Department for Education

3D printers in schools: uses in the curriculum

Enriching the teaching of STEM and design subjects

October 2013

Contents

The 3D printer project

In 2012-13, the Department for Education (DfE) funded a small 3D printer project to explore the potential for use of 3D printers to enrich teaching across STEM (science, technology, engineering and mathematics) and design subjects. In particular, schools were asked to explore innovative ways of using the technology to help teach more complex scientific and mathematical ideas. This report outlines what was learnt from the project.

The twenty-one schools which took part in the project were:

- Archbishop Holgate's School, York
- Arden Academy, Solihull
- Balcarras School, Cheltenham, Gloucestershire
- Chelmsford County High School for Girls, Essex
- Court Moor School, Fleet, Hampshire
- Cramlington Learning Village, Northumberland
- Dame Alice Owen's School, Potters Bar, Hertfordshire
- Glyn Technology School, Ewell, Surrey
- Gosforth Academy, Gosforth, Newcastle-Upon-Tyne
- Highworth Grammar School for Girls, Ashford, Kent
- King Edward VI School, Southampton
- Kirkby Stephen Grammar School, Cumbria
- Millais School, Horsham, West Sussex
- Roundwood Park School, Harpenden, Hertfordshire
- Settlebeck High School, Sedbergh, Cumbria
- Simon Langton Girls' Grammar School, Canterbury, Kent
- The Honywood Community Science School, Coggeshall, Essex
- The Windsor Boys' School, Windsor, Berkshire
- The King's School, Peterborough
- Waldegrave School for Girls, Twickenham, Middlesex
- Watford Grammar School for Boys, Hertfordshire

The role of 3D printers in education

3D printing is now an established industrial technology used for prototyping and manufacturing products and components across a range of industries. It already has applications in many areas of everyday life[1].

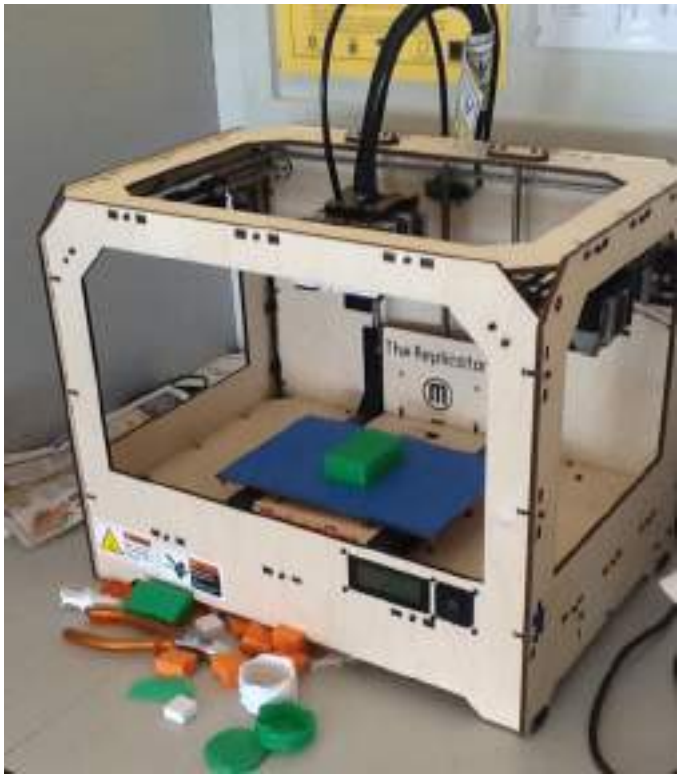


Figure 1 - 3D printers create solid objects by building up layers of material, guided by models created in computer aided design (CAD) software.

Equipping pupils to understand the application and potential of this new type of technology will be important to helping prepare them for a world in which similar technologies will be increasingly commonplace, particularly in STEM contexts.

3D printers are gaining popularity internationally across STEM education[2]. So far in the UK, the technology has been restricted largely to Design and Technology (DT) classrooms. There is considerable potential, however, for them to be used within a range of STEM subjects, for example to enable links to be made between mathematics, design and physics in a similar way to, for example, ‘sound’ enabling links between music, physics (wave properties), biology (hearing) and engineering (concert hall design).

[1] Visit the ITV website for more information

[2] See fab@school project and the Makerbot 3D project in New York public schools

The 3D printer project offered an opportunity for schools to explore innovative ways of teaching STEM subjects, stimulating pupil interest and enriching the curriculum.

Summary of learning from the 3D printer project

Twenty-one schools were provided with funding to purchase a 3D printer, consumables and support. The aim was to investigate the potential of 3D printing to support innovative and stimulating ways of teaching STEM and design subjects.

DT departments tended to form the ‘hub’ of learning through 3D technologies in most cases. 3D CAD software is already a feature in many DT curricula, so the introduction of a 3D printer did not require such a steep learning curve compared with other departments.

Science and mathematics departments explored the potential of 3D printing within their subject area. Many schools reported high levels of pupil motivation when engaged in these projects.

> “All the pupils who have been involved with the 3D printer so far have been inspired by its possibilities. The opportunity to realise a concept or idea quickly into a 3D product is an incredibly powerful teaching tool.”
>
> **David Jermy - Head of DT, Settlebeck School**

Schools reported that early work with the printer was often a trial and error process and limited to demonstrations and printing of small files such as 3D shapes. More effective and informed use to deliver the curriculum developed over a period of time. The project highlighted the need for good quality upfront training of teachers when introducing new technologies including teaching approaches, and sufficient non-contact time to plan the most effective use of the printers. Most schools relied on good technical support both from manufacturers and internal staff to start using the printer effectively.

