Developing outcomes within the CAD/CAM in Schools Initiative – a rapid prototyping project in schools

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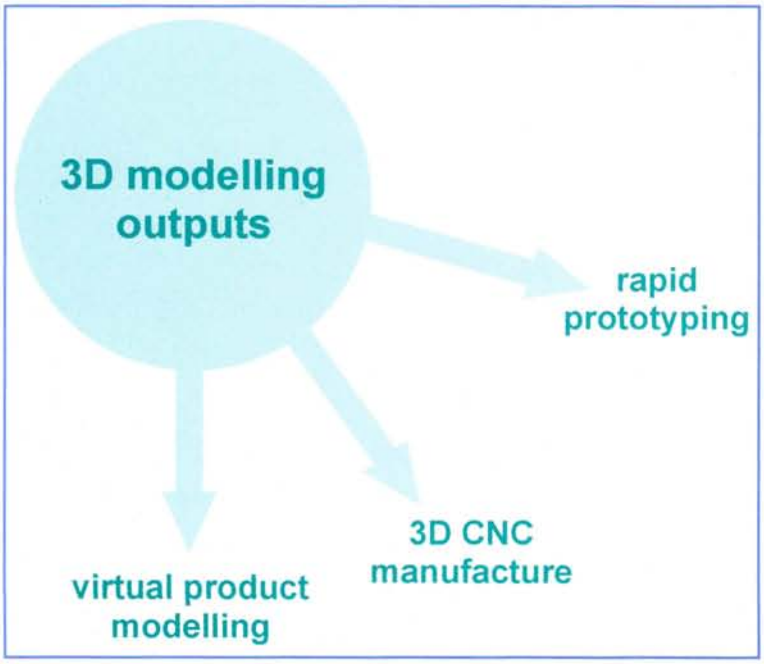
Abstract
This paper begins with a consideration of the scope and nature of school-based product outcomes within the CAD/CAM in Schools Initiative. An overview of one possible outcome, a collaborative project designed to introduce both teachers and pupils to new rapid prototyping technologies is then presented. The authors have worked with REACT Regional Technology Centre and local teachers to develop a Key Stage 3 design and make activity that incorporates Pro/DESKTOP as well as working with pupils involved with GCSE and post-16 examination work. Final design work from pupils has been e-mailed to the rapid prototyping centre for conversion into stereolithographic models. The paper concludes with a discussion of potential further developments in this area.

Introduction
The world of design and manufacture has undergone tremendous change in recent years. Shorter product development times and the capability to deliver 'right first time' and customised solutions are now the key to success in the contemporary global marketplace. To minimise the crucial 'time to market' for new product development, companies have had to embrace faster and better design and manufacturing technologies to remain competitive. This has led to the tremendous rise in investment in computer aided design, computer aided manufacture and rapid prototyping technologies aimed at accelerating the speed of new product development. (Farish, 1995).

Figure 1: Where to next?



The CAD/CAM in Schools Initiative has attempted to bridge the widening gap between the 'traditional' design and manufacturing strategies employed in the design and technology curriculum and the more innovative approaches now prevalent in professional practice. Now in its third year, it continues to provide pupils with an exciting opportunity to develop their creativity and ability to innovate in an 'e' design-based society in a way that mirrors developments in the wider world.

Extending the scope of the CAD/CAM in Schools Initiative?
The CAD/CAM in Schools Initiative has clearly provided the design and technology community with a huge impetus for change. Inevitably, the implementation of such rapid change is proving to be quite a challenge in many respects. There are issues which still need to be resolved, to do with the integration of new ways of working into existing curriculum frameworks that centre on pedagogical aspects of progression and the need to assess and monitor outcomes. However, there can be little doubt that the introduction of 3D modelling software has provided pupils with a powerful vehicle that allows them to develop ideas of a quality and complexity that would not previously have been feasible. A number of schools have now reached this point, which begs the question for many of where to next? Through our undergraduate and INSET programmes we have been exploring the three potential avenues illustrated in the model.

Virtual product design
Reflecting on future directions in computer aided design and manufacturing at the recent CAD/CAM conference held at Warwick Manufacturing Group, Jon Stevenson of PTC used the phrase 'total digital confidence' to describe the continuing shift towards a greater reliance on computer generated models in the early part of the design process (Stevenson, 2001). Many designers in professional practice now produce virtual, computer based concepts that can be used in a number of ways. Applications include design verification, analysis prior to manufacture and use as a marketing tool. For many manufacturers, a substantial amount of work of this nature is now carried out before the first physical models appear in the product development process. For example, the new Virgin Voyager train was described by one of the design engineers involved as the first 'virtual train' due to the extent to which virtual modelling was employed in its development.

