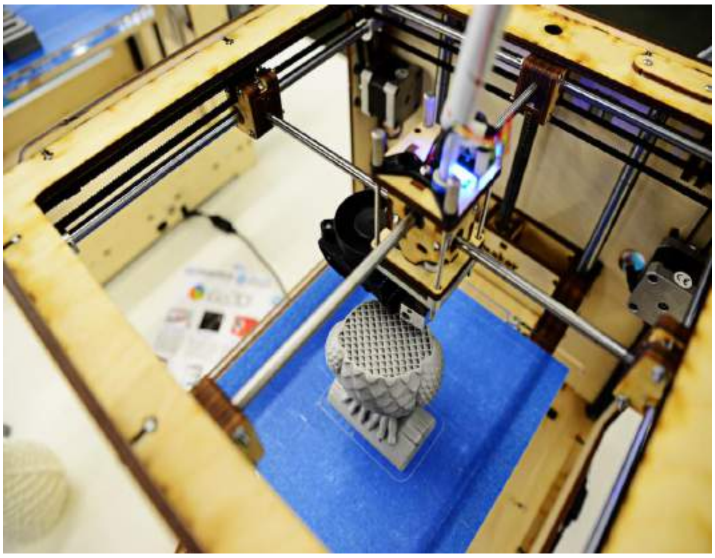
3.1 Extrusion

FFF

This is an important technology and is starting to become quite widespread. Fused Filament Fabrication(FFF), at its most basic, is where a melted material is built up in layers on a platen. FDM, Fused Deposition Modelling is a similar manufacturing process but is attributed to Stratasys Inc.

Typical materials include: ABS, PLA, silicon rubber and porcelain.

Typical 3D machine manufacturers include: Maker Bot, Ultimaker



A typical Extrusion Technology Printer that could be used in education.

3.2 Wire 3D Printing

Electron Beam Freeform Fabrication

This may be a little too expensive for educational use as this process has been pioneered by NASA to produce near net shaped parts. These are parts which require very few finishing techniques. The technique uses an electron Beam to melt wire in a vacuum. The process has primarily been developed for use in space. The basis of this sort of technology was vacuum welding.

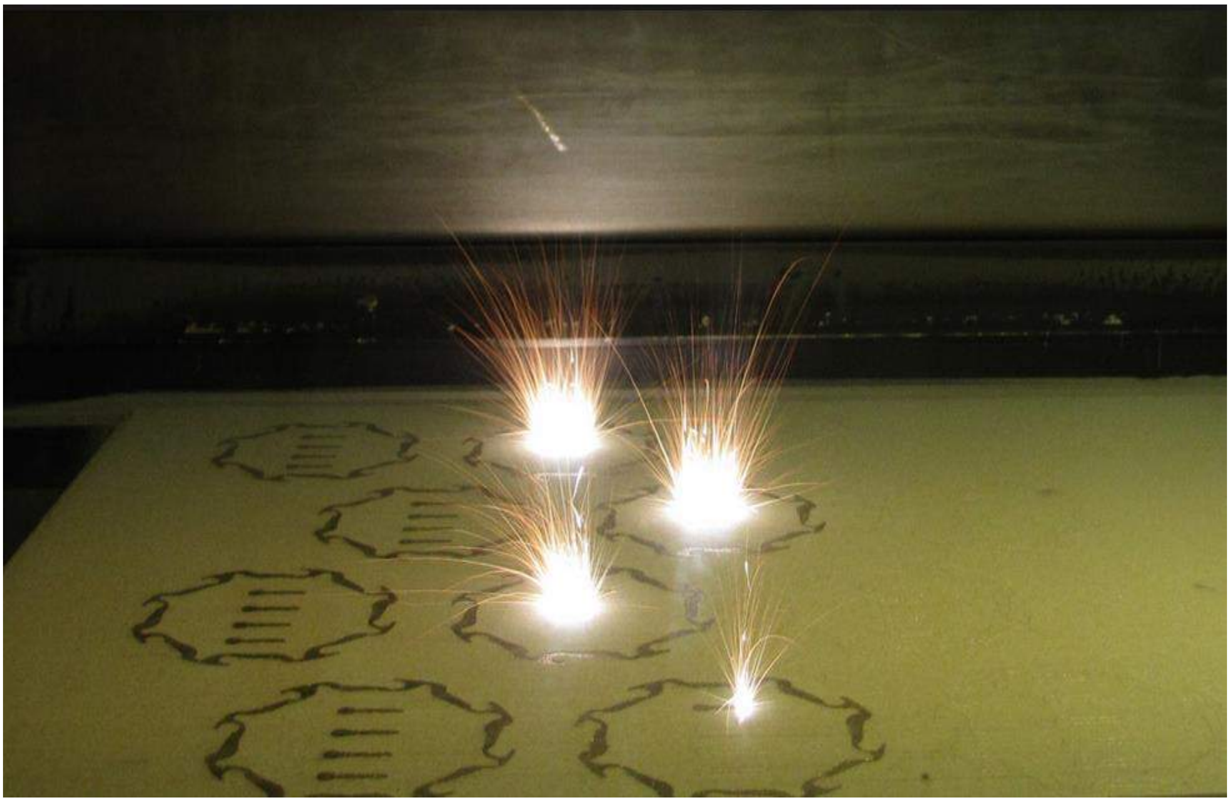
Typical materials include:
Aero-space alloys

Typical 3D machine manufacture:
NASA EBF3

3.3 Powder 3D Printing

Direct Metal Laser Sintering, Selective Heat Sintering & Selective Laser Sintering

This uses expensive technology to create metal components by sintering powder to build layers of sintered, not melted, metal into the component. DMLS uses a powder metal to cover a platen. The laser then melts the powder and an arm wipes another layer of powder over the existing printer layer. SHS & SLS use a bed of powdered metal for the component to be manufactured in.



A picture showing lazers fusing titanium together.

Using this type of process very complex components as can be manufactured. This is mainly for the aerospace industry however all the applications can be seen in Formula One racing cars, dental and medical fields.

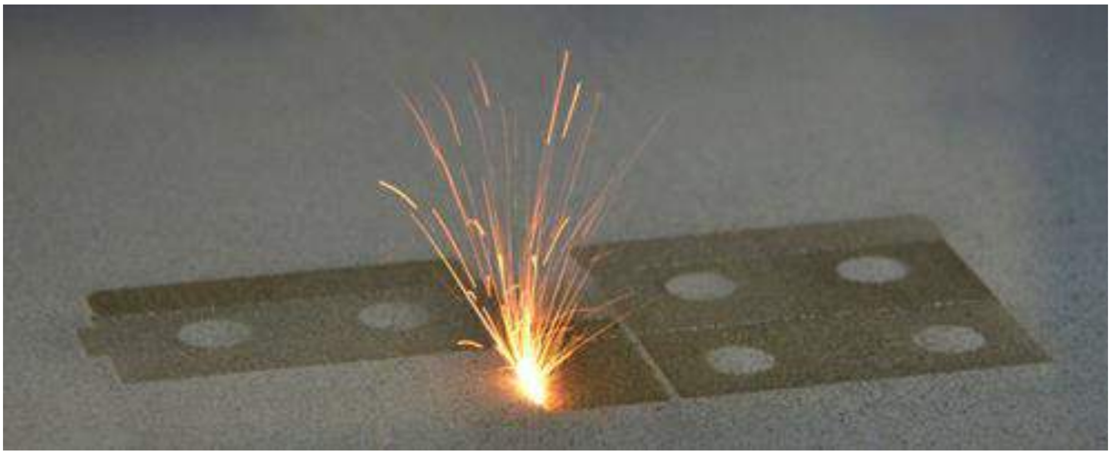
Typical Materials include Stainless, Inconel and Titanium.

Typical 3D machine manufactures:

Typical products manufactured from titanium for Aerospace industries.

3.4 Electron Beam Melting & Selective Laser Melting.

Again these processes are prohibitively expensive for educational institutions. Basically they use the same concept that is melting powder or vaporised metals and layering them on top of one another. More often than not this process is performed within a controlled and environment, that is one that is either a vacuum or an inert gas.



Art and technology meet, products manufactured impossible in anyother way.

3.5 Powder Bed Printing

An inkjet print head moves across a bed of powder, depositing a liquid on the powder in selected places to form the shape in layers. A thin layer of powder is spread across the completed section with a wiper arm and the process is repeated with each layer bonding to the last. When the model has been completed it needs to be depowered. This is where any unused powder or partially bonded powder is blown or brushed off the surface of the model. Another process, which makes the prototype more structurally sound, is to infiltrate the model with other liquids. This can be done in a vacuum chamber. Surfaces can also be smoothed and then painted to give a more realistic finish.

Originally water was used on gypsum-based powders. This was effective but models tended to lack strength. Various other powders can be used and again these can be strengthen by using other binders which can be infiltrated into the completed models. The trouble with these systems are the mess and time needed to print and cure the model.

This is called *post-processing* regimes. The processes vary. Burning or melting may be used to consolidate or coalesce the powder or remove the initial binder. Colour printing may be done. More recent developments have included making objects from sand and calcium carbonate which can form a sort of synthetic marble. Sugar and water can be used to form sweets!

This sort of 3D printing process is generally faster than other additive manufacturing technologies such as Fused Deposition Manufacturing. Another advantage is that supports are not necessary if overhanging parts need to be printed as the powder will support the structure. However, de-powdering itself can be a delicate, messy, and time-consuming task and any hollow sections will need to have holes in them somewhere to let the powder out. However a negative aspect of powder bed printing is the lower strength of components.

Powder bed and inkjet 3D printers can be expensive compared to fused deposition 3D printers but recent models introduced by Yvo de Haas and open source can cost as little as £1300.

3.6 Laminated object manufacturing (LOM)

This Rapid Prototyping Process is where layers of an adhesive coated paper, plastic or metal are progressively placed down to build up a model. The shape is cut out using a knife or laser. These printers are usually cheap to run and can produce larger size models. However thay can be a little crude.

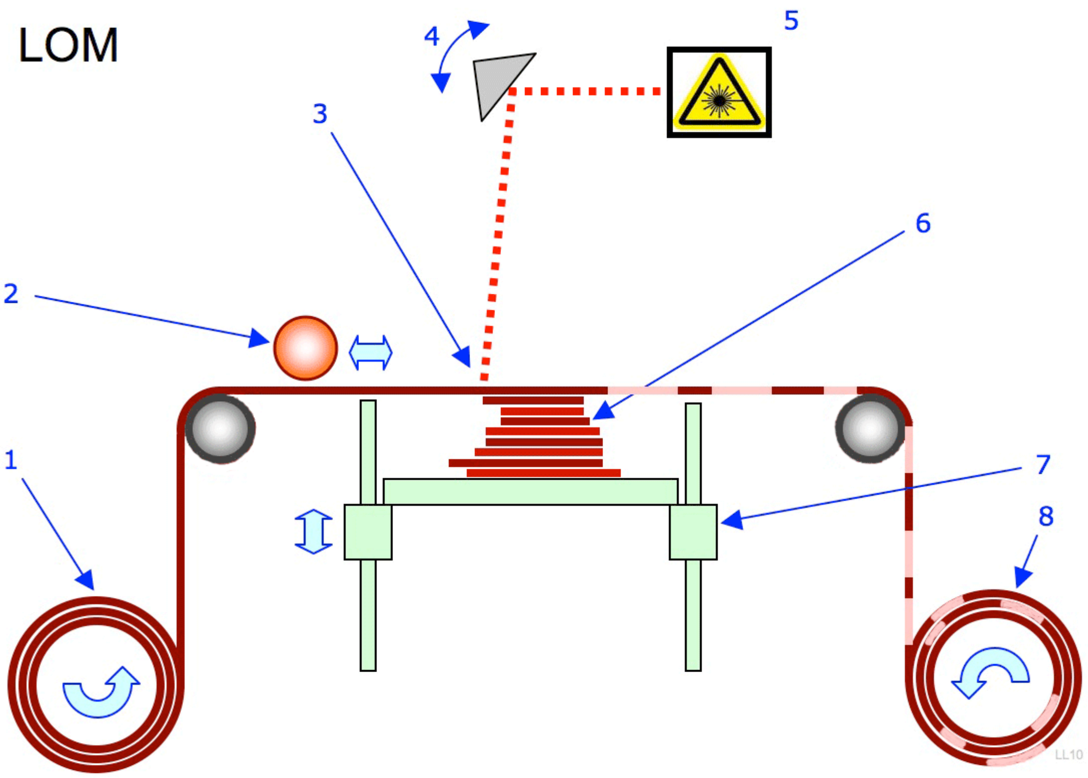


Diagram of LOM showing how it works, courtesy of Google images.

3.7 Photo polymerisation and DLP

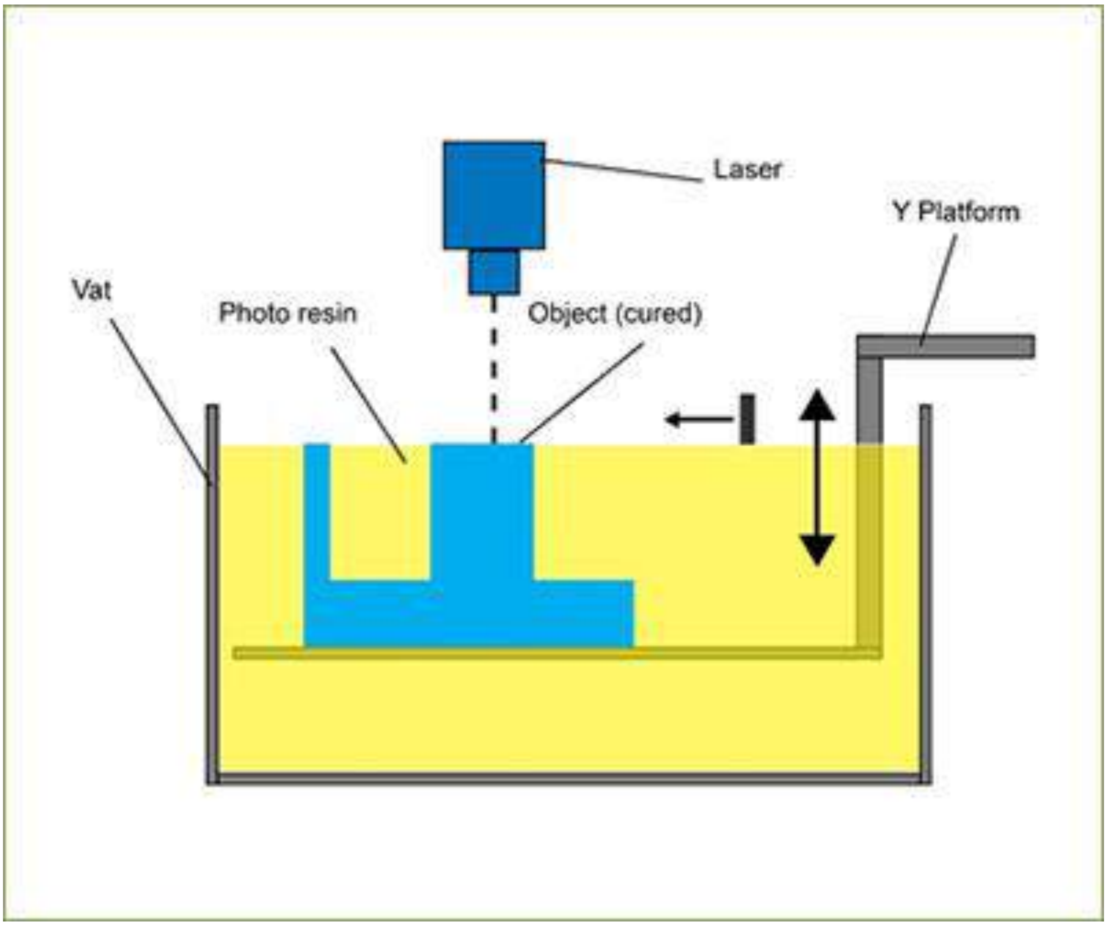
Vat Photo-Polymerisation is where a large vat of liquid has UV light moved over the surface of the liquid to chemically set the liquid into the desired shape. The UV light effectively cures the resin. A platform moves the model down layer by layer to build up the model. As can be seen in the diagram a mirror accurately moves the UV light across the surface of the resin.