Exploring teaching approaches

Where schools chose to engage in cross-curricular work they needed to overcome logistical challenges and difference in approach to teaching between subjects. The 3D printer is ideally suited to project work, where learning arises naturally as part of an investigation or construction project. DT teachers were more familiar with this type of teaching, where pupils spend time on individual project work. In DT it is common for pupils to be given a design brief and be expected to make personal choices about the design, which they then test out for themselves.

This contrasts with common teaching practice in science and mathematics. Here the focus is frequently on teaching concepts discretely and in depth. Where physics and maths teachers engaged with use of the printers successfully, they did so to promote thinking, reasoning and understanding of their subject.

The lead engagement of 3D printing in the pilot schools frequently came from DT staff, who organised the printing for mathematics and science teachers. This allowed teachers from other STEM areas to see how their subject could make use of the printer. Even within a single subject such as DT, the printer encourages cross-curricular thinking.

> "…. Moves pupils away from the practicality of design (i.e. how to use a saw) and allows more opportunity to see how maths and science are an integral part of the process.
>
> **David Jermy - Head of DT, Settlebeck School**

The projects

Computing

Honywood Community Science School designed an advanced 3D development learning tool, enabling pupils to create 3D objects using typed code in POV-Ray[3]. This enabled pupils to practice writing and debugging code and also supported studying algebra and understanding 3D/2D space.

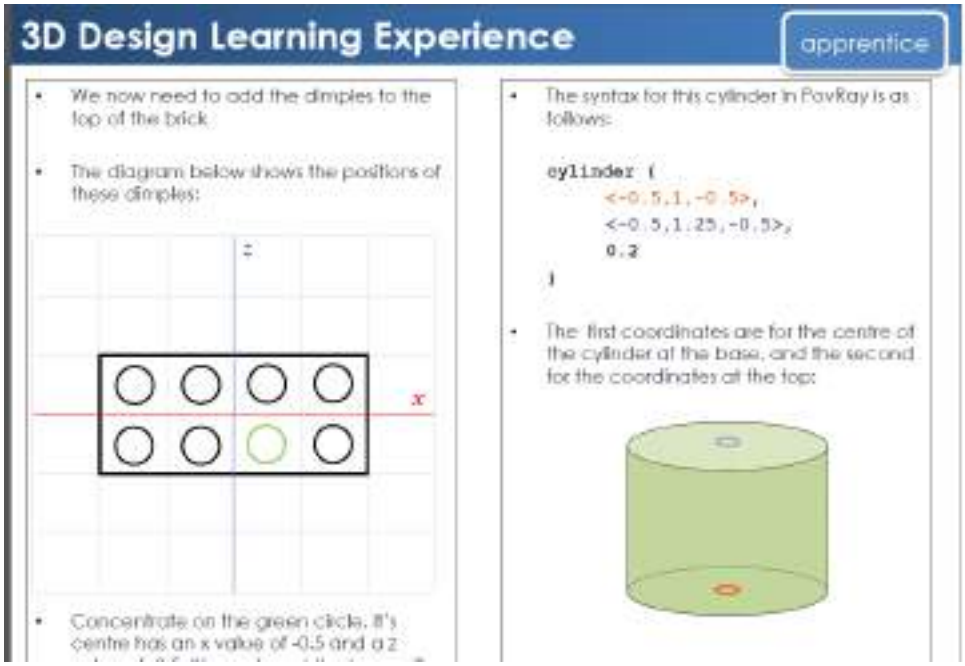


Figure 2 - Honywood's pupil instruction booklet for their collaborative Toy Project. Pupils designed, costed and marketed a plastic toy.

A prefect team at the school are now building a mechanical computer using downloaded components.

Balcarras School got their computing/ICT pupils designing their own 3D models on the program SpaceClaim, moving away from downloaded models. They used the ReplicatorG programme to convert .stl files from the CAD software into .s3g format for the printer. Pupils explored the ideas behind the code used in the conversion. During the next academic year the department plans to integrate the outcomes of this pilot into extracurricular lessons and run further curriculum trials. In this way they aim to use the 3D printer for more valid experiences rather than superficial, novelty approaches.

[3] www.povray.org

Design & technology and engineering

Figure 3 - DT departments made good use of the 3D printers, with many examples of GCSE and A level projects using the printer.

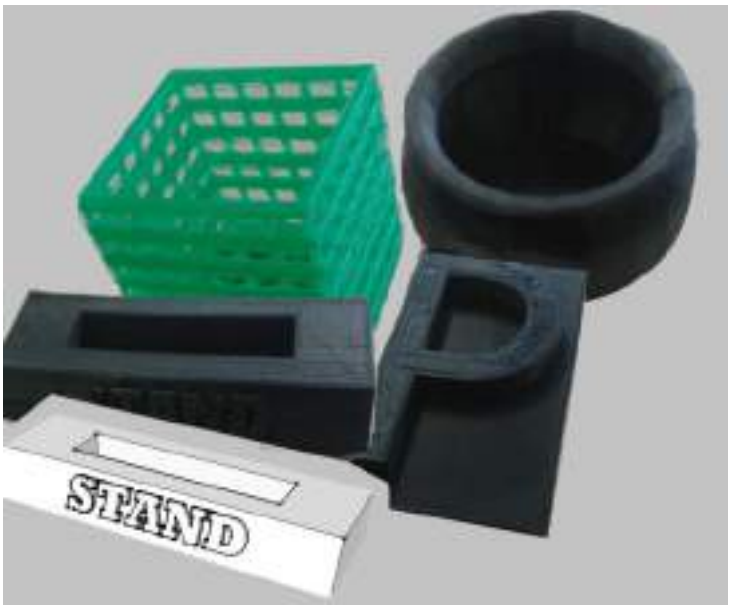


Figure 4 - Year 10 projects at Waldegrave School for Girls produced drawings and products ranging from letter stands, business card holders and phone stands for Father's day's gifts.

At **Chelmsford County High School for Girls**, pupils made brackets and injection moulded cases for GCSE Engineering projects, and vacuum formers and model bottles for GCSE Graphics.

Figure 5 - Following complex A-level projects which would not have been possible without a 3D printer, The Windsor Boys' School experimented with building complete objects and looking at linking component parts together to incorporate movement.

The **Windsor Boys' School** pupils also made a desk lamp in model format and were looking to create a life-size "to-scale" version. This version would then incorporate the underlying concept of all component parts joining together and working independently.

"Older pupils who were familiar with the design cycle (plan, design, make and evaluate) were able to exploit the use of the 3D printer to shorten the "make" phase as the printer was quicker at producing items. This meant it was possible to spend more time on "design" and "evaluate" to produce a better quality product."

S Griffin-Raphael – Head of DT, The Windsor Boys School

Science

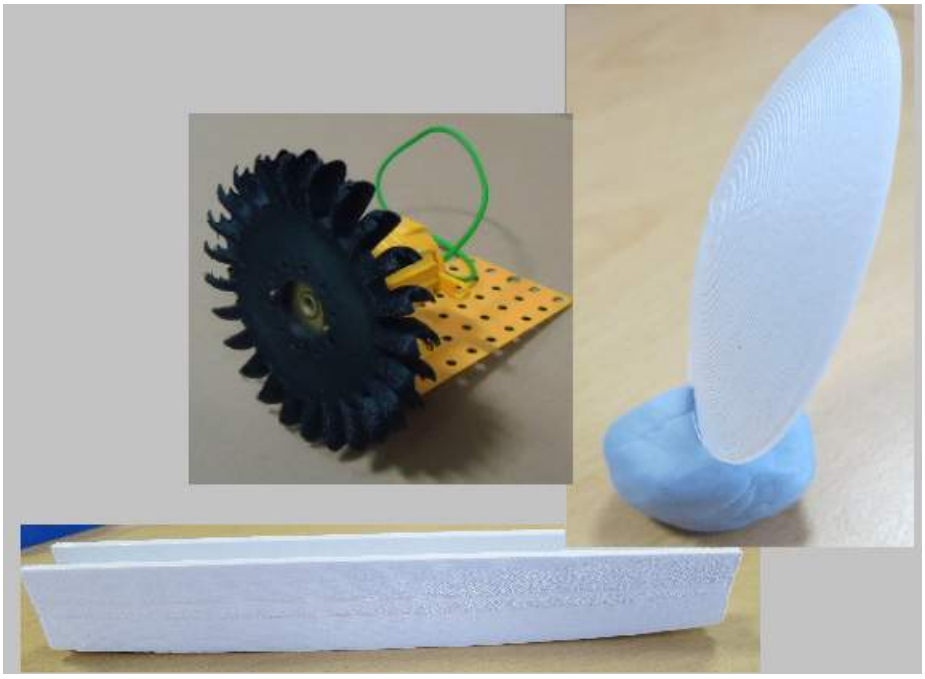


Figure 6 - The Kings School, Peterborough bridged expertise in the DT department and the demands of the physics curriculum. Pupils designed and printed objects for use in scientific experiments.

Some of the prints made by various students across the schools were developed from scratch rather than from a downloaded template. Products included a multi-coil replacement for the Westminster Motor Kits, 3D girders to use with strain gauges and a Pelton Wheel used as part of an energy turbine. Water-soluble plastics affect microwaves, so the effect of shape on lenses can be investigated with printed lenses. A microwave lens helped in the teaching of electromagnetic radiation lens design.

Science departments used the 3D printer as a context to discuss the properties of plastics, to build models for teaching science such as molecules, eye-balls, cells and sine waves, and to build components for working equipment such as rockets. The science departments were less interested in the design process of the models, so printing tended to involve ready-made designs from downloadable file libraries such as Thingiverse[4].