Advantages:

- High level of accuracy.
- Good finish.
- Relatively quick process
- Large build areas: 1000 x 800 x 500 mm
- Heavy objects up to 200kg

Disadvantages:

- Expensive machines
- Expensive resins
- Post processing time can take time
- Removal from resin can also be lengthy
- Requires support structures
- Post curing for parts to be strong enough for structural use



Photopolymerisation – Step by Step

- Build platform lowered from the top of the resin vat downwards layer by layer.
- A UV light cures the resin layer.
- The platform continues to move downwards.
- Additional layers are built on top of the previous.
- After completion, the vat is drained of the resin and the object is removed

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/vatphotopolymerisation/

3.8 Digital light processing

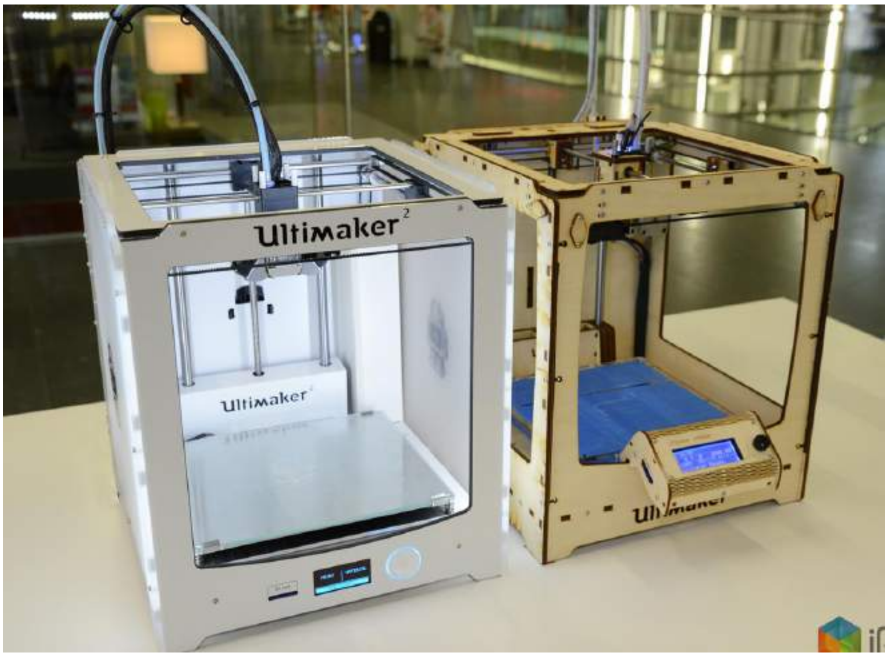
DLP — or digital light processing — is a similar process to Photo-Polymerisation in that it is a 3D printing process that works with photopolymers. The major difference is the light source. DLP uses an arc lamp, with a deformable mirror device (DMD), which is applied to the entire surface of the vat of photopolymer resin in a single pass, making it a reasonably fast process. However the resins on both sorts of process can be very expensive and prohibitive for educational establishments. £50 for 1 litre of resin.

Chapter 4. 3D Printing in Schools

Effectively there are only 3 methods for printing which, as education establishments, we need to consider. These are FFF or FDM, Fused Deposition Modelling as it can be referred to; powder bed printing and Photo polymerised printing.

4.1 Fused Filament Fabrication

At present these are the most popular types of printers in schools, particularly in the UK. The typical examples are now quite well know but eg's are Maker Bot and Ultimaker. The reasons why FFF technology is popular is due to a number of reasons. These are cost; simple tested technology; relative robustness; cheap running costs; wide range of models and manufacturers; good web support with forums; libraries and wide spread use, making purchasing relatively easy.



Picture showing 1st and 2nd generation Ultimaker 3D Printers.

4.2 General Comments About FFF

Advantages

- Low cost of materials.
- Low cost printers available.

- Wide variety of machines to choose from.
- Bed sizes vary from A5 sizes to A3 sizes and beyond.
- High strength models.
- Shortish build times.
- Easy to operate.
- User friendly.
- Multi-colour modelling possible.
- Easy to maintain.
- Readily available filament.
- Small printers can be portable.

Disadvantages

- Material or structures needed to support overhangs.
- Support material must be removed with possible damage to model.
- Can go wrong.
- Setting up ie levelling build plate can be time consuming.
- Earlier printers can be a bit temperamental.

4.3 Suggested Printers

There are many websites which recommend a variety of 3D printers. The information below has been sourced from 3D Hubs. This is an open sourced website where different people have given feedback about printers they have.

The printers have been categorised as Enthusiast Printers only. However this has been chosen as comments in the first Questionnaire suggested that a number of printers would be better than a larger more expensive machine. Many of these machines have been tested by single users. However the Ultimaker 2 has been on a long term test by Dr Dave Jermy at Settlebeck school. It has proved to be a reliable and durable printer with excellent build qualities. Using this as a guide it would also suggest that a number of these printers have similar characteristics.

Choosing an appropriate printer for educational use and one for your own specific establishment needs to be based around your educational needs. Any decision about the printer will ultimately be a compromise. It may be more appropriate to discuss with other educational establishments nearby about their printers and form support networks if purchasing the same printers.

4.4 Purchase Criteria

Criteria for the selection will need to be drawn up by different institutions depending upon their needs. These criteria fit into two main areas Technical and socio-technical. The following criteria may need to be used to judge as to whether a printer should be purchased. The list is my no means exhaustive.

4.5 Technical Criteria

Reliability

This has to be one of the most important issues. Having reliable technology which is able to work without resorting to continually setting up, levelling build plates, loading and unloading filament etc is very important in an educational setting where failure to meet deadlines can be disruptive educationally. Coupled to this is the time allocation or personnel allocation which would be required to fix the printer. Reliable and durable printers will cost less in the long term, as less attention will be needed to maintain, tweek and fix it.

Dual head printers

Dual headed printers can be found on quite cheap models and give the ability for different colours to be deposited on one another but also to interlock quite complex designs. This may initially be a function which is not required but could be experimented with later on.

Computer Connectivity

Another important issue in the classroom or educational setting. Initially 3D Printers used SD cards and cabling in order to access the required designs. Wi Fi and USB are now becoming wide spread. The use of SD cards in educational setting means yet another piece of equipment needs to be looked after and accounted for, worth considering. If Wi Fi is used then this gives the option for the Printer to be remotely located in a clean environment. Something which can improve the reliability of the 3D Print itself.

Plug n Play

Easy to set up and quick to get printing

Filament Drive Motor Location

This is important depending on the type of filament intending to be used. TPE or Thermoplastic Elastomers often work better when the filament motor pulls rather than pushes the filament into the extrude nozzles. However some push technology manufacturers have now over come problems associated with this.

Spare parts availability

The technology is moving so quickly models can date within a few years. Larger 3D Printing companies should have better spares availability. New to market companies may not. However open source forums are usually very good at providing solutions to issues which may arise. A large forum may be a more important consideration.

Dimensional Accuracy and Stability

Warping can cause significant issues with large or flat builds, wasting significant amounts of time and resources. This has been one of the areas of much discussion on forums. Using adhesives, mirrors and dissolved ABS or PLA in a solvent. In education this should be a key consideration. To some extent experimenting with different methods of reducing this problem may be necessary.

Print speed

Larger prints will take considerable amounts of time no matter how quick the printer works. It therefore makes sense to leave the printer working overnight. Smaller mid-sized prints may be able to be turned around quicker during the day if a printer works quickly or the resolution is reduced.

Print speeds are still such that in education projects have to be designed and integrated to ensure that pupils are not waiting for the print to finish. This links in with software conversion programmes which allow multiple files to be printed out in one go. Check it out man.

Software Costs

Open source verses manufacturer specific. In many ways open source makes more sense as it is widely accessible and free. Conversion software has been developed, for example Cura which is able to support an number of different 3D Printer manufacturers.

Print libraries

Always handy to have. Whether you are designing your own products, modifying existing ones or simply printing somebody else's design having the ability to do this can be inspirational.

4.6 Socio-technical Criteria

Initial Cost

This is obviously dependant on the amount of money available. However it is worth considering three points: is it worth buying 2 printers: one expensive one or starting with the cheapest one possible and deciding how to continue. In Dave Jermy's experience as an international 3D Printing expert "it is nearly always better to have two printers rather than an expensive 3D Printer". The advantage of having a number of printers is simply to do with the throughput of prints that can be done. This means multiple prints can be completed quickly. For example if the 3D Printer is left on over night and has been configured to print a whole classes work this will be a lot quicker than single prints throughout the day. Printers can be run simultaneously or one can be being loaded whilst another is waiting for the next class or being unloaded.

Amount of Use

3D Printing project inevitably have bottle necks, times during the project when the 3D Printer is needed continuously. However when other projects or topics are being covered it may not be used for days. Timing and completion of projects need planning as any slight problem can rapidly lead to deadlines not being met as time allocations become compounded.

Projects could be developed which can take place over an academic year. For example pupils could do some design work at the start of the year and print these out over the remainder of the year. Group work could be considered too.

Who will use it?

Getting pupils to use the 3D Printer is an important part of the design and manufacturing process. Allowing pupils to engage with the technology can only have a positive effect on the learning experience, leading to a greater understanding and creativity in the design and application of this technology.

3D Printing technology (FFF) is relatively safe to use as there are few parts which could cause injury. Very often acrylic covers are needed to protect the print from cool air or drafts which can affect the quality of the print, making the technology even safer.

Having pupils who are capable of using the technology can be an excellent way for teachers to gain support. Pupils in class could act almost like technicians, loading unloading and setting manufacturing parameters. Alternatively pupils could develop additional skills and knowledge, which can be used by the teacher to actually improve the teachers understanding of the technology.

Manufacturer support

This is obviously an essential criteria when selecting any printer. Selecting a manufacturer who has sales and support within the country, where it is intended to be used, will make any technical issues simpler and easier to rectify. However as the 3D Printing market becomes more competitive remote support over the internet may be just as good. Down loading up to date versions of software or mechanical improvements should all be provided by a large cutting edge manufacturer. Very often online communities are also able to support in this way and can provide more down to earth and practical advice.

On line community

As mentioned previously online support can be an excellent way of gaining solutions to technical issues. Some of the larger manufactures very often encourage forums to promote and support their products. Having a large network of forums specifically dedicated to your printer could be another important criteria for choosing one specific printer manufacturer. 3D Hubs is one such example.

Libraries

File types tend to be saved as STL files making them accessible for most printers. Printer manufactures usually have open source websites where models can be downloaded too. Again as STL files.

Ease of use

When teaching in class issues of reliability and ease of use are vital to the smooth running of 3D printing projects. First generation printers often needed a lot of attention and skill to set up. Fifth generation printers are now far more sophisticated and have software, which will do this automatically.

Another problem common to some printers are the printer head nozzles, which can clog. Again the ease with which this can be sorted is important for the smooth running of projects.

Filament changing needs to be considered too. On most printers this is a relatively straight forward process. However some printers need the filament to be trimmed to help the extruder motors take it up. This is not too onerous task and can be completed in a few minutes.

Possible FFF 3D Printers

Below are a list of ten manufactures considered to be amongst the best as reviewed by users on 3D Hubs website. This information will be constantly changing as new models are added or reviewer's opinions change.

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

Materials

There are two main materials, PLA and ABS. These are both Thermoplastics, which means that they can be heated and moulded, continually, i.e. over and over again. Both these materials are available in a wide variety of colours. However for a material to be useful for 3D Printing, it has to pass three different tests;

- initial extrusion into Plastic Filament.
- extrusion and trace-binding during the 3D Printing process.
- end use application.

However there are more materials being introduced all the time. New materials also offer a wider variety of properties and post-printing modification. Amongst them are rubber or metal based materials which can be finished to appear like metal. Dissolvable filament is also available.

Storage

Both ABS and PLA should be sealed off from the atmosphere to prevent the absorption of moisture from the air. This does not mean your plastic will be ruined by a week of sitting on a bench. However long term exposure to a humid environment can have detrimental effects, both to the printing process and to the quality of finished parts. If the polymers have absorbed moisture:

ABS - will tend to bubble and spurt from the tip of the nozzle when printing; visual quality of the part, part accuracy, strength and the risk of a clogging in the nozzle. Are all more likely. ABS can be easily dried using a source of hot dry air.

PLA – will bubble or spurt at the nozzle. It may also discolour and a reduction in 3D printed part properties. PLA can react with water and undergo de-polymerization. PLA can also be dried using warm hot air as too high a temperature could alter it's material structure. For many 3D Printers, this need not be of much concern.

Part Accuracy

ABS and PLA are capable of producing dimensionally accurate parts. However:

ABS – the biggest issue with ABS is the curling up of the edges of the print. To reduce this heating the print surface and ensuring it is smooth, flat and clean goes a long way in eliminating this issue. Various solutions can be useful when applied beforehand to the print surface. For example, a mixture of ABS/Acetone, or a shot of hairspray.

For fine features on parts involving sharp corners, such as gears, there will often be a slight rounding of the corners.

PLA - demonstrates much less part warping. For this reason it is possible to successfully print without a heated bed and use more commonly available Masking tape as a print surface. PLA can also produce stronger bonds between layers.

4.7 Summary

PLA - The wide range of available colours and glossy feel make it popular to pupils. The environmental aspect can also be used as a teaching / learning experience, as it has plant based origins. PLA can have a higher printing speed, lower layer heights, and sharper printed corners. Combining this with low warping on parts it makes it a popular material for schools.

Advantages of PLA

Cheap affordable polymer £ 40 per Kg

Can give a smooth shiny surface finish

Bio-degradable

Gives off very little fumes

Low toxicity

Low UFP's

Reduced distortion compared to ABS

Disadvantages of PLA

A little more brittle than ABS

Melts at a lower temperature, (this may be an advantage if welding)

Softens at 50deg's, lower than ABS

Slow to cool (may need a fan to blow onto the print.)

More difficult to glue than ABS

Typical application of PLA

Necklace curtsey of Thingiverse

ABS - Its strength, flexibility, machinability, and higher temperature resistance make it attractive for more durable models or products. The additional requirement of a heated print bed means there are some printers simply incapable of printing ABS with any reliability.

Advantages of ABS

Tougher and stronger polymer than PLA.

Able to be used in higher stressed models.

Doesn't need a cooling fan.

Filament tolerances are tighter.

Can be bonded using solvents or adhesives.

Higher heat resistance.

Can be painted and sanded.

Disadvantages of ABS

Must use a heated print bed

Prone to curling, cracking and delaminating

Fumes unpleasant and require fume extraction.

Petroleum based plastic making it less environmental friendly

Can degrade in sunlight.

Typical ABS Model

Gear wheels using greater strength of ABS

Health Issues Associated with 3D Printing Polymers

Limited research on the health effects of 3D Printing have been done. However there is research been done into UFP's, Ultra Fine Particles, of which PLA and ABS when melted will emitted.

Elevated UFP concentrations are linked to adverse health effects, including cardio-respiratory mortality, hospital admissions for stroke, and asthma symptoms. However this will only be in large concentrations. PLA emits typically 10 times less UFP's than ABS. PLA is seen as being non-toxic and far more environmentally friendly due to it being derived from plant-based materials.

ABS is more durable and rigid but appears to be a less favourable choice when compared to PLA for use in the classroom. Some manufactures say that ABS 3D Prints should not be used in offices or school buildings without some sort of extraction system. However these extraction systems do not need to be expensive or elaborate and could be some sort of simple hood over the printer with a forced air circulation and filter.

Chapter 5. Identification of Programmes for File Conversion

5.1 Slicers & 3D Printer Hosts

STL is the standard file type used by most additive manufacturing processes. This is the file type which will be saved from the 3D design software package, eg Sketchup.

Before printing a 3D model from an STL file, it must first be examined for "manifold errors," this step is called the Fixup. Manifold errors are where surfaces or facets don't meet or overlap. Software programmes such as Netfab, Meshmixer, Cura and Slic3r are examples, which will correct these issues.

Once this has been done the next stage is to convert the model into a series of thin layers or slices. This is then converted into G-Code. This G-Code can then be used to print from. However usually Client Printing Software is nearly always needed to turn the G-Code into instructions, which the printer can interpret and print from. It is here that print parameters can be selected for the printer.