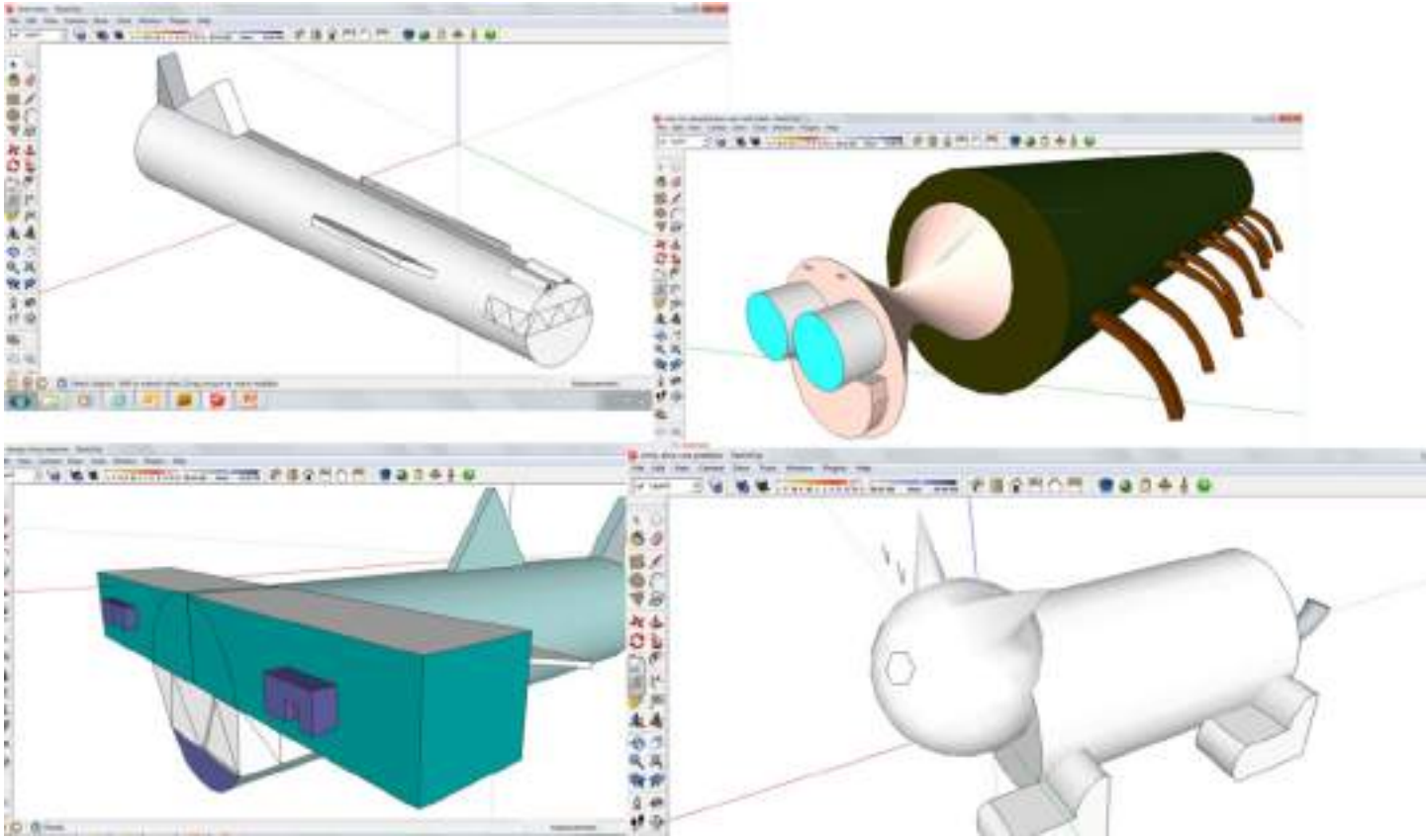
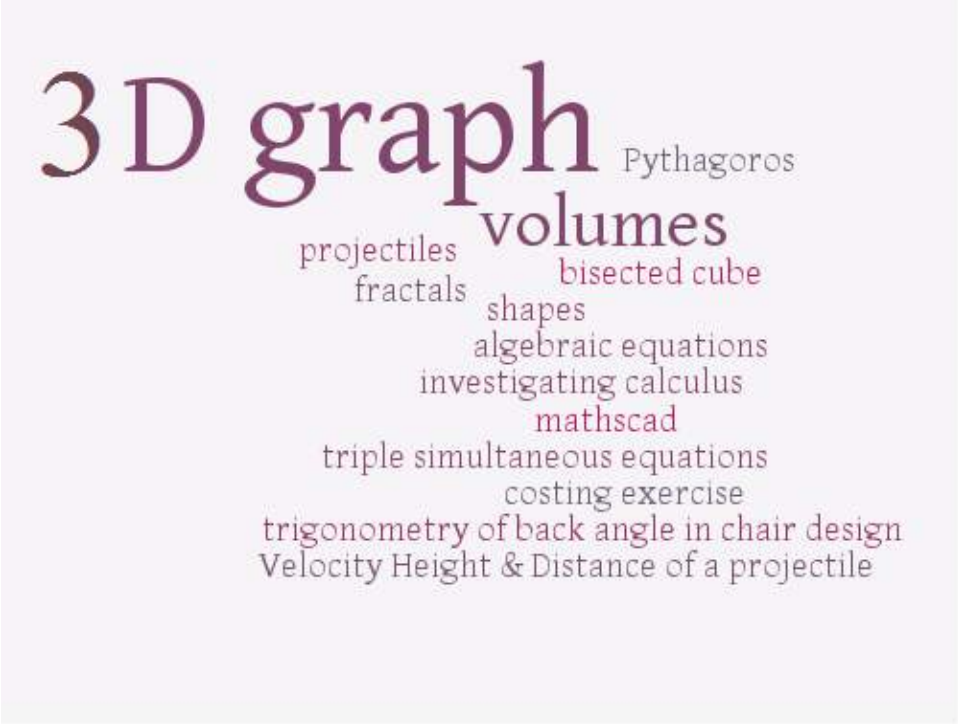


Figure 7 - Arden's Year 7 project looked at the chemistry of plastic, the physics of the 3D printer and the idea of predators in biology. Pupils created a 'Pokémon' style predator in Google Sketchup and printed these off on the 3D printer.