Most commonly the slicer and the client software are combined, making the conversion from STL file to 3D Print straight forward and simple. Repetier-Host and ReplicatorG are examples of these.

You cannot build the model smoother than the STL file, so if the STL is coarse and faceted, this is what the final model will be like. When exporting to STL in your CAD package, you may see parameters for chord height, deviation, and angle tolerance. These are the parameters that affect the faceting of the STL. The more detailed the STL, the larger the file size, which will affect processing time. Sometimes manufactures will also give options for quick or detailed prints, this will obviously affect conversion time as well as print times. However some manufactures will give you approx. print times so you can make decisions about what sort of print you want.

5.2 Typical Basic Printing Parameters

Below are a list of typical basic parameters which will need to be considered before printing out. More advanced settings are also available but will not be considered as these will need individual experience with each different printer.

Layer Height

This is the height at which the layers will be put down onto the bed of the machine to build up the model. Issues about nozzles catching layers as they are put down and the slump that the plastic will undergo when extruded will be factored into the manufactures default settings. Layer height can also affect the adhesion of subsequent layers.

Shell Thickness

When models are made that are supposed to be solid they will in actual fact be hollow. The thickness of the outside surface of this shell will be considered here; as the whole object will not be solid plastic all the way through but will be partly in filled.

Retraction

When there is a change between the x & y axis Cura retracts a certain amount of the filament to stop any blobs forming.

Bottom / Top thickness

Similar to wall thickness as these 2 manufacturing perimeters may need to be altered to improve the strength of the print as well as provide a good base for the print to be built from.

Fill Density

As previously mentioned solid objects are not in actual fact solid as this would be a waste of plastic and possibly lead to distortion and or delamination. Instead objects have a criss cross pattern to provide support and strength. Usually this can be set at around 10%.

Print Speed

Fast print speeds are what most users want. However this can lead to low quality prints with flaws or printers not being able to manufacture reliable prints. As a rule of thumb the slower the print the higher the quality.

Nozzle Temperature

As the name suggests this is the temperature at which the nozzle works at to extrude the filament. This will be dependant on the type of filament being used as PLA and ABS for example have different melt temperatures.

Build Platform Temperature

This is only applicable on printers with heated platforms as some printers using PLA can print without. PLA can use lower temperatures than ABS however factory pre-sets should always be tried first.

Supports

When prints have overlapping parts or surfaces, supports will need to be used to stop the plastic slumping or the model from being impossible to print.

Platform adhesion

There is a lot of discussion about this. Some printers simply use a high heat temperature film, such as kapton tape or even mirrors to print onto. Others use simple paper glues whilst other groups of users recommend using solvent dissolved ABS. Only through experimentation will the best method be found.

Diameter

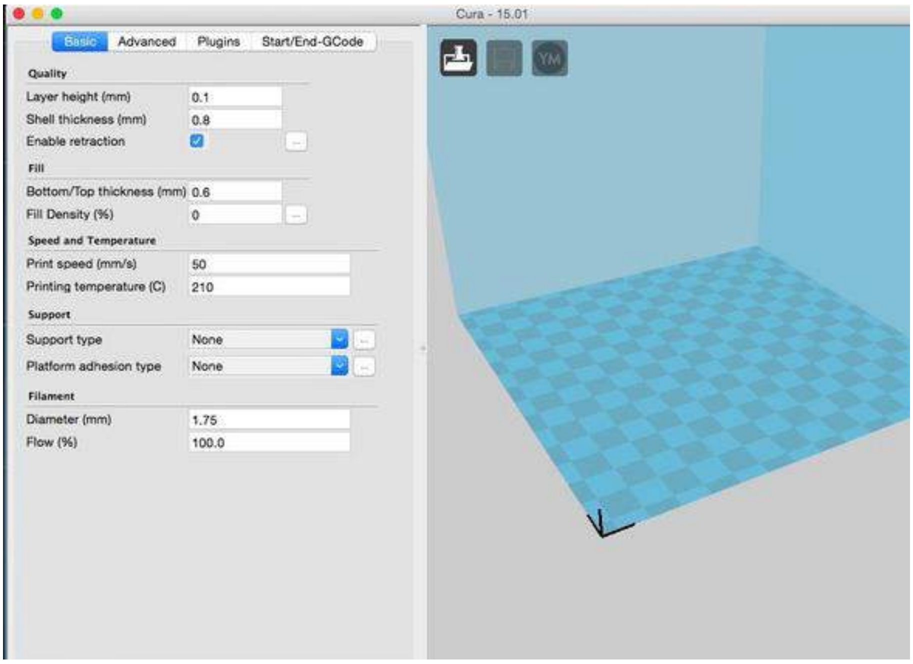
This can refer to the diameter of the nozzle for extrusion and the filament size too. PLA and ABS usually come in 2 main sizes 1.7mm and 3mm and this applies to the nozzle diameter too

Flow

This refers to the speed with which the printer will extrude the plastic. Filament diameter and nozzle diameter all affect one another and are interrelated. Again manufacturing pre-sets will really be the best. However some specialist materials such as metal, rubber or wood may require different settings, very often, internet forums will be able to make provide suggestions about this information.

Ultimaker; Cura

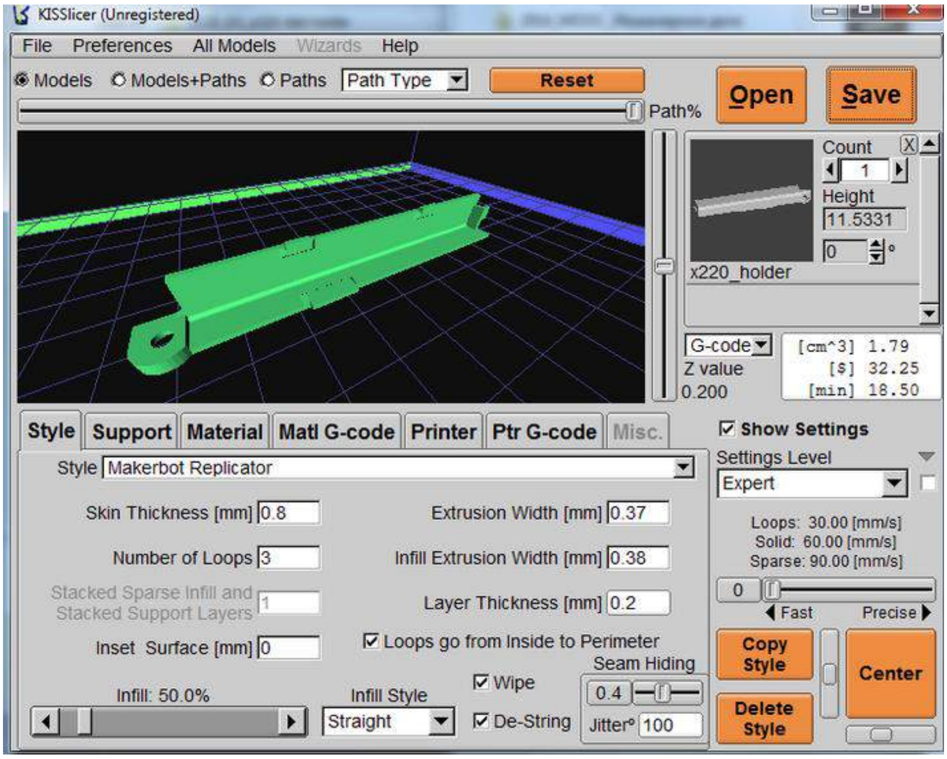
This is a free open software print controller developed by Ultimaker. This can be used by other printers. It's easy to use and simple to use. A good choice for schools and beginners.



KISSlicer

This can be used on a number of 3D printers. This is a free download. However if more complexity and specialist support is needed a bought version is available.

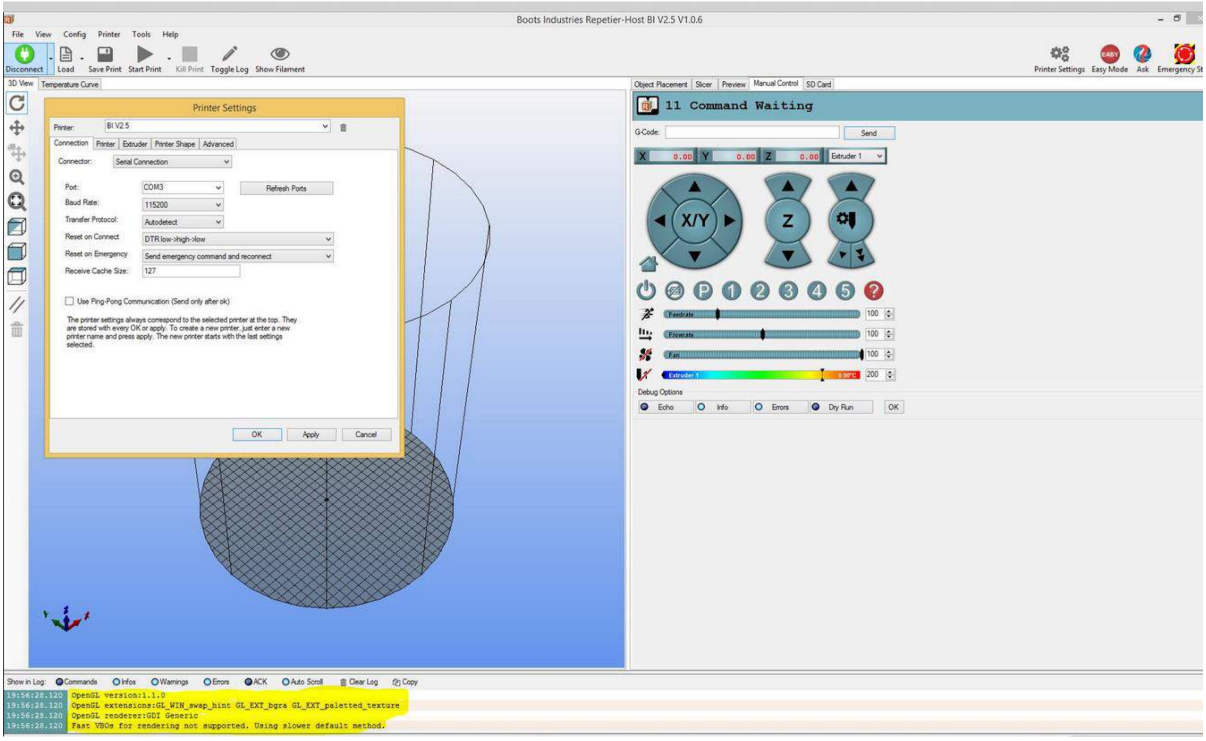
Although the “front end” of the KISSlicer looks a little complex it has the usual print settings, skin thickness etc. However more specialist settings are also shown in tabs.

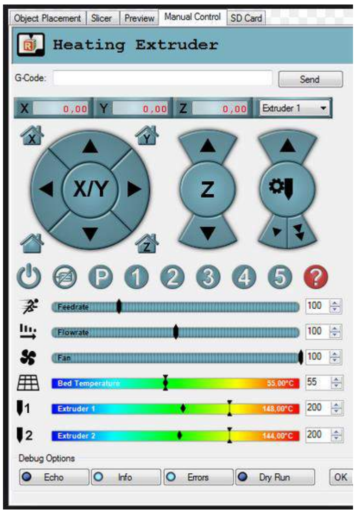


One of the screen images which will be seen when using KISSlicer. Although a little complex looking, it soon becomes apparent that all previously mentioned Production Parameters are available. Other information and more advanced settings will be available hidden behind tabs.

Repetier Host

This again is a free download / open-source for 3D printing. This is the typical screen image where selection of printing settings are available. KISSlicer or Skeinforge are the software programmes which will scan the STL file to ensure that the models are free of defects or unprintable surfaces and turn this into G-Code. Typical settings and options are available as per most 3D Printing software programmes.

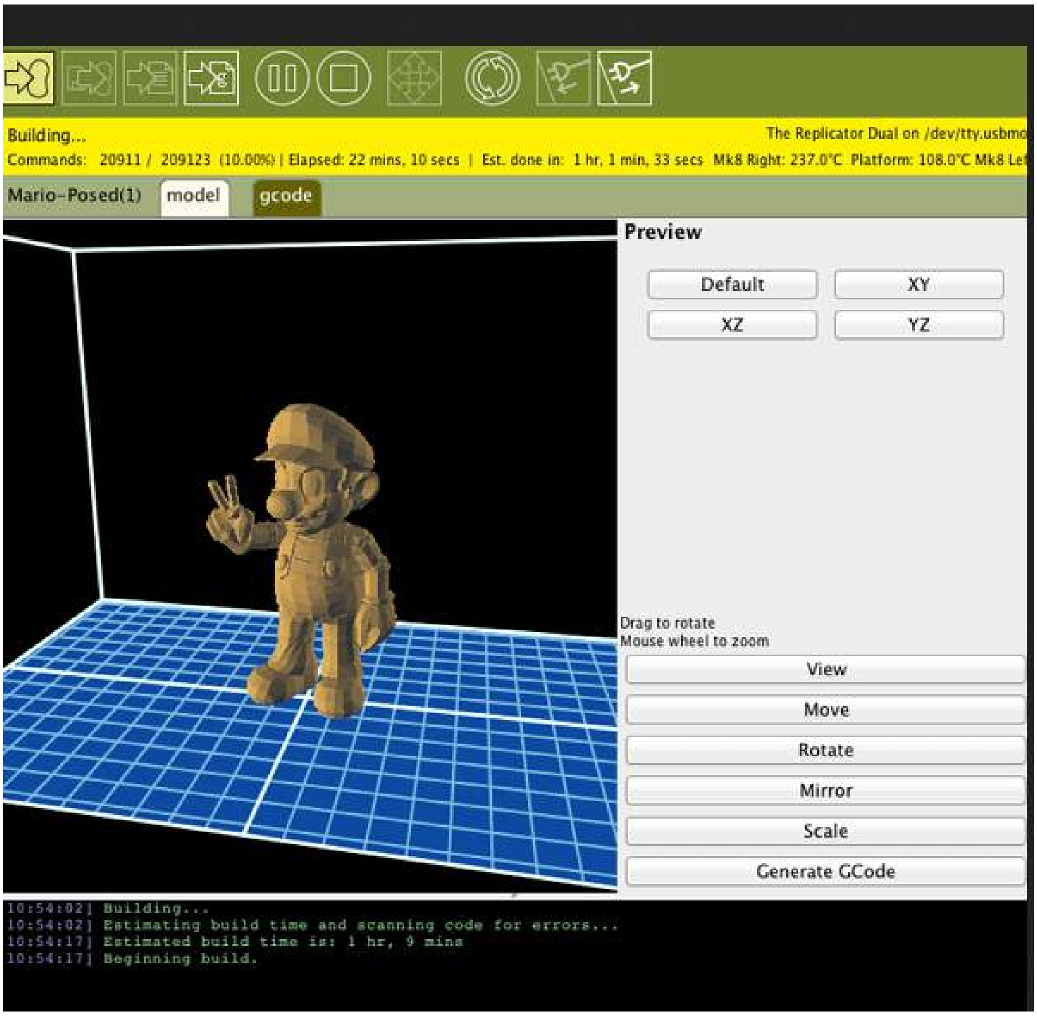




A close up of the user interface to alter settings for printing.

Replicator

This is an open source 3D printer software programme which can be used to convert STL files to G-Code files ready for printing. A number of 3D Printer manufactures have printers which are compatible with these. This uses Skeinforge to check and convert STL files to printerable objects.



The programme allows the object to be manipulated, with regard to size, orientation and other typical manufacturing parameters. This software is still quite serviceable but is becoming one of the older 3D Printing conversion programmes.

Chapter 6. Identification of 3D Programmes

6.1 Overview

There are a vast range of 3D Programmes for use in schools, colleges, and industry. Some 3D modelling software can be very expensive costing E800 or more with, annual renewal fees too. This sort of cost makes it difficult for schools to afford, unless they are specialist colleges where engineering is being promoted or the school is sponsored by a manufacturing industry such as schools in and around Coventry UK where Jaguar Land Rover have large engineering, manufacturing plants.

3D Modelling software up until the late 1990's was the sole preserve of engineering companies and was used extensively in the motor vehicle industries to not only design parts but to also test and evaluate them for weight, strength and aesthetics. However a number of these 3D modelling programmes have become available to schools and colleges as free downloads. Many are available for home use too. Much of this software is either dumbed down from industry or is dated or is about to be updated. One of the first companies to do this was PTC with Pro-Desktop. This was a complex piece of 3D software and required quite a lot of experience to use. Pupils found this frustrating and difficult to use.

Most schools and colleges may have existing 3D software programmes. Pupils may already be familiar with these and will want to continue using them. As a teacher many may have invested both time and money into both using, learning and trouble shooting the software. Teachers will have set tasks, projects and teaching aids to support pupils. Many schools and colleges may need to make the decision as to whether or not to continue with this software. It may provide the impetus to change to more appropriate software.

This is one of the key issues with 3D modelling software; ease of use. Much of the modelling software can be very difficult to use and requires a lot of practice, something which pupils will have little time to do in 1 hour lessons. Any selection of 3D software must use this as a criteria to judge the effectiveness of the software and whether or not to use it.

As mentioned, with PTC Pro-Desktop, these programmes usually have a product life cycle which means that they become dated and are either developed further in a way which means that it is necessary to re-learn or support is withdrawn and no further development work is continued, in effect becoming obsolete.

3D modelling and software is now so common that many issues of compatibility are unlikely. STL files tend to be the industry standard which are used to export the print files. It is the file conversion after this into G-Code or other file types that are most likely to cause problems, with these, in some cases being specifically dedicated to particular manufacturers. However, as discussed in the software conversion section of this document, there are, again, a number of free downloads and software programmes which will do this in a very easy to manage way.

3D modelling software by it's very nature requires a reasonable amount of processing power. The speed with which alterations can be made or designs changed and updated can lead to buffering and processing problems which can be time consuming, again leading to students becoming frustrated and the amount of effective lesson and learning time being significantly reduced.

Pre-designed models or libraries of existing components or printable models could be useful for printing, modifying or providing inspiration for projects. The free software packages with open source libraries can have extensive models which are easily accessible. Very often open source software packages have an online community, which can support users through tutorials or forums where specific questions can be answered. U-Tube tutorials can be very helpful to teachers and pupils who may need help with specific modelling tools or just as class lessons to develop pupil skills.

6.2 Criteria For 3D Modelling Software

Cost	Can the school or college afford the initial cost or annual renewal costs.
Freeware	Is it appropriate for the school to use dated or dumbed down versions of existing software.
Existing Software	Schools may prefer to use their existing software as pupils and teachers have invested time and knowledge.
Ease of Use	How easy is it for pupils to learn the use of this software.
Compatibility	Is the software compatible with 3D Printing. Does it need to be compatible with other modelling or rendering software.
Computers	Are the schools existing computers able to run the software with the minimum of trouble and buffering.
Libraries	Is there a readily available library of existing products.
Communities	Are there communities which exist for help and support.
Tutorials	Does the software have a large enough following for tutorials and support tasks.

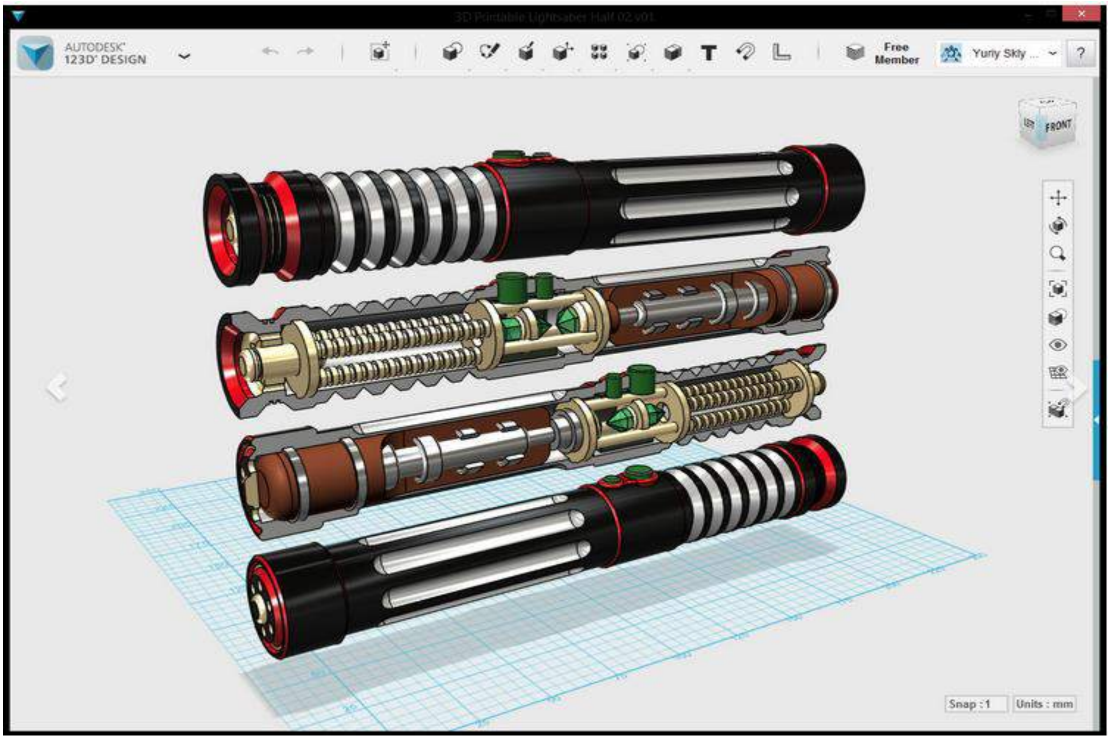
Parametric	Parametric software has a system that interrelates with the way and order in which you build up a model and so can be a little more complex to learn. However this is the system usually used by the engineering industry.

6.3 Free 3D Software

Autodesk 123D

Autodesk has a number of applications, 123D Design is a typical 3D modelling piece of software however it is able to work with other applications such as 123D Catch this is able to generate 3D Models from photo's or 123D Meshmixer, which is able to mix different models and work as a sculpting tool. The advantage of a suite of software packages like this is that there is greater flexibility with the ability to go between different packages making alterations as well as creating different presentations for assessment purposes.

Below is a sample of Autodesk 123D Design.



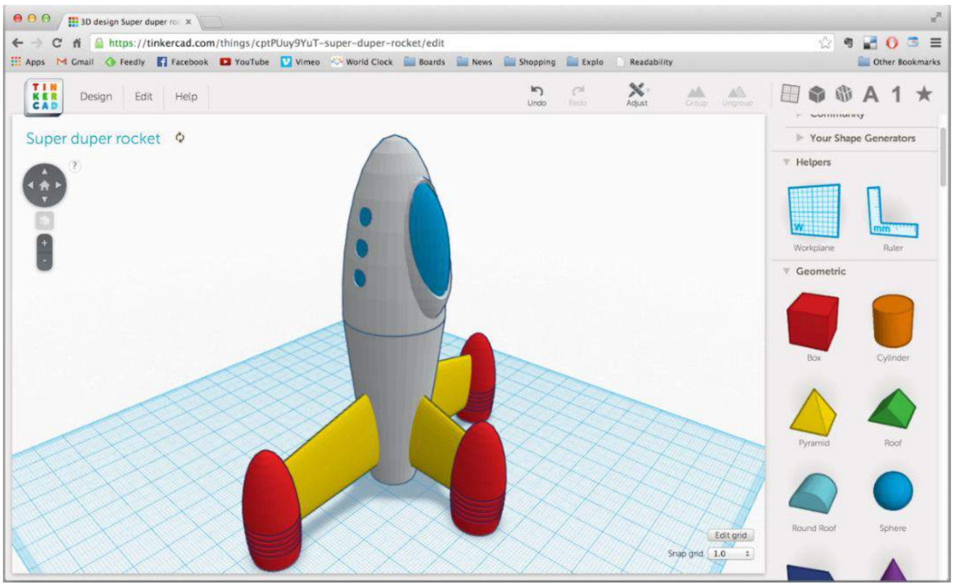
TinkerCAD

Again this is a free browser drawing package, from Autodesk 123D. As this is browser based there is no need for downloads and models can be stored online. TinkerCAD is very easy to use and because of this is popular, especially by people who have no prior knowledge or background in CAD or 3D Printing. Essentially TinkerCAD uses basic shapes as building blocks to piece together and form designs with. You can use TinkerCAD's basic pre-existing shapes and also import your own. Another feature is the ability to import a 2D vector images and convert them into a 3D printable design.

TinkerCAD is compatible with all 3D printers that use the standard STL file format, and it also lets you easily export the files you've created to an external program or device if you'd like to work on it further and produce something more complex.

Another useful feature is the ability to import external 3D files and work on them in TinkerCAD. File types available for import are SVG and STL. SVG files are 2D design based but can be used on laser cutters.

As can be see, the front end of TinkerCAD is basic, clear and tools are easy to find. However if more detail is wanted it is possible to export to other 3D packages that will accept it's file types.



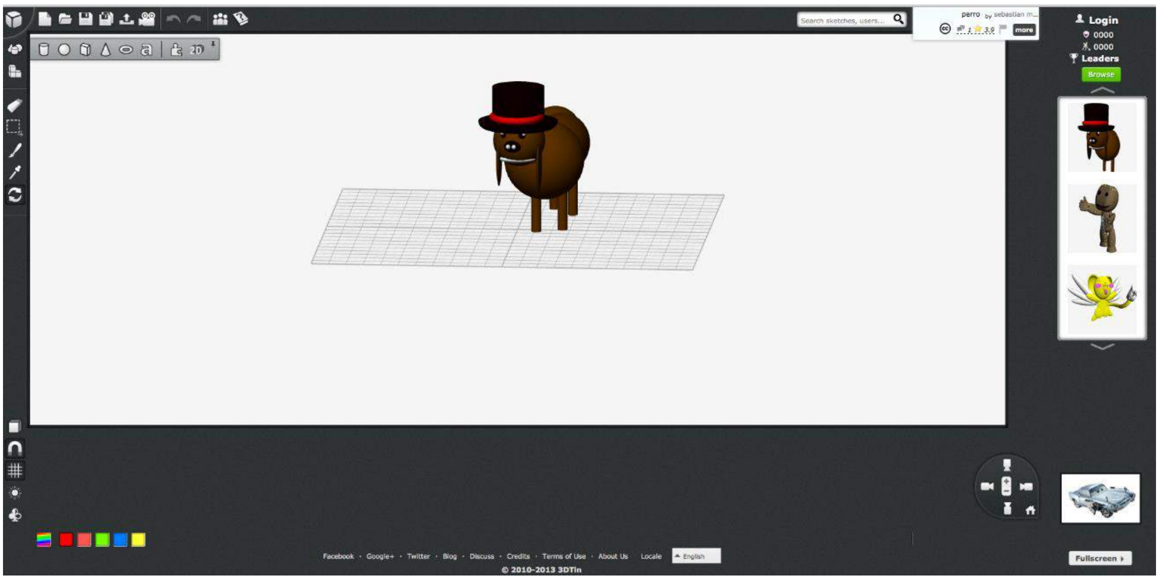
3DTin

Once you have created a user account you also get access to the huge repository of Creative Commons 3D models.

This is a browser-based 3D modelling tool which allows you to create 3D models on the web, without the need to download additional software. It's basic software, has its limitations but it is also one of the easiest and fastest ways to create 3D models. There are more than 100,000 users and it was one of the first 3D modelling applications, launched in 2010.

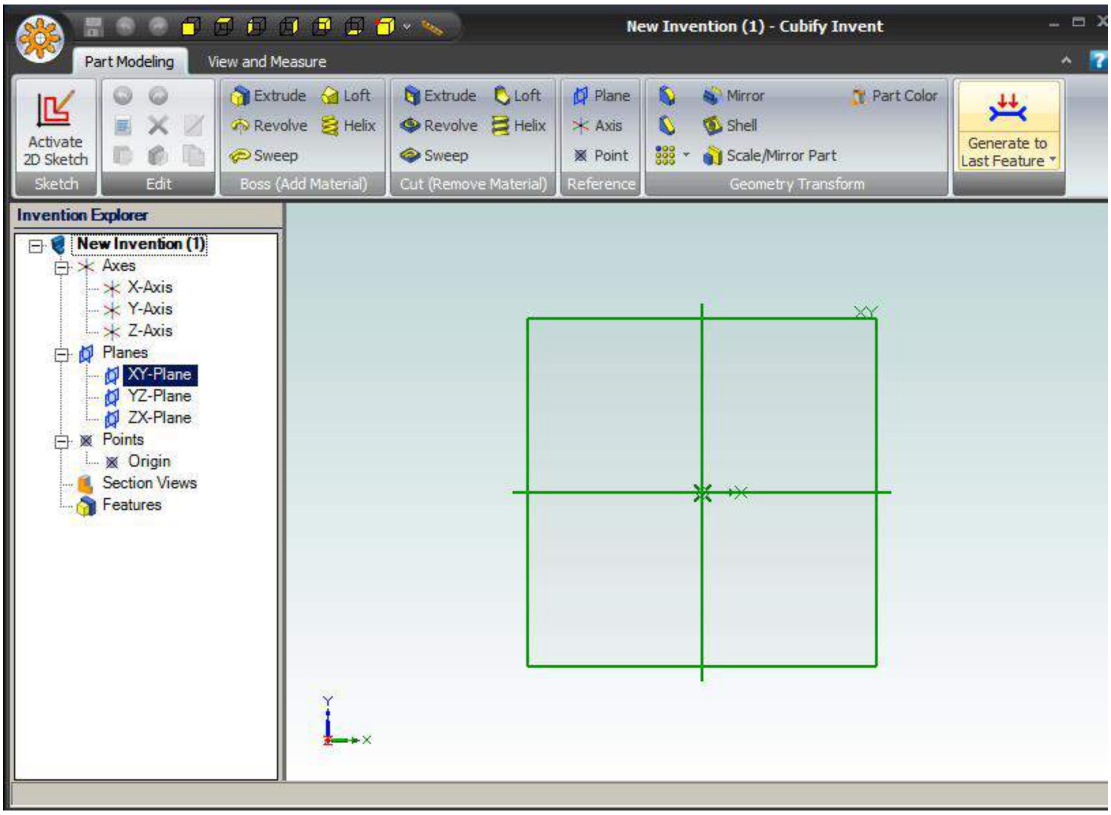
Browser capability means that other software requires a download or installation of complex software 3DTin allows you to start creating models in seconds. 3DTin is compatible with Google Chrome, Mozilla Firefox, and other browsers.

Once you have created a user account you also get access to the huge repository of Creative Commons 3D models.