[4] www.thingiverse.com

Maths



Work in mathematics emphasised developing pupils' 3D visualisation skills. Printing of 3D graphs was not straightforward as they needed to be printed with a supporting medium which is removed after the print. Nonetheless, this was attempted by several schools. 3D Pythagoras theorem and trigonometry were also investigated.

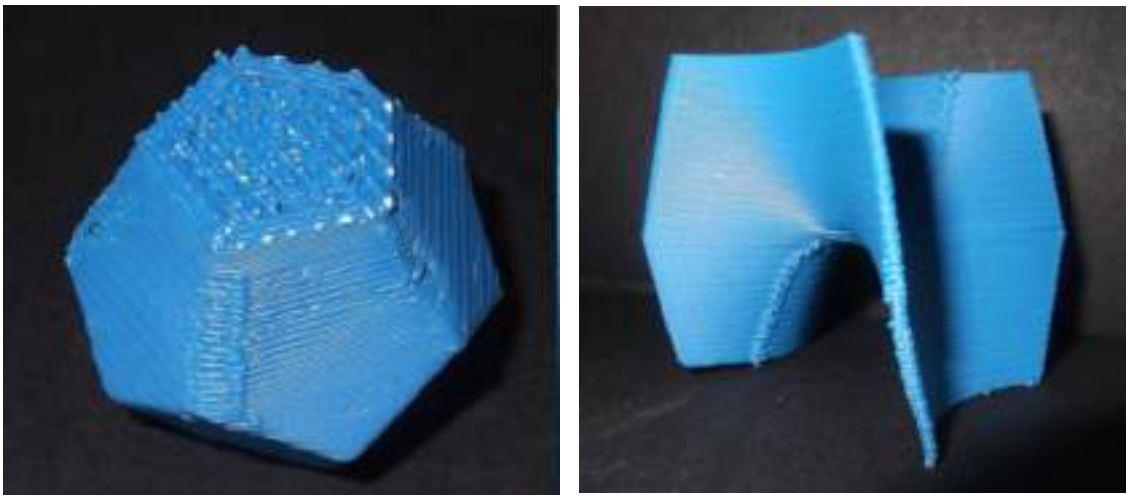


Figure 8 - At Watford Grammar School for Boys the printer was used to demonstrate a 3D graph for various algebraic equations as well as producing examples of regular shapes (Dodecahedron).

Figure 9 - A Watford Grammar School sixth form group investigated calculus relating to velocity, height and distance of a projectile. A device that had previously been used had become unreliable and a coupling was produced on the 3D printer to hold the internal catapult. A series of projectiles were then produced for the project using the 3D Printer.

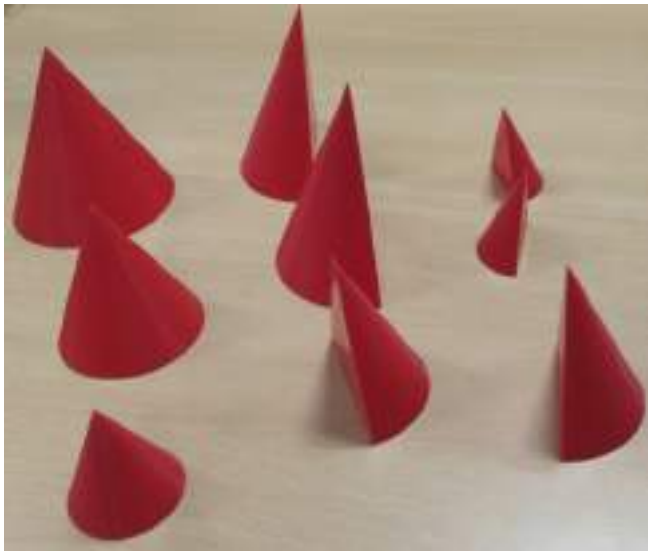


Figure 10 - The Kings School, Peterborough made a set of cones and part cones for a mathematics investigation into areas and volumes.

Figure 11 - At Highworth Grammar School for Girls, a set of laminae were made to support the teaching of centres of mass in mechanics instruction.

STEM cross curriculum

Cross curricular STEM learning was offered to a small number of pupils as an extracurricular activity in some schools, generally with an engineering focus, as this naturally incorporated skills and knowledge across ‘STEM’.

Figure 12 - Plans, printed prototypes and manufactured chairs from engineering lessons at the Cramlington Learning Village.

In addition to production skills, this involved aspects of the physics curriculum, such as chair stability, forces weighing down during chair occupancy and equilibrium within chair production. Pupils also applied mathematics, such as trigonometry involved in calculating back angles, plotting coordinates in the software so designs would maintain balance once printed by the 3D printer, and performing a costing exercise to evaluate value for money.

Figure 13 - A printed rocket and launcher from a fortnightly dedicated ‘STEM’ lesson at Simon Langton Girls’ Grammar School. The school plans to incorporate 3D technologies, focussing on project work which will contribute towards CREST awards. Topics such as robotics, solar and hydrogen powered cars, trebuchets and rockets will make use of a STEM apprentice to support printing of 3D files.

Factors affecting success

Schools reported a number of features that they felt contributed to effective use of their printers.

Experimenting and learning

Many of the project teachers reported that it took a few months to become familiar enough with the printer and associated software to use it successfully and confidently in teaching. Integrating use of the 3D printer into the curriculum proved most successful with self-confident teachers who were passionate about their subject and not afraid to experiment and innovate. In contrast, progress was slower where teachers were working in isolation and did not persist in problem solving or accessing support.

It is clear that use of a 3D printer will not instantly change teaching, coursework or lesson plans. Teachers require time and training, and it will take time for schools to integrate the technology into the curriculum.

Collaboration

The most interesting uses arose when teachers worked collaboratively and where the entire school community was invited to use the printer. Liaison between departments was important to ensure that the teaching of the selected software was planned collaboratively across the school and across subjects. In two successful schools the lead teacher was both a physicist and a member of the SMT.

In several schools technicians played an active role in both facilitating printer use and assisting in the design work. Excellent in-school technician support was an important factor in the success of project schools. For example, at **Highworth Grammar School for Girls**, the DT teacher and the physics technician worked closely together to design a class set of equipment which modelled the scattering of alpha particles by gold leaf foil.

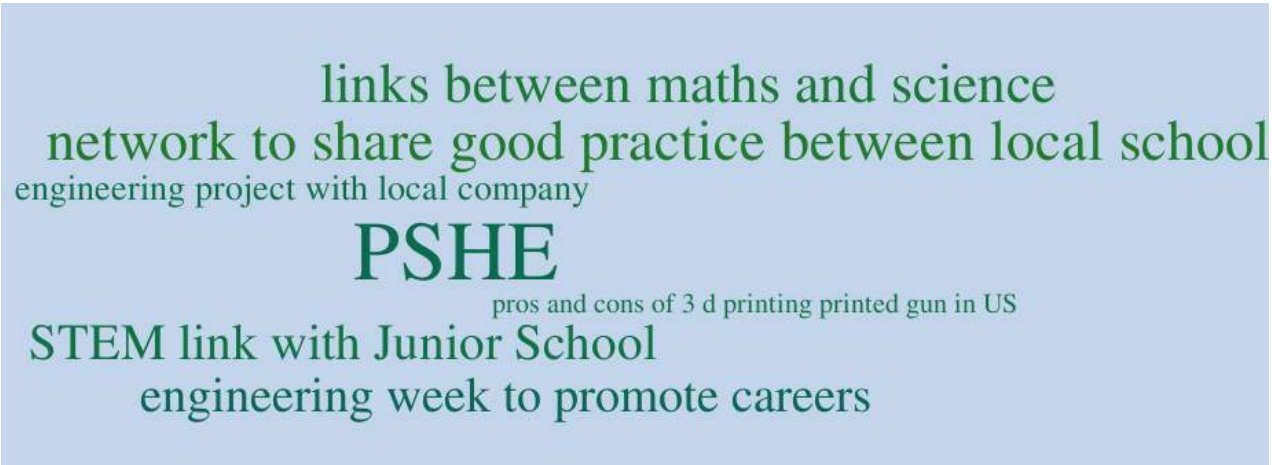


Figure 14 - Some broader applications of 3D printer technology

Senior management support

In the most successful schools senior managers offered practical and financial support as well as offering their own vision for innovative use of the 3D printer. The positive role of senior managers also included encouraging and supporting teachers to use unfamiliar technology, and building strong teams of talented individuals who could disseminate their technical knowledge to pupils. Trusting these teams through 'light touch' management allowed teachers to focus on the technology and learning aims.

In the majority of schools (but not all) the lead teacher was a DT specialist (this is where the CAD expertise lies in most schools).

Accessibility

Schools reported that accessibility of the machine was a factor in staff and pupil motivation to make use of it. The majority of printers were kept on view and accessible to pupils in DT teaching rooms as the DT staff were typically the major users of the printer and the people with the greatest expertise in its use.

The logistics of using the printer were important. In some schools, the printer was permanently housed in one location; in others it was located in several locations including a staff room. The location of the printer was based upon school preference and there was no right or wrong with regards to this.