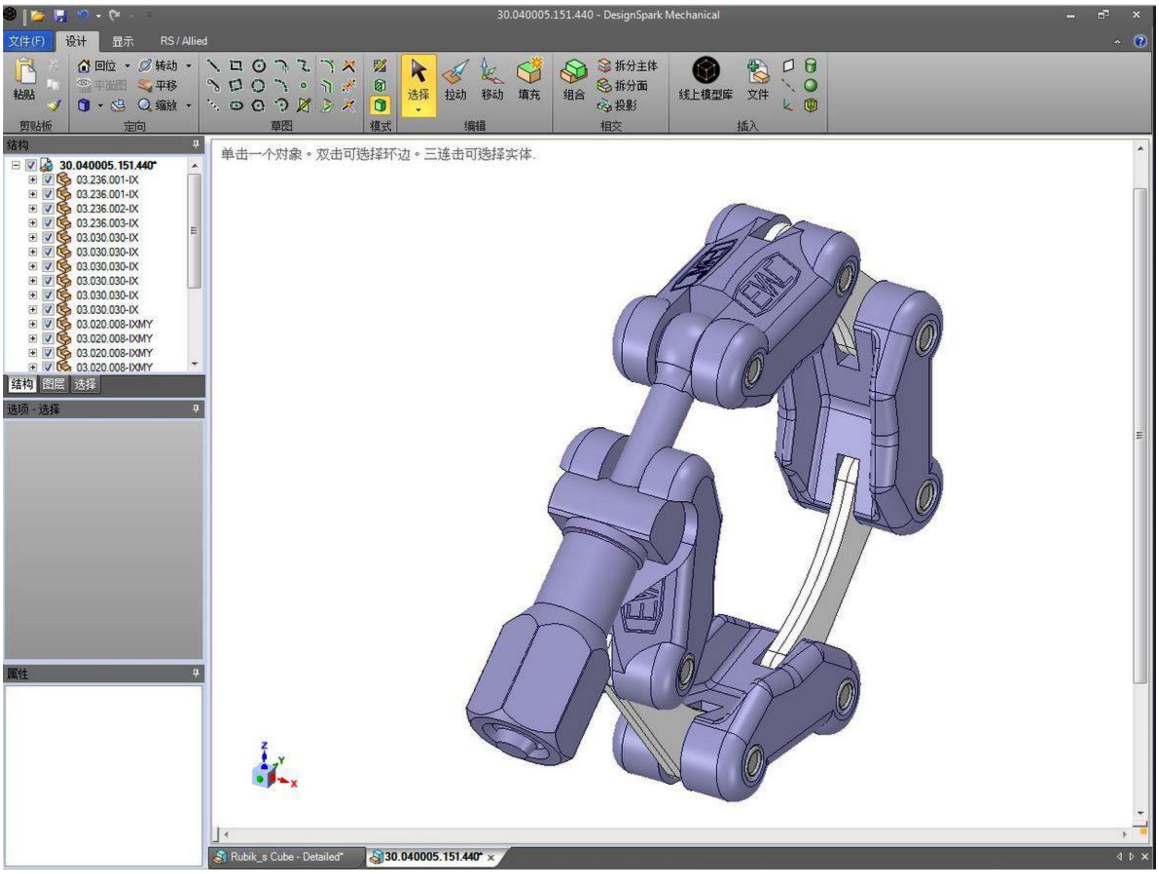
Cube Team

This is an American based company which produces it's own printer too. The software, which comes with the 3D printer, is file conversion software. 3D Cubify Design is the software, which allows you to design 3D objects. You are able to export in STL files which should make it compatible with other printers and other conversion software. However this needs to be verified. The package can only export STL files and is not able to import them. Other packages are Cubify Sculpt, which allow you to create more freeform designs. There is technical support from the manufacturer too. Cost for the software seems to be negligible too at E100 approx.



DesignSpark

This has been developed by an electronic supply company who have also linked it with PCB manufacture. The mechanical aspect of the software allows you to export STL files only, however this should not be a problem as STL files are the file types, which can be printed. Again this has a forum and library of components which can be used. However very often the number of users and availability of support are linked, this seem to be more a little more obscure than other 3D Mechanical £D packages. The package is supposed to be intuitive to use. Again a free down load.



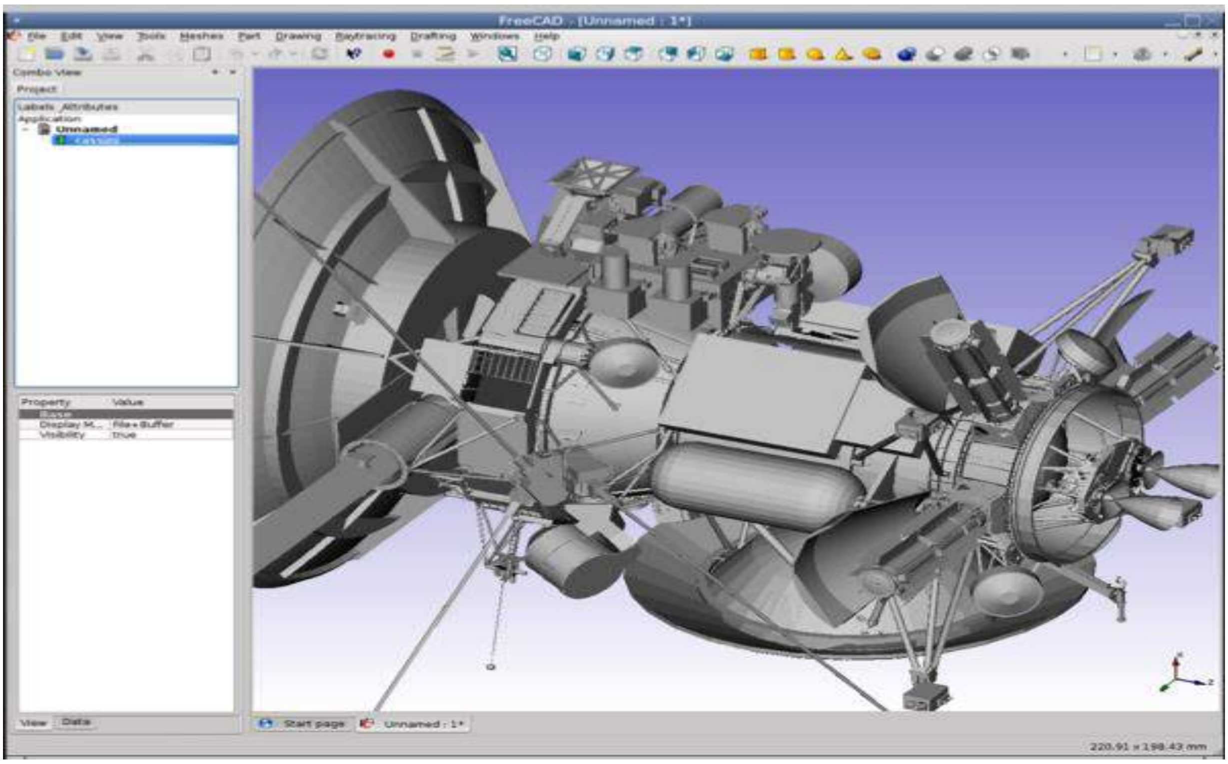
FreeCAD

Ageneral purpose parametric 3D CAD modeller. It is completely open source. It is aimed directly at Mechanical Engineers and Product Designers and also fits in a wider range of uses around engineering, such as architecture or other engineering specialties. The development is completely Open Source and has a following by other online communities and DIY hobbyists.

FreeCAD is also fully functional on most computer platforms and currently runs on Windows and Linux/Unix and Mac OSX systems, with the exact same look and functionality on all platforms.   It has very similar tools to Solid Works and Solid Edge and has a large library of open-source models.

It is able to produce 2D Orthographic Drawings but has not been primarily designed to produce these.

The FreeCAD forum and contributors are relatively active and can help out with tutorials.



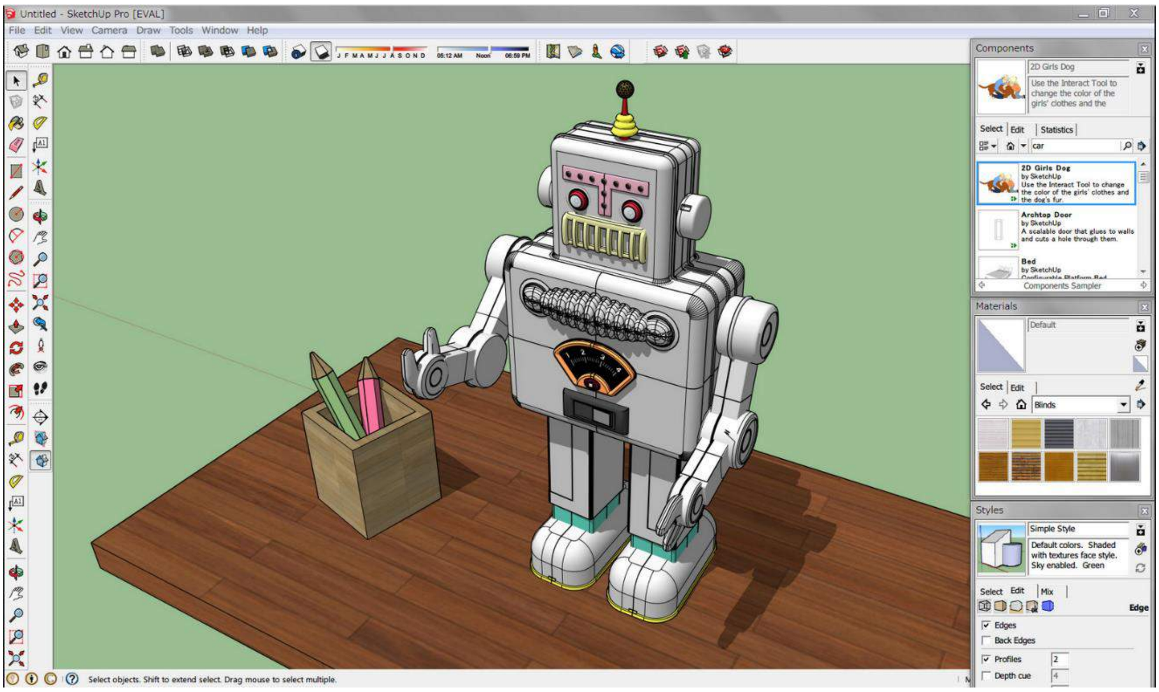
Sketchup

Sketchup was initially developed by @Last Software and then bought by Google. It then became a free downloadable software program, which has reduced functions than the professional package. It has proved popular with schools, architects, planners and other communities. However at the moment it is not seen as being an engineering orientated package but it is able to produce designs, which are dimensioned and accurate. One of its great assets is its ease of use. Very simple tools are initially easy to learn and use. When more complex drawings are required the user can explore other functions, which allow this.

There is a large on-line community and the libraries are quite extensive. It is a very popular free download which means it has plenty of support, forums and U-Tube demonstrations / tutorials.

Plugins are available which extend its usability and are required for exporting STL files, obviously important for 3D Prints.

The main advantages of this software are intuitive, ease of use and it's extensive support network.



6.4 3D Software to Purchase

Cubify Invent €39

Cheap 3D software Cubify Invent is an easy-to-learn 3D modelling tool aimed at helping users to quickly create 3D printable files. The software which comes with free tutorials only runs on Windows though.

Geomagic Design €1799

Geomagic Design is a comprehensive and robust mechanical CAD design tool. Used by engineers, students and hobbyists and Product Designers. Geomagic Design is available in three versions: Personal, Professional and Expert, each meeting the needs and budgets of each user.

Autodesk Inventor €6500

Inventor 3D CAD software is a complex engineering 3D Package. The dashboard or front end of Inventor is nice clean and simple it offers easy-to-use tools for 3D mechanical design, documentation, and product simulation.

Rhino €995

Rhino is a stand-alone, commercial 3D modelling software commonly used for industrial design, architecture, marine design, jewellery design, CAD / CAM and rapid prototyping. Rhino's strengths are its wide ranging ability, simple learning-curve, relatively low cost, and its ability to import and export over 30 file formats, which allows it to act as a 'converter' tool between different design packages.

Solid Works €3500

SolidWorks is a 3D mechanical CAD program widely used amongst engineers and designers. It is one of the market leaders in professional use. The software features powerful simulation, motion, and design validation tools, advanced wire and pipe routing functionality, reverse engineering capabilities, and more. It is a very accomplished 3D Tool but is expensive.

6.5 3D Freeform & Sculpting Software

Essentially these do the same thing. Blend and curve surfaces in multi-directions. Freeform surfacing is mathematically based where as Sculpting tools are mesh based, this means that the surface is made up from polygons, for example hexagons. When it is manipulated the hexagons move in relation to one another.

Of all the briefly outlined sculpting packages and freeforming tools below Blender is probably of most use to schools and colleges.

Freeforming tools

123D Creature	Free	Used on I pads mainly for animation.
3ds Max	€3200	for games, films & animation
Blender	Free	Covers engineering type requirements.
Cinema 4D	€3500	Artist based software
Maya	€3500	Animation based

Sculpting Tools

123D Sculpt	Freemium	Used on I Pads, drag, pinch mould objects
Cubify Sculpt	€100	STL file based virtual clay software.
Leopoly	Freemium	Web-based pay to export as STL
Sculptris	Free	Virtual clay modelling software.
SculptGL	Free	Browser base STL file exportable

Chapter 7. Identification of Libraries

7.1 Overview

STL files are the important link with most, if not all, 3DPrinters and 3D manipulation software. In many ways manufacturers have realised that having files types which are standard and open source increases their chance of selling the 3D Printer hardware as users will have a far greater range of models or libraries to choose from. Online communities now have a very important role to play as they are effectively supporting the customer and manufacturer, providing help, advice and sometimes quite specialist support.

Much of the 3D design software has specialist libraries and online support and communities. The issues, which will face an educational establishment, will mainly centre around cost and accessibility. If pupils are to be motivated and allowed to extend and take ownership of their learning giving them the chance to explore libraries and online communities are just other ways of motivating them.

One of the important criteria which needs to be considered is importing STL files into the 3D software so users can modify existing files then print them out. Some software allows this, some doesn't and some needs a lot of altering and other software allowing it to be manipulated.

There are a number of dedicate 3D Printing search engines that can be used to access a number of sites to look for an even greater variety of models.

7.2 Some Of The More Known Libraries

Below are some of the more known libraries. The main issues associated with these are the file types, quality and how to access the models you want.

123D Design & Tinker CAD

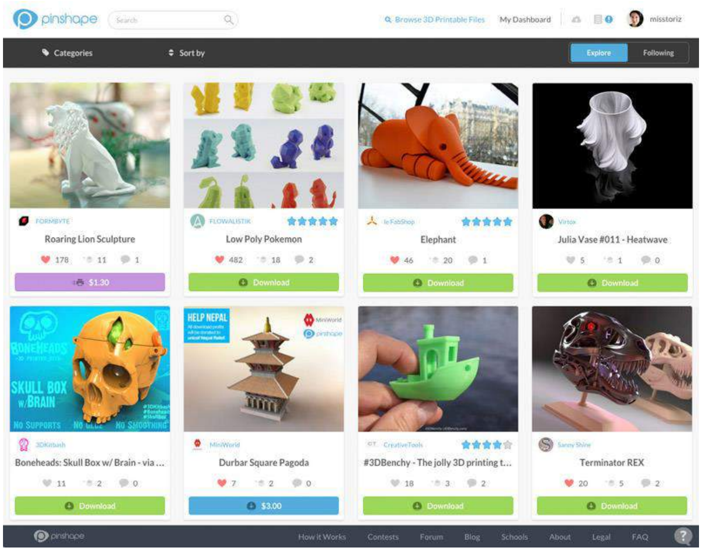
These have their own library of specific components to down load and print. However as yet STL files cannot be downloaded to the software for modification or manipulation for user customisation.

3D Tin

This piece of 3D software has a forum and is involved with education. It is Australian and New Zealand based and uses models from a number of libraries. It is able to down load and stl files from Thingiverse, GrabCAD, Trimble's Sketchup 3D Warehouse; However if using this preparing 3D Warehouse files for 3D printing needs to be read as sometimes STL files may need "cleaning up". 3D Content Library can also be used but will need registration.