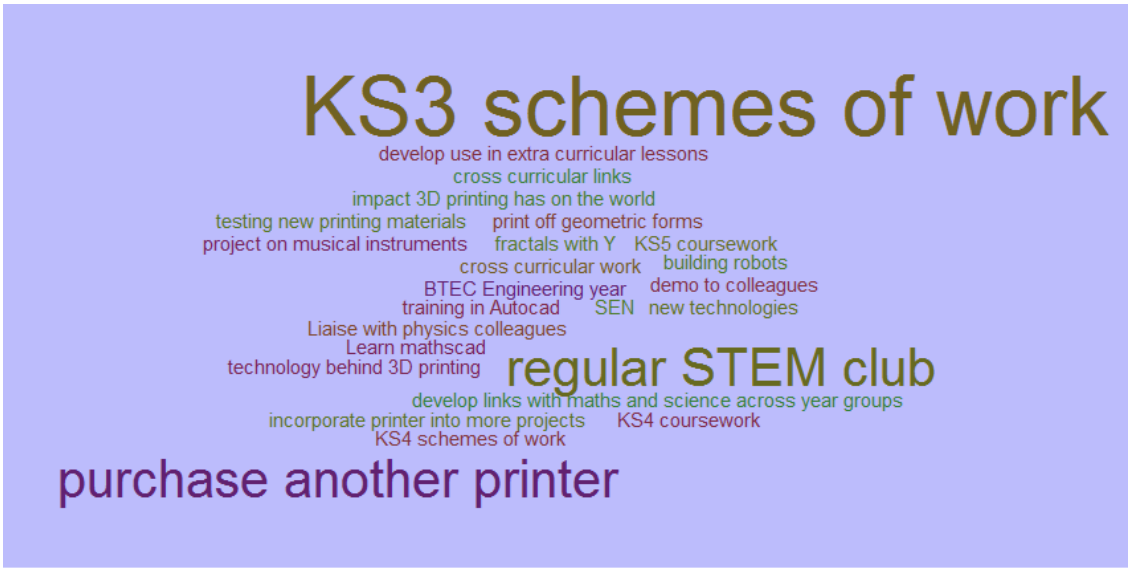


Figure 15 - Future plans of project schools

Effects on pupils and learning

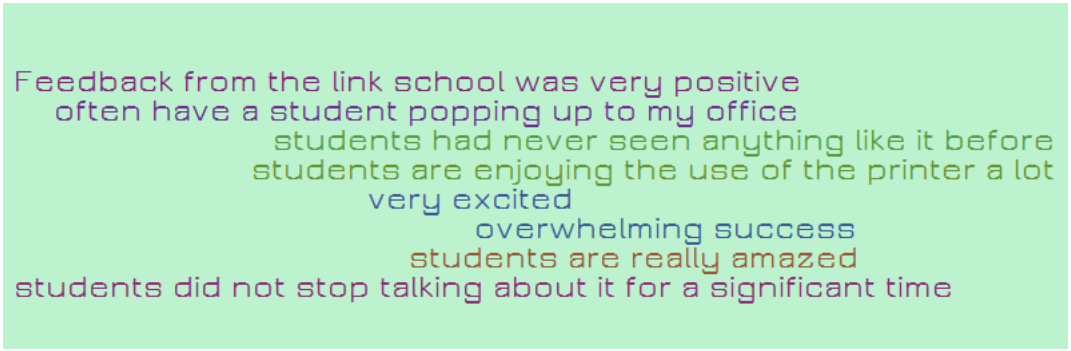


Figure 16 - Schools reported on the motivating effect of the printer on pupils.

"With the printer carrying out the 'production' of objects, more time can be spent considering the science and mathematics involved in design. One pupil stated that the 3D printer had heightened her interest in mathematics and improved her desire to learn; subsequently she commented that it improved her level of achievement."

James Brady – Head of Technology, Simon Langton Girls' Grammar School

Some schools reported that pupils with poor concentration were able to see tangible results more quickly and as a result they kept interest in the lesson. Several pupils commented that they could make shapes and components on a 3D printer that they couldn't make with the technology they had in class. They were able to explore more complex designs and ideas which meant they remained more interested.

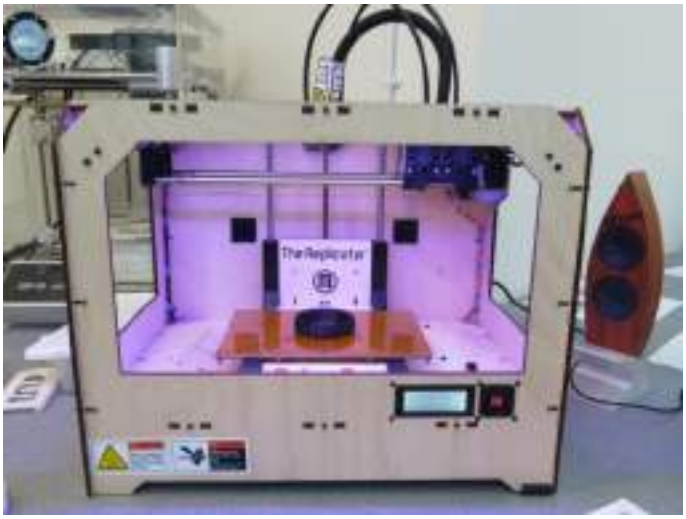


Figure 17 - Pupils were 'in awe' when seeing the printer producing their designs in front of them.

Training and development needs

During this project, many of the committed and hardworking teachers and technicians taking part took a few months to become familiar enough with the printer and its associated software to begin to use it with pupils. For this reason, the project was regarded by many schools as an exploratory pilot. They plan to build on this work, making more informed use of the printers in the next academic year.

In a training session provided at the start of the 3D printer project, teachers valued the opportunity to share ideas for using the 3D printers with colleagues. They also benefitted from demonstrations of the printer set up and software by experienced presenters. The two schools that were unable to attend this session took longer to get their printers into use with pupils.

Training sessions need to be followed by opportunities to practice what has been learnt. One teacher felt progress would be impossible unless his teaching load was temporarily reduced. He asked for, and was granted, a period of time off-timetable to consolidate his programming skills.