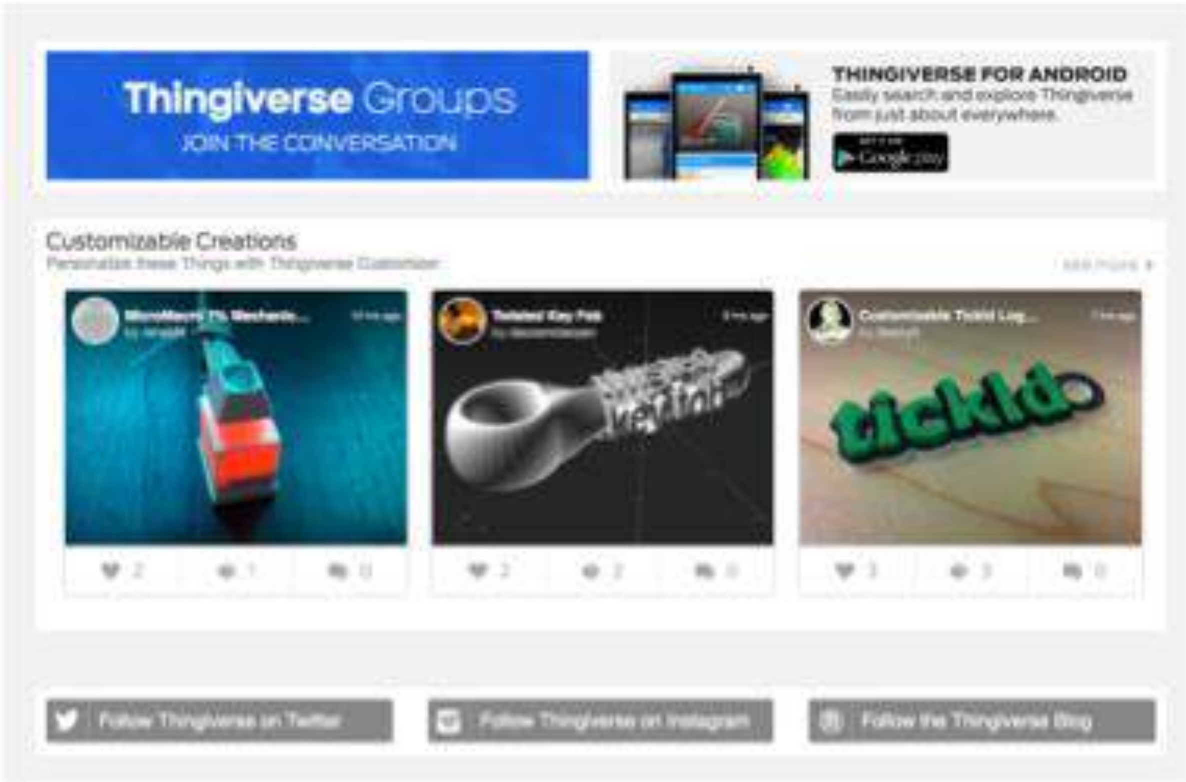
Pinshape

Pinshape is a recent 3D Printing community & marketplace for designers and makers. This site is growing quickly, and making it easy to find and successfully print quality 3D designs. They are hardware agnostic and have community features like 'prints', that allow users to upload print settings & photos of models to help you print better models.



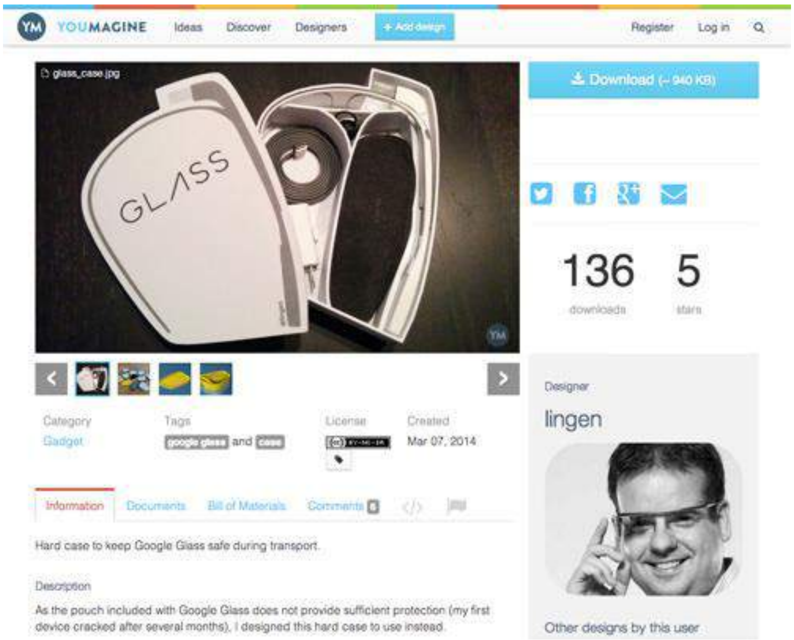
Thingiverse

Thingiverse is a website operated by MakerBot Industries, the manufacturers of the Replicator range of 3D Printers. The website allows users to **upload and share 3D model files to be used on 3D printers.** The Thingiverse site has very large following and massive range of models. These models are very varied, from toys to engineering products. This could be an important site for educational users looking for models or inspiration.



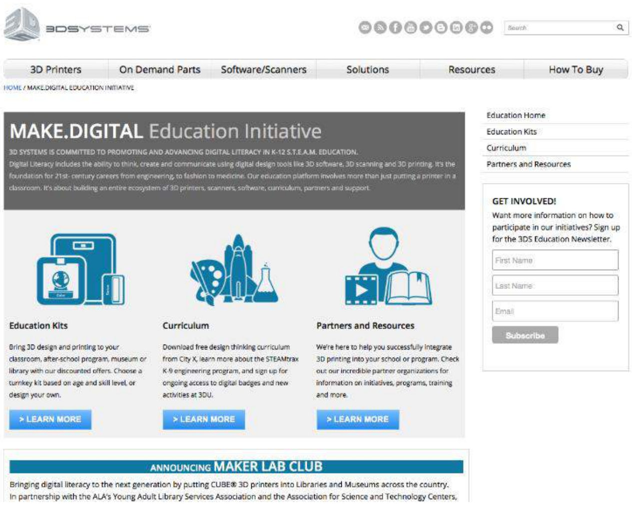
YouMagine

This site is run by Ultimaker. It started in 2013 and is becoming quite popular. The site has a variety of functions and has a strong element for education. YouMagine has links to a British website Create which has essentially set up to support education. Although the site supports Ultimaker the main aim is to create a community with a strong educational / learning background.



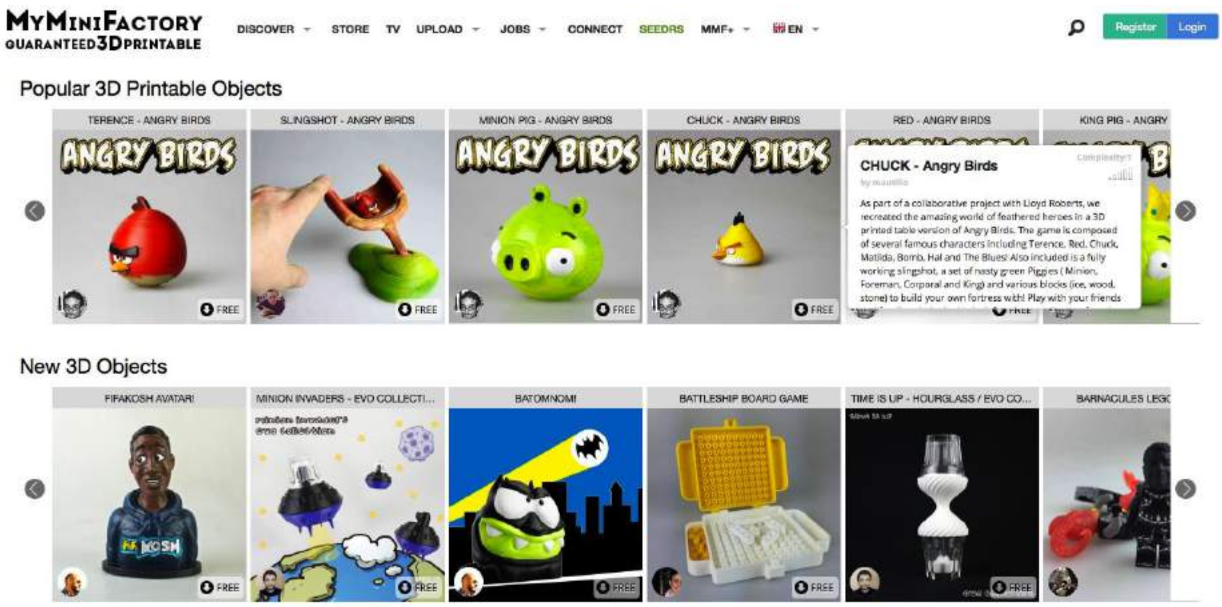
Cubify

Cubify is a site set up primarily to support the sale of Cube 3Printers. It offers the ability to have work designed and printed for users. It has an education section to the website which would be useful, however, at present the project still seems to be developing and needs to gain a greater user following. The library of models it has also seems limited.



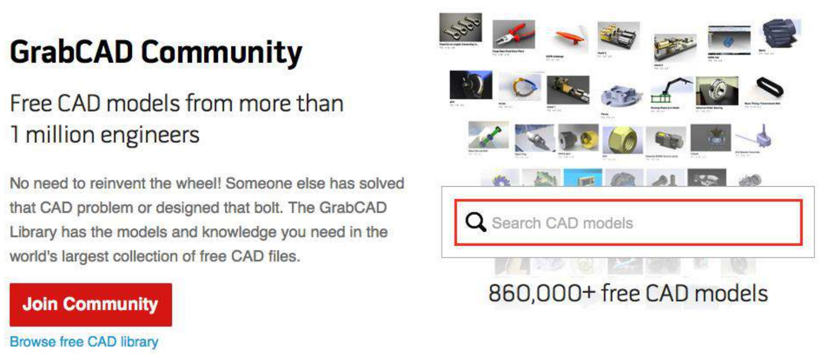
My Mini Factory

My Mini Factory is the 3D model library managed by iMakr, like other manufacturer or suppliers websites it has an educational area for pupils and teachers to access. It also operates the largest 3D printing store in Central London and contains **3D models designed by professionals**



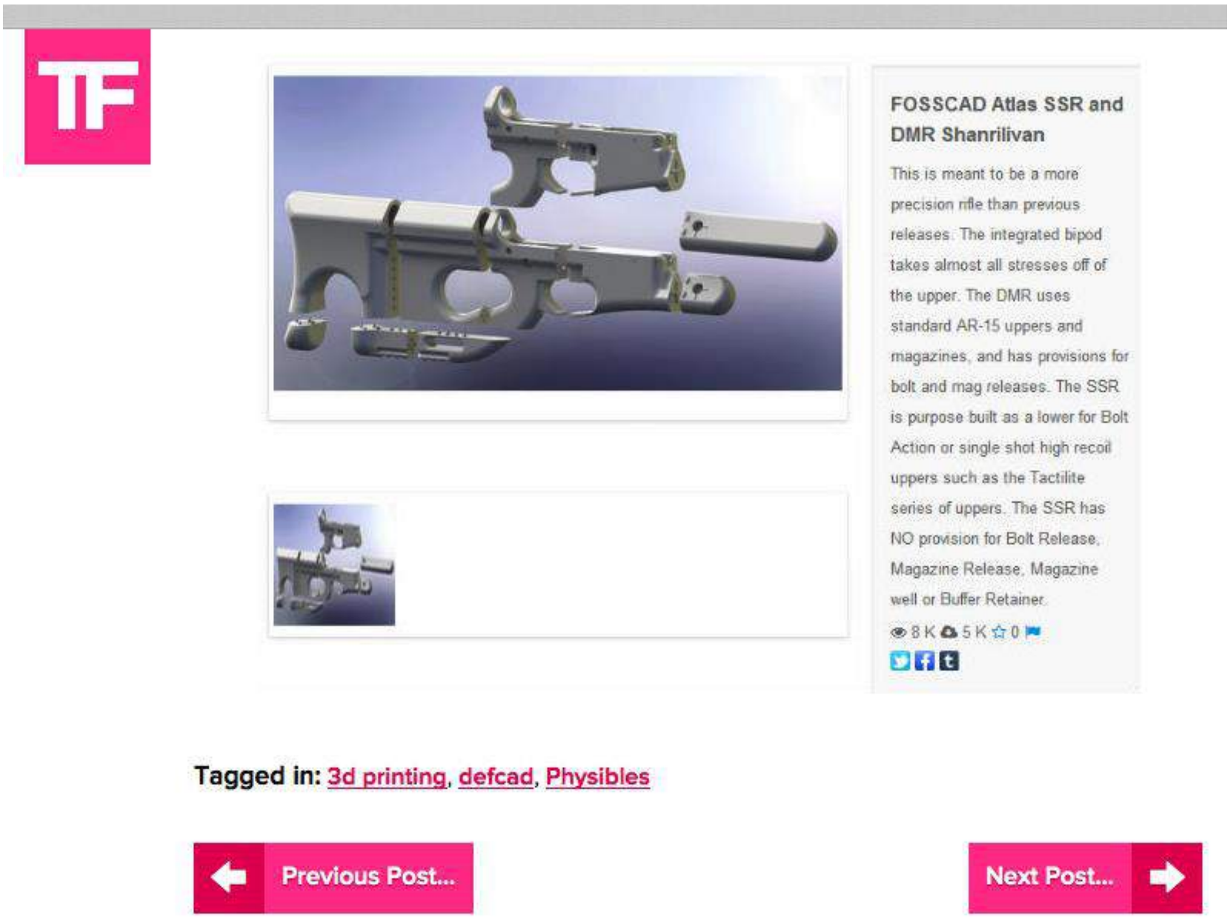
GrabCAD

This is mainly aimed at professional engineers and has a wide variety of models. However GrabCAD has an online application, which allows multiply engineers to work on one particular drawing, store and update it all on line. The whole GrabCAD application requires users to create a login and would perhaps be more use to education if aimed at developing or teaching engineering or science based courses.



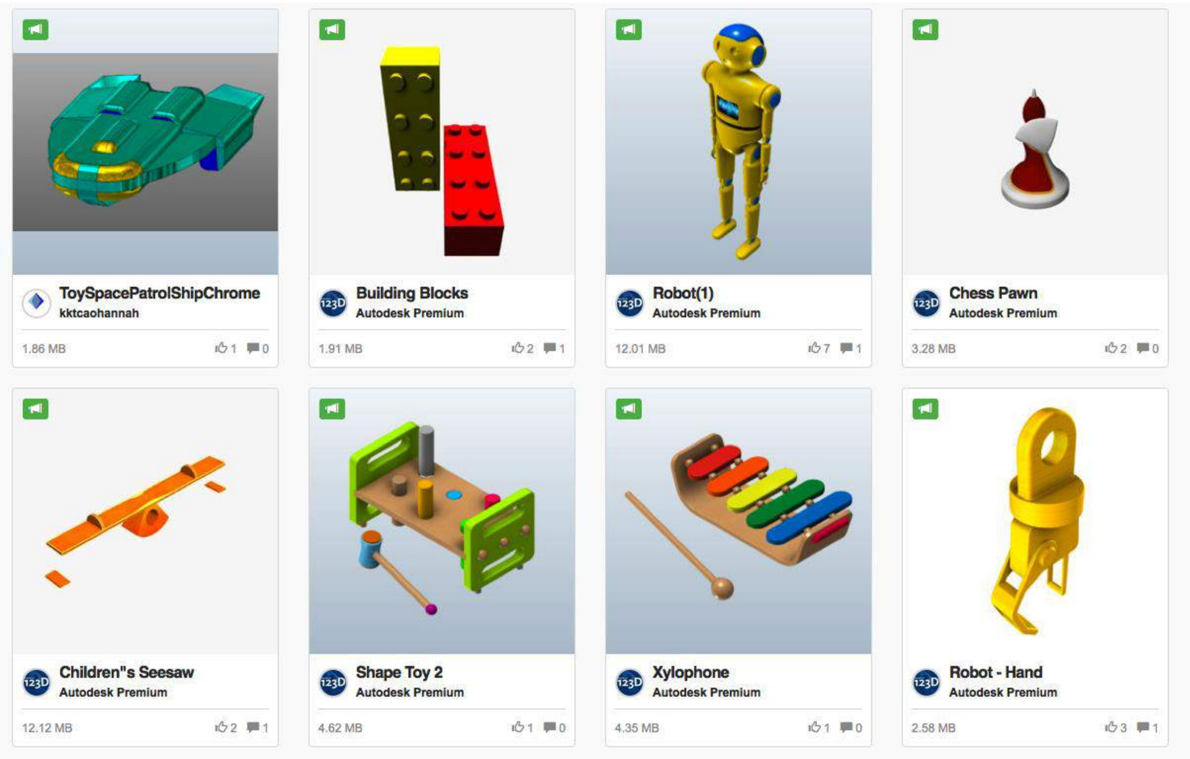
DEFCAD

This is a 3D model search engine. It was developed from users who designed the first 3D printable gun. It's open sourced and allows users the chance make file connections without downloading links, presumably in an attempt to make users who download guns unable to be tracked down. In some ways this site can be seen as being a little contentious and maybe even illegal. For educational users this may be a site to avoid. Especially as one of the most popular download is a gun.



Autodesk 123D

As mentioned in the 3D Software part of the report Autodeas123D is a range of software applications which allow a range of alterations downloads and uploading to take place. It has a range of models for downloading but not as extensive as Thingiverse.



Instructables

This is more than just a3D Printing Library. It does contain printable objects but has a wide variety of DIY projects which range from Burger recipes to Burt and Ernie hats.

3DVIA

Host, manage and market your digital assets anywhere, anytime in 3D. This is the aim of 3DVIA. This site allows you to. "Upload 3D Content in over 30 formats, including the most popular CAD and DCC file types. "Integrate digital product files into engaging, mobile-ready web apps for Apple iPad™ platform." Create custom collections of your digital assets. Then invite others to view and share these files. Choose from a variety of settings to ensure that only those who have permission can view your files, groups and apps. (Taken from 3DVIA website.)

Cubehero

Community based store of 3D components. This also allows users to communicate on projects and related issues. You also have the ability to make requests so designers or other users can design components which you may need or can't design yourself.

Bld3r

This is similar to a search engine in that it links a number of 3D Print libraries together. Searching for model downloads allows you examine models from Thingyverse, Instructables and other sites, as well as the library on its own site.

Sproutform

Sproutform is a community for sharing 3D printable designs. Sproutform is trying to create a community crowd sourced site with designs which are more usable and appropriate. They are not interested in toy, trinkets etc. They want designs to be meaningful and useful. These are the advantages which it promotes: Community moderated designs enable you to find the best stuff to print: Sproutform learns what you like and shows more of it: sharing designs within the community; Sproutform would never claim to own or share your designs without acknowledgement.

Shapeways

Shapeways is mainly an online shop for 3D printed goods. You can contact designers who will be able to design and manufacture a product which you may want. As this is a commercial site it seems to be inappropriate for educational use.

Cults

A French initiated website which is a 3D Print library. It features designers who you can follow. In effect this is another 3D Printing library to rival other 3D Printing libraries.

RascomRas

RascomRas is a Spanish website that **allows users to upload and share 3D model files.**

Repables

Repables an upload and download site.

ShapeDo

This is another community share, upload and download site.

Fabribles

Fabribles has a number of replacement parts for RepRap 3DR Delta printers.

(Information taken from www.hongkiat)

Chapter 8. Creating Teachers Team and Experimentation Projects

8.1 The Teachers Team

The Teachers group conducting activities of 3D printing on STEM subject should include at least 1 teachers from each STEM subject in the aim to work with an interdisciplinary approach on teaching subejcts with innovative technical approach.

Teachers should undergo training in order to get acquaitant with all the amount of specifications and should be first of all involved in group meetings where to know more about the printers. Also teacher of IT and technical drawing should be part of the interdisciplanry group of teachers. All of them togther will be able to to support each other and carry out successful didactic innovation.

Teachres will have to prepare long before the practical use of printer within school by aanlysing together all sort of interdisciplanrity among STEM subject in order to to build up the best experimentations in the sake of pupils to learn practical competences and acquire deep understanding of interrlation in real life of theoretical and abstract STEM concepts and formulas.

3D printing is becoming not just more and more commonplace but also vital in some areas of modern life. It is opening up new opportunities all the time and replacing some traditional manufacturing processes but also allowing designers to think in many new and different ways.

It would be wrong for schools and any educational establishment to ignore the application and use of this technology and not to use it to support and enthuse their pupils.

However, we are not advocating replacing tradition ways of teaching nor solely focusing on using 3D Printing technology wherever possible. There needs to be a balance between these two methods of teaching. Sometimes 3D printing may prove to be too time consuming or difficult to implement in teaching, at other times it may provide a real insight into the world of work or application of scientific principles.

Projects need to be carefully considered. STEM teams will be needed to select appropriate projects and how to teach and incorporate 3D Printing into these. Teachers have little time to develop projects and test them. This is why a European wide project such as this, bringing together a variety of teachers with differing backgrounds can be so profitable.

Focusing on existing examination topics may well be the way forward for a host of reasons. Keeping projects simple, tightly focused and short should be the main criteria by which projects are selected. This will give maximum impact with little time wasted if the project does not go to plan. It could also keep students keen.

However 3D Printing is used in schools, teachers must give it ago before deciding whether this technology is supportive or not.

The initial Delphi questionnaire survey carried out within the PRINT STEM project suggested that some sort of compromised solution as to how the experiments needed to be run and what sort of methodology should be used for the implementation of the experiments. A mixed solution to this problem would be best. One of the projects that has already been tested and was suggested by other teachers was initially started by printing out an existing project. Effectively by reverse engineering it is possible to arrive at a method for producing an existing project. This in itself, reverse engineering, is actually a valid way of producing an experimentation or project. This existing project could then be modified or parts or components added to improve the design.

There are a wide variety of projects, webpages and forums that provide existing designs. These cannot be ignored as they provide a means of motivating pupils and developing the teacher's own projects. For speed and ease of use it is possible to use an existing project and get pupils to modify this as part of the project.

Yet another way may be to allow pupils to test existing projects. Using scientific explanations provided by the teacher, pupils could then go away and modify the existing product, hopefully to improve upon its performance. This can then be linked in with testing an existing product making these modifications using scientific principles and then testing the new project. These improvements would then required performance tests, measuring outputs, calculating forces, motion, electricity etc. This is where demonstrating the application of scientific and mathematical principles could be made interesting and relevant. This process of testing, measuring, interpreting data, predicting, re-designing, manufacturing and then testing is typical of what may be done in industry.

From experiences and the suggestions from other educational institutions keeping projects short and simple is very important during the initial experimentations. Ensuring that teachers have control of the pedagogy is really the only way to ensure success. Later on in further experimentations the teachers, once they have a little more appreciation of how projects are progressing, can they then start to release control of the projects.

8.1 Downloadable Designs or Teacher Designed Projects

Teacher Designed Projects. By this we mean an overall project and the creation of a scheme of work. As 3-D printing is a new phenomena within teaching and has only been introduced recently there are few educationally designed projects that teachers can use. This is where the Erasmus project could be an important European wide project. The creation of teacher-designed projects, which are able to be "off the shelf" projects, is an ideal situation. Schemes of Work, detailing objects keys skills and lesson outlines could be very useful. This could then be backed up with specialist teacher comments, calculations and the theory behind scientific principles used in the project. I have included a typical example of the layout called a Scheme of Work.

Inevitably a mixture of both teacher designed projects and bought in projects will be used. I have already spoken about reverse engineering, which can be very useful but more importantly a quick and easy process. It will however be an excellent way of learning how to improve the 3D drawing package which is being used.

Teachers must focus on the aims of the Erasmus project and what the 3D Printer is being used for, which is to enhance and engage pupils within the STEM subjects. If teachers from a Design background are to lead on these printer projects we run the risk of the project being one of designing products; which is obviously important and a key part of the project but it must not be allowed to over shadow the STEM content which we are aiming to deliver through teaching and experimentation.

Developing projects, which are heavily biased towards designing need to be carefully considered as it, will all to easily become too broad and wide ranging. Quick, easy to deliver and sharply focused projects is initially the way to go, this is where buying in existing 3D print files would beneficial. This is why the first experimentation, to ensure it runs smoothly, should use an existing print file.

Scheme of Work	**4 sessions of 1 Hour Lessons.**

Lesson	**Objective**	**Methods**	**Content**	**Health & Safety**	**Differentiation**	**Resources**	**Notes**
1	Intro to LED Light Project & Sketch-Up	Discuss Examples Power Pt Presentation Show Printer	Overview of Project. Samples. Sketch-up tasks	N/A	None	Printer; LED light samples; Sketch-up tasks / tutorials.	
2	Complete LED light design task.	Class complete task.	Using CAD to produce design	N/A	Some components may already be made.	Whiteboard & Computers	
3	Print-out Scientific task	Practical work and chalk & talk	Start printing Start on science of electric flow, voltage, etc	Use of 3D Printer in a workshop.	Close supervision. Example calculations.	Whiteboard & Computers	
4	How do batteries work? e.m.f	Discussion Demo. Work with class	Electrolysis	N/A	Phrase sheet to fill in answers.	Whiteboard & Computers	

8.3 Mapping Out of STEM Projects

On the page below a matrix has been plotted out to demonstrate how projects could be used or designed to satisfy differing aspects of the programme requirements. A similar matrix could be drawn up for the scientific aspect of the programme.

Problems may occur if examination courses are not being taught due to the experimentations. This is why it will be important to ensure that the experimentations closely follow exam syllabuses.

Simple grids like the one below can be used to draw up possible over laps with other areas. The grids can be made as simple or detailed as needed.

Maths		**Criticality**				**Priorities**			**Feasibility**				
Project		**Basic Maths Skills**	**Reasoning & Argument**	**Devising Strategies to**		**Geometric Relationships 2D**	**Measurments**		**Measurements**	**Geometric Relationships**	**Coordinates**	**Percentages, Ratios &**	**Numbers & Units**
LED Light													
Rocket													
Water Turbine													
Wind Turbine													
Robot Arm													

8.4 Possibility of Use

Intellectual output 1 examined and collected the typical sort of Mathmatical, physics and engineering concepts which teachers and lecturers think are important and relevant to teach. These include Literacy of both language, maths and science.

Essentially all the teachers who were contacted and submitted their opinions covered a wide range of topics within the expected content for the STEM subjects. Each teacher and subject prioritised different aspects or concepts within their own personal subject and experiences and indeed these experiences will differ within Europe itself.

One of the key challenges of the project will be to fit these 3D printing projects within the existing schemes of work and exam work. In parts of Europe teachers are under intense pressure to deliver exam results both from pupils; parents and governments. Deciding within the project what we think is important and what we need to teach is a luxury.

The project needs to gain confidence and approval from all staff within the educational institution and also deliver the results, which are expected and needed. To these ends projects need to be designed to support, reinforce or initially introduce pupils to concepts which are already on the school curriculum or perhaps more importantly on exam syllabus.

Only by teaching or ensuring that projects which are taught contain this exam content will staff be brought “on board” to support the project and more importantly use 3D Printing within there subject and incorporate it into future schemes of work.

Due to these important factors we need to consider approaching the problem of what exactly we need to teach from the aspect of; were can 3D printing most effectively be deployed to improve and enhance key STEM areas. In essence each teacher needs to examine the curriculum that they are teaching and see how these aspects can be taught.

By starting to look at what each individual institution needs to teach we can then try to select projects, which will enable this subject content to be taught. However this could cause other problems by allowing us to select quite complex projects which will be quite unrealistic to teach within sensible time limits.

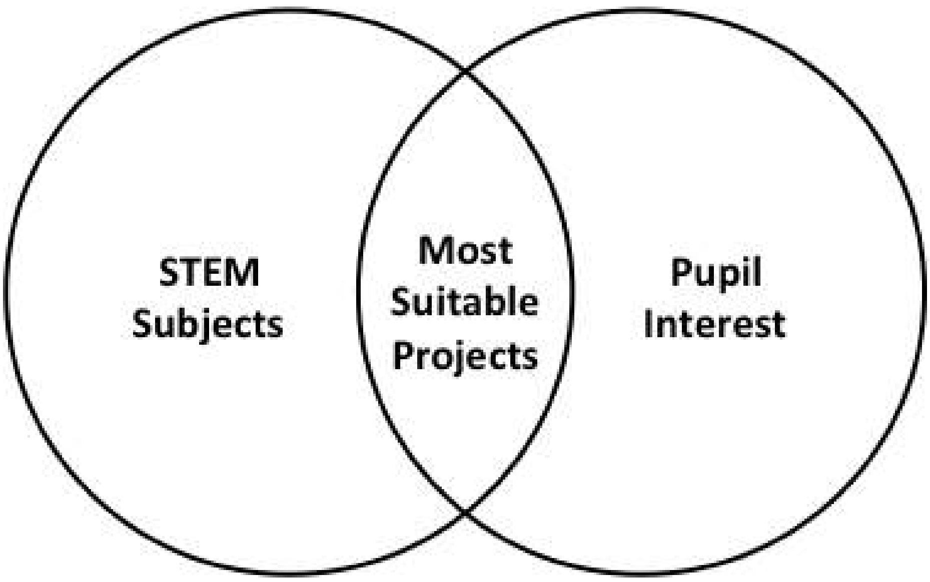
The most likely way that topics could be taught using the 3D Printer is by taking simple existing products, ie “bought in” models and then looking at what STEM concepts can be taught through the product.

For the first project this idea of looking at simple prints then seeing what concepts can be taught relating to the print would be initially a simple, quick and easy way to kick-start the project. I have shown some of the other key factors which need to be considered too in a Ven diagram below.

8.5 Key Factors for STEM Project Design

Pupil Interest

Pupils obviously need to be engaged with the project. 3D Printing will go part way to doing this but this still needs to be considered. Interesting projects relating to their experiences should be sought as much as possible. It would be worthwhile considering only very tentative STEM links to the 3D Print, if pupils were enthused by what they made. For example, a simple badge could be designed and manufactured by the pupil. The STEM part of the project could then focus on polymers and how polymers are manufactured.



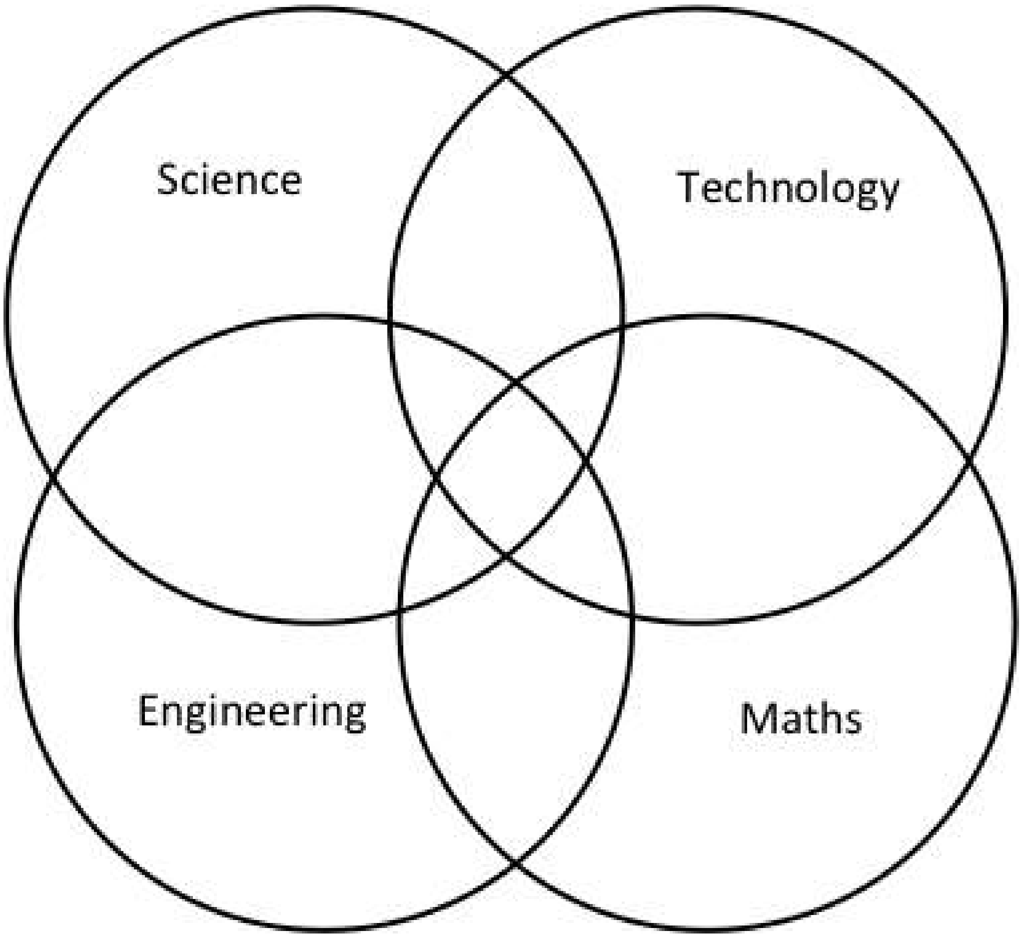
Whole School Support

Communicating what the project is about and what departments could or are doing with this technology would gain support whole school support and not suspicion. This could also lead to other ideas or inputs making the technology more widespread and understood. For example the ethics of printing, how it might be applied; ecological and environmental impact and the shift it might have on heavily and emerging industrialised countries are some of the ideas discussed in my school.

Interdepartmental Cooperation

Without this the whole project will be very difficult if not impossible to implement. 3D Printing could have a very positive influence on bringing different departments together to share and support learning around school. This could include the humanities subjects as well as the STEM subjects.