> "As part of the bid we brought in training on AutoDesk Inventor and we trained five members of staff from around the school in using this software. The day was very intense and the training provided the school with open licence software, for the pupils and staff, which we then provided across the school network."
>
> **S Griffin-Raphael – Head of DT, The Windsor Boys School**

> "We had a really good training session. My school and Settlebeck school did a joint course which worked out very well."
>
> **Kevin Gough – D&T Subject Leader, Kirkby Stephen Grammar School**

Training across subject departments is also important: lack of CAD expertise amongst non DT teachers was reported as a barrier to using the printer to its full potential in these areas.

Schools wishing to introduce 3D printing technologies into teaching of STEM and design subjects need to factor in time required to train teachers and embed new approaches to teaching. This allows teachers starting from a lower base of expertise in 3D technologies adequate time to reflect on the various possibilities and to work with other teachers to develop and implement their ideas.

Figure 18 - Successful teachers can guide learners in using technologies where the learners may be more adept than the teacher.

To maximise the opportunities that 3D printing offers for subjects beyond DT, particularly physics and mathematics, teachers should be open to new ways of teaching, including pupil-led experimentation. Anxiety about the volume of the curriculum to be 'covered' may result in more teacher-led approaches in science and mathematics classrooms. A recent review of research[5] found that independent learning can result in improved academic learning and other, wider benefits.

There was successful teacher-led training of colleagues and pupils seen within some schools and in other local primary and secondary schools during the project. Where these informal networks were set up, other secondary schools were prompted to buy their own printers.

Printers were showcased at Parents' Evenings and press coverage of one school's projects[6] led to several requests for advice locally and globally.

[5] What is independent learning and what are the benefits for students?

[6] www.thisiskent.co.uk

Technical views

Software

Objects to be printed by a 3D printer are created using software design packages. The output, usually a .stl[7] file, is then fed into second piece of software which generates printer instructions (G code[8]) specific to a particular printer. The G code in .s3g[9] file format is then input to the printer via an SD (secure digital) card. In this project *Makerware* and *Replicator G* programmes were generally used to generate the G code.

Simple, freely downloadable designs from websites such as *Thingiverse* were useful as an introduction to how the printer worked. These stimulated ideas for further possibilities by staff and pupils during the initial training period.

The majority of schools used *Sketchup* as their software mainly because it is a free program, available for pupils to download out of school hours. In some schools it was taught at KS3 as part of the ICT curriculum.

Dedicated training and on-going support in using the relevant software across departments proved essential, as it took a while for inexperienced teachers to become familiar with the capabilities of both the printer and the design software. When teachers were confident, they could teach usage of the technology effectively to pupils.

[7] stl stands for stereolithograph

[8] G-code is a computer programming language which provides instructions for computerised machine tools on what to make and how to make it. G code gives instructions on where to move to, speed of movement and the path of movement.

[9] Sanguino3 G-Code

Choosing a printer

The project highlighted important considerations for schools in choosing a printer.

Points to consider are:

- Who will use it?
- What will it be used for?
- Speed of printing
- The interface between the printer and the files to be printed e.g. SD card, USB flash drive, files sent via school network
- Cost of consumables (in the case of ABS and PLA plastics very low)
- Ease of use
- Accessibility of printer location
- Suitability of printer local environment e.g. to minimise draughts and lifting problems
- Compatibility of firmware with school operating systems and networks
- Quality and accessibility of after sales support

Other points of feedback from schools:

- Some prints can take an hour and a half to complete
- Pupils have designed models that the machine has been unable to make
- Number of faults that were diagnosed have been relatively easy to fix
- The machine requires technical support
- Open sides on the printer need protecting to avoid draughts, otherwise issues such as prints drying prematurely and warping before the printing has been completed
- Some printing materials flow better than others and it was a case of testing these out to find which was most suitable for the work being undertaken
- Time and energy is needed if the printer is intended to be more than a demonstration machine – subsequently larger items take many hours to print
- It is worth persevering with using the machine and overcoming problems
- Networking software has been an issue
- Have software in place before engaging with the printer

Conclusions

Feedback from this exploratory project confirms that 3D printers have significant potential as a teaching resource and can have a positive impact on pupil engagement and learning if schools can master how to use the printers in an effective and meaningful way. The project allowed participating schools to explore potential benefits and challenges of using this technology in the curriculum and to share their experiences with other schools wishing to introduce 3D printers.

Individual schools decide how to integrate new technologies into the curriculum. This report highlights successes and challenges in effectively implementing 3D printers in the classroom.

Many of the schools involved in this project commented on how motivated their pupils were by using the printer. Many of the teachers involved were passionate in their desire to successfully embed the printer into their teaching and often devoted much of their own time to exploring new ways to teach their subjects.

If the benefits seen by the participants in this project are to be more widely experienced, schools need to consider challenges faced in introducing the technology, including those relating to developing teaching, teacher training and technical support.

Acknowledgements

The DfE wishes to thank the teachers and pupils of the schools involved in this pilot project for their hard work and commitment during this project and for sharing their experiences and results with other schools through this report.

Our thanks also go to Joan Ashley, the project manager, and to the Institute of Physics and National Centre for Excellence in the Teaching of Mathematics for their advice and support throughout the project. We would also like to give a special thanks to Angela Hall for her support in compiling this report.

Any enquiries regarding this publication should be sent to us at www.education.gov.uk/contactus.

This document is available for download at www.gov.uk/government/publications

Reference: DFE-00219-2013