At the centre of the diagram we have projects which will link all departments together and more importantly cover concepts relevant to all STEM subjects. These are the type of project we should be aiming to teach.



Curriculum Relevance

Fitting in extra work or more modern ways of teaching will require change, something not particularly easy to introduce. By starting off with small simple projects or even one simple project that is easy to deliver teachers will gain confidence and will continue to use or develop further projects. Providing extension activities within projects will be required to enhance and "stretch" the more able students.

Exam Syllabus Relevance

This is perhaps the crucial area. Only by convincing STEM teachers; that this sort of technology and slightly different way to approach learning; will the technology be used. As I have outlined before; linking project work to an improvement in hard exam results; should convince teachers of the use and relevance of this type technology.

Time Constraints & Practicality

In many schools, STEM subjects often deal with quite difficult concepts and little time. Projects need to be effective with guaranteed outcomes to convince the educational establishments that 3D printing is a reliable way to teach and gain improved, sustainable results. Projects must be short and sweet. Pupils need to be supported as much as possible so that they have all the information they need. Clear expectations and outcomes must be specified as well as time limits. Projects of one to two hours should be aimed for. The advantage of this is that if projects don't work or the theory is a little too difficult then the project can be finished and another one introduced. Small, short and sharply focused projects would initially be the best structure to have. After which the results or projects can be evaluated, refined or extended.

In Britain the focus on results has meant that some subjects have very limited time to teach the examination material. These teachers will be wary of loosing valuable teaching time to 3D Printing projects. In other subjects such as Engineering or Design based subjects these projects could be selected to run alongside the work being done in Science and Maths. However this will be very much dependant on the type of institution that teachers work in.

Vocational Relevance and Practical Application

Schools should consider vocational relevance by strengthening links to there industrial partners and further educational establishments. For pupils who withdraw for STEM subjects creating links to industry and seeing the application of what they are actually learning in class is a powerful motivator for learning and gaining qualifications.

Success

Will 3D printing make an improvement to STEM teaching? 3D Printing is already a success in industry, medicine, space travel and many other applications. Education must lead and reflect issues, which effect everyday citizens and prepare future generations for the advances in technology, that will occur in their lifetime. 3D Printing is a success; education now needs to incorporate this sort of technology into it's teaching.

Designing 3D Printing Projects For STEM Subjects

There are two possible approaches in the use of a 3D printer in schools: we will call the "SIMPLE approach" and "ADVANCED approach". We will refer to them using these names throughout all this document. We would like to point out that the choice of one method does not exclude the use of the other one at a later time; in both of them the role of the pupil is fundamental: pupils are not mere observers and are prompted to work, suggest solutions and ask questions to attain the best results. In both of them the teachers following the pupils during the process must have a good knowledge of the softwares they are going to use for modeling objects, scaling them and interacting with the printer.

SIMPLE APPROACH is about the printing of an already modeled object. In this approach 3D modeling is not considered: simply speaking objects already exist and the pupil's attention is not centered on the way they are created, he is prompted to discover the capabilities, the potential and the results that can be attained with a 3D printer. For this reason, even if it may seem in contrast with what we said before and with the concept of "simpleness", during this experimentation teachers could propose very complex objects. We suggest that the first objects shown and printed have structural characteristics that only a 3D printer can produce them (as the Möbius strip or fractals like the Sierpinsky Tetrahedron and the Menger sponge). In this way, pupils are satisfied by quickly seeing how a very complex result can be attained "simply" and, at the same time, they are urged to familiarize with the printing options (size, filling, color, material…) and with the first problems that one must solve before printing (time, just to point out the most important). As an additional task, the pupil can be shown the operations that have to be done AFTER the printing has ended, like removing the additional material used as structural support or filing away little imperfections with a rasp. After this initial phase, the pupil is asked to print himself very simple objects (3D polygons like cylinders, cones, pyramids) mastering the main settings of a slicing 3D software like CURA.

ADVANCED APPROACH is basically an integration of the SIMPLE APPROACH with the modeling of the object to be printed by the pupil himself. With this approach the pupils face, first of all, the difficulty of using a 3D modeling software. Given our personal experience as teachers, this approach should not be used at first: this to avoid a too steep learning curve, a very long procedure before seeing the actual object printed that surely could bring the pupil to a loss of attention and motivation. Should a school choose to follow this path immediately, we think that additional effort should be put in the choice of the teachers pool (it must include a very skilled 3D expert) and a more accurate planning of the teaching method since the increased number of problems that could arise endangering the pupil's path to the final result and decreasing his motivation.

Moreover, time is a critical variable during this experimentation because the long realization time could compromise the pupil's attention, leaving him in the middle of the process without the interest needed to complete the task. Teachers must keep awake the pupil's attention in two ways:

1. Transforming him from a simple observer to an actual "junior technician" that is actively involved in every step of the experimentation.

2. Dividing the experimentation in many small steps in a way that each one of them produces a little, tangible result.

8.6 Linear Approach

Basically this is either, examine a STEM subject or concept that requires teaching then find a 3D Print which can explain or demonstrate the principles of this. Reversing this approach is to find a print and see what STEM concepts the 3D Print can be used to explain.

Advantages:

1) This approach is quick and easy. There are a wide variety of prints available for teachers to choose from. Similarly there will be a wide variety of STEM concepts that a teacher will need to explain.

2) It has a sure output. This is effectively like bolting a 3D Print project to a STEM concept. Very straight forward.

3) Easily controlled by the teacher. This is what teachers want, nothing left to chance. Teachers are able to adapt aspects of the project if things start going wrong.

4) This process should guarantee success. The theory aspect of the project can still be covered no matter what happens to the print.

Disadvantages:

1) Disjointed. If the print and the concept are not carefully chosen it will appear as two separate projects with no interrelationship. Could be odd.

2) Limited motivation. With guaranteed outcomes or obvious outcomes it could lack the excitement required to inspire students.

Project Idea 1

Pupils follow a design booklet leading them to design and manufacture a light. The STEM teacher then explains how batteries work, converting chemical energy to electrical energy. Current and voltage calculations could be made using Ohms Law and the flow of electricity could be linked to energy consumption, carbon footprint and then the ethics of developed countries using a disproportionate amount of fossil fuels.

8.7 CAF Approach

CAF or Consider All Factors. This may require STEM teacher teams to list all concepts they need to teach and then looking at possible overlap. A 3D print or project could be found to model these concepts. The input of the Design Teacher may be to alter aspects of the print to make sure that the project works. These changes could be to simplify the design, ensure quick and successful printing or suggest prints that can be used by the STEM teachers.

Advantages:

1) More Coherent. Projects could, potentially, be developed which link a number of STEM concepts together. This approach would support each STEM subject reinforcing the concept or allowing it to be explored even further. If the project includes a mathematical component the application and practical use of maths would be demonstrated too.

2) Greater Theoretic Coverage. Having a number of different disciplines involved would see a greater range of curriculum concepts covered.

3) Increased Chance of Success. When everybody works together and has a stake in the project the project is more likely to succeed.

4) Support. Staff will be able to help and support one another if lessons don't quite go according to plan.

Disadvantages:

1) Nobody accepts responsibility. There is a risk that a STEM group will not accept responsibility or that a person is not selected to oversee the groups activities.

2) Complex. With all STEM teachers wanting to emphasise their subject the project could become a little disjointed and confuse pupils.

3) Disinterest. Teachers may prefer to continue teaching in the way they have traditionally done and have little enthusiasm to deliver the project.

4) Time Dependant. Teachers will find it difficult to commit to extra projects and curriculum changes.

This example taken from AQA GCSE Specifications for Science, Engineering and Maths shows general headings for topics which need to be taught and which could potentially be examined for GCSE's. Highlighted are areas where a project could be designed to satisfy all 3 subjects.

GCSE Coursework Topic

Science	Technology & Engineering	Maths
Infrared Radiation	Designing and Communicating	Statistics and Number
Kinetic Theory	Understanding Engineered Products	Number and Algebra
Energy Transfer	Manufacturing an Engineered Product	Geometry and Algebra
Heating and Insulating	Application of New Technologies	
Energy Transfers and Efficiencies	Application of Technologies	
The Usefulness of Electrical appliances	Manufacturing Systems	
Transferring Electrical Energies		
Methods to Generate Electricity		
Generating Electricity		
The National Grid		
Use of Waves For Communication		
Properties of Waves		

Taken from AQA Maths Specification. Pupils need to be able to:

Data Collect:

- Distinguish different types of data including qualitative, discrete and continuous. Use grouped and ungrouped data.
- Identify possible sources of bias
- Design an experiment or survey and understand what primary and secondary data is.
- Design data-collection sheets distinguishing between different types of data. Including observation, controlled experiment, data logging questionnaires and surveys.

- Extract data from printed tables and lists.

Taken from AQA Science Specification, Physics. Pupils need to know:

1) Electricity is distributed from power stations to consumers along the National Grid.

2) For a given power, increasing the voltage reduces the current required and this reduces the energy losses in the cables.

3) The uses of step-up and step-down transformers in the National Grid.

4) Investigating the effect of changing different variables on the output of solar cells, eg distance from the light source, the use of different coloured filters and the area of the solar cells

5) Planning and carrying out an investigation into the effect of changing different variables on the output of model wind turbines, eg the number or pitch of the blades, the wind velocity

6) Demonstrating a model water turbine linked to a generator

7) Modelling the National Grid

Taken from AQA Engineering Specification. Pupils should be able to:

1) Manufacture an Engineering Product

Produce production plans. Manufacture to a production plan, which is related to the production of a “one–off” or limited batch production of an engineering product.

2) Impact of Modern Technologies

Describe the impact of modern technologies; when engineering a product; on engineered products; engineering industries; the stages of engineering a product. Describe advantages and disadvantages that the use of modern technology has brought to society; including environmental issues and sustainability. Investigate a range of engineered products to determine the impact of modern technology on design and production methods.

Wind Turbine

From above it can be seen that by "stitching together" different GCSE Specifications it is possible to arrive at a project that all subjects can collaborate on. The project is actually stated in the Physics part of the Science Specification.

A Wind Turbine project could be envisaged as an excellent project to teach the above highlighted concepts to students. The project would require testing before being taught and carefully planned out to ensure what data would be collected and how. How successful the results would be. How reliable the data would be. The speed the printer could be expected to produce components and how quickly

8.8 Design Approach

This can be tackled from two ways. For example theoretical aspects are first discussed then pupils have to design and manufacture a product using the data or understanding that they have. Alternatively a product could be manufactured and then the student will be required to improve the design. However I would recommend that this sort of project be used for high achievers or more mature pupils, even when teachers need to learn from their pupils.

Advantages:

1) This sort of project could become quite open ended and has the potential to explore a wide variety of scientific theories requiring higher level thinking.

2) Benefit pupils who really enjoy the project or subject.

3) Is initially quite engaging if the manufacturing hands on part is started first.

4) More like a real life scenario. Things can go wrong and predictions are inaccurate.

5) Makes you think. When things go wrong it is more than likely that you start researching and exploring ideas for yourself.

Disadvantages:

1) This could become a nightmare as the project could become quite involved and require lots of time and energy.

2) Designing and experimentation could be time consuming and fraught with problems.

3) The results may be difficult to interpret and show little of the effort that has been put in.

4) Difficult to manage as the outcomes are not able to be predictable.

Water Turbine

This project is courtesy of Dr Dave Jermy of Settlebeck. Dave manufactured a water turbine using the 3D Printer. The impeller was modified from an existing design. He had involved a maths teacher who had worked on the mathmatical side of the project to allow pupils to work out efficiencies, pressure work done etc. The project was to be based upon students developing their own turbines to see which one was the most efficient. This would be done by measuring the electrical energy from a simple dynamo. However when tested the project failed to produce any measurable outputs. The project is continuing to be developed but will require further development and testing.

8.8 Exam Specifications

Below are copies, with thanks to OCR, of exam specifications that should be available for most exam boards Europe wide. These should perhaps be the starting points for most projects.

It is possible to either design projects which use prior learning or which allow the introduction of the topics.

3

1 Data: their importance and limitations

Data are the starting point for scientific enquiry – and the means of testing scientific explanations. But data can never be trusted completely, and scientists need ways of evaluating how good their data are.

	Candidates should understand that:	A candidate who understands this can, for example:
1.1	• data are crucial to science. The search for explanations starts from data; and data are collected to test proposed explanations.	• use data rather than opinion if asked to justify an explanation • outline how a proposed scientific explanation has been (or might be) tested, referring appropriately to the role of data.
1.2	• we can never be sure that a measurement tells us the true value of the quantity being measured.	• suggest reasons why a given measurement may not be the true value of the quantity being measured.
1.3	• if we make several measurements of any quantity, these are likely to vary.	• suggest reasons why several measurements of the same quantity may give different values • when asked to evaluate data, make reference to its repeatability **and/or reproducibility.**
1.4	• the mean of several repeat measurements is a good estimate of the true value of the quantity being measured.	• calculate the mean of a set of repeated measurements • from a set of repeated measurements of a quantity, use the mean as the best estimate of the true value • explain why repeating measurements leads to a better estimate of the quantity.
1.5	• from a set of repeated measurements of a quantity, it is possible to estimate a range within which the true value probably lies.	• from a set of repeated measurements of a quantity, make a sensible suggestion about the range within which the true value probably lies **and explain this** • **when discussing the evidence that a quantity measured under two different conditions has (or has not) changed, make appropriate reference both to the difference in means and to the variation within each set of measurements.**
1.6	• if a measurement lies well outside the range within which the others in a set of repeats lie, or is off a graph line on which the others lie, this is a sign that it may be incorrect. If possible, it should be checked. If not, it should be used unless there is a specific reason to doubt its accuracy.	• identify any outliers in a set of data • treat an outlier as data unless there is a reason for doubting its accuracy • **discuss and defend the decision to discard or to retain an outlier.**

2

2.3 J567/03 and J567/04: *Mathematics Paper 3 (Higher)* and *Mathematics Paper 4 (Higher)*

The Higher tier subsumes the Foundation tier. The content of the Foundation tier Initial and Bronze stages will not be the focus of a question in Higher tier papers, but knowledge of them will be assumed.

2.3.1 Higher Initial Stage

Ref	*J517 ref*	Subject content - Candidates should be able to...	Notes and examples
		Number	
HIN1	*N6.4*	Multiply and divide simple fractions. Add and subtract mixed numbers	This does not include multiplication and division of mixed numbers.
HIN2	*N5.5*	Express one quantity as a fraction or percentage of another.	
HIN3	*N5.4*	Increase and decrease quantities by a percentage.	
HIN4	*N6.3*	Use the four operations on decimals without the use of a calculator.	
HIN5	*N6.2 N7.4*	Use ratio notation including reduction to its simplest form. Understand and use ratio and proportion, including dividing a quantity in a given ratio.	
HIN6	*N6.1 N6.5*	Use a calculator effectively and efficiently, entering a range of measures including 'time', interpreting the display and rounding off a final answer to a reasonable degree of accuracy. Perform calculations using the order of operations.	This includes using the memory and bracket keys, and function keys for squares and powers where appropriate.

Programming of Industry and Universities

Working with and making links with the world of work can provide a massive motivational factor for pupils who are either disaffected with education or don't see the relevance of STEM subjects. Going about making these connections with companies can be difficult on a number of levels.

1) 3D Printing may not be a manufacturing process which is done locally.

2) 3D Printing companies will have limited time to work with schools.

Universities and educational institutions may be able to provide greater support. Many Universities will have a remit to run courses and work with other institutions and businesses. These will be easier to approach and may offer a different type of support.

Professional Bodies

This is another area where contact could be made to see if support is available. Very often professional bodies like the Institute for Mechanical Engineers would be keen to become involved in school projects.

Competitions

Many STEM institutions, NGO's and Professional Bodies provide competitions for pupils to enter. If appropriate competitions are selected then 3D Printing could be used quite effectively.

Ultimately the teachers who will be working in school will need to review what local companies; Universities and Institutions are available locally and approach them to see what sort of support they are able to offer. Projects could be designed to include aspects of local manufacturer's products or processes then a simple visit to see these production or machining process would help students to see the application and relevance of what they are learning and working on.