Pro/DESKTOP has powerful virtual modelling capabilities. Photo realistic models can easily be exported from Pro/DESKTOP for further digital manipulation in software such as Corel Draw or Photoshop. Kinematic modelling can be used to prove mechanical functions and test for interference between moving parts. Similarly, the use of the 'Configuration' and 'Animation' tools in Pro/DESKTOP make it relatively simple for pupils to produce animated 'movies' of their product in action, very useful when attempting to convey information about product function.

Taking advantage of these capabilities and in keeping with contemporary industrial practice, virtual modelling is now a perfectly viable route for pupils to take at the development stage of their individual project work. Of course this type of approach needs to be viewed in the context of the broader curriculum. It will only be feasible where the capability of pupils to design has been underpinned by skills and knowledge that enable them to produce virtual models in an informed way. To achieve this, they will still need to know how materials behave, and the nature and purpose of the production processes that are available.

3D CNC manufacture

With the advent of post processing software designed for the educational market and the increasing sophistication of CNC machines, 3D manufacturing capability is now within the means of many schools. Collaborative ventures that allow resources to be shared and the opportunity to access remote manufacturing facilities are extending this provision still further. One of the benefits of manufacturing in this way is the ability to produce 'real' components in appropriate materials. There are some limitations however, for example, machining cycles tend to be relatively long for anything but the simplest forms and the complexity of detail achievable is restricted when using tools robust enough for sustained use in the school environment. Typically machines found in schools are 3 axis, which means that they are only able to machine concurrently in the X, Y and Z axes. There are techniques such as splitting the model and machining in two halves or inverting the work piece to allow machining from both sides, which go some way to overcoming these limitations. There are still problems, however, when trying to deal with the full range of outputs from 3D solid modelling software, for example where there are complex internal details or a design that may include undercuts.

Figure 2: Virtual product design – The Atomiser.

Rapid prototyping

There are a number of processes that can translate the digital output from 3D solid modelling packages such as Pro/DESKTOP into three dimensional physical forms using what have been termed rapid prototyping technologies (RPT). Rapid prototyping is increasingly employed in manufacturing industry as a means of reducing development time of new products. Figures suggest that RPT can reduce the time to market for new products by up to 90% and development costs by up to 70% (RPMA, 2000). The relatively high capital costs of these technologies have led to a rise in dedicated centres offering 'bought in' rapid prototyping services. There have been considerable development in this area and the number of processes and formats continues to expand, but there are three principal methods that have some relevance to school based design and technology due to their current availability, future affordability or prominence in the field.

All three methods are based on a principle of 2D layering where the 3D computer generated model is broken down into layers (lamina) before being processed. Subsequently, the

Figure 3: SurfSafe animation.

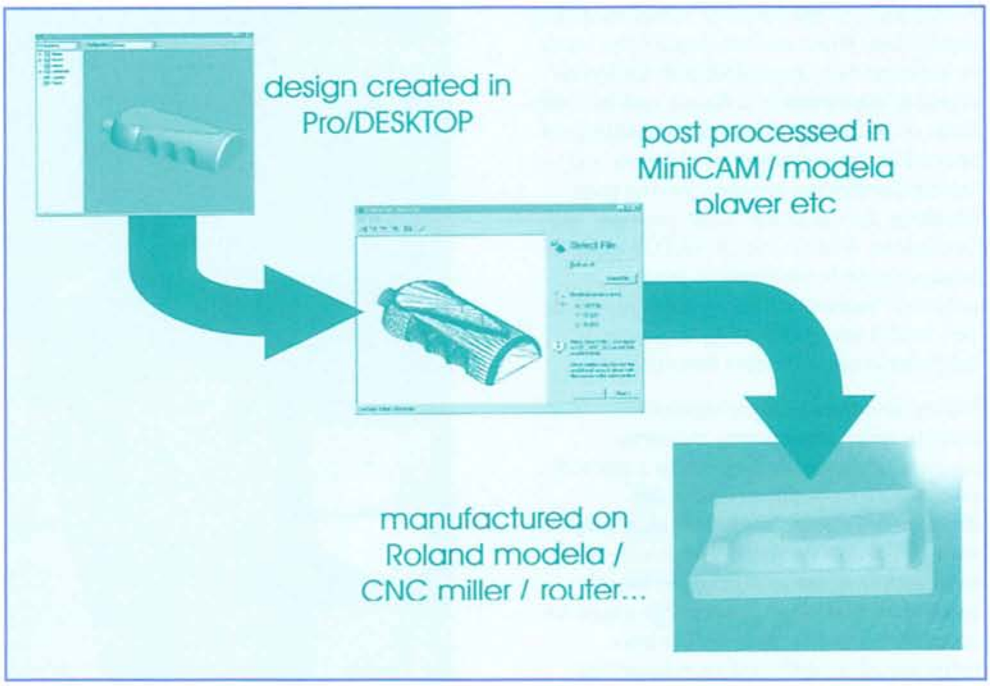


Figure 3a: 3D CNC manufacturing flow diagram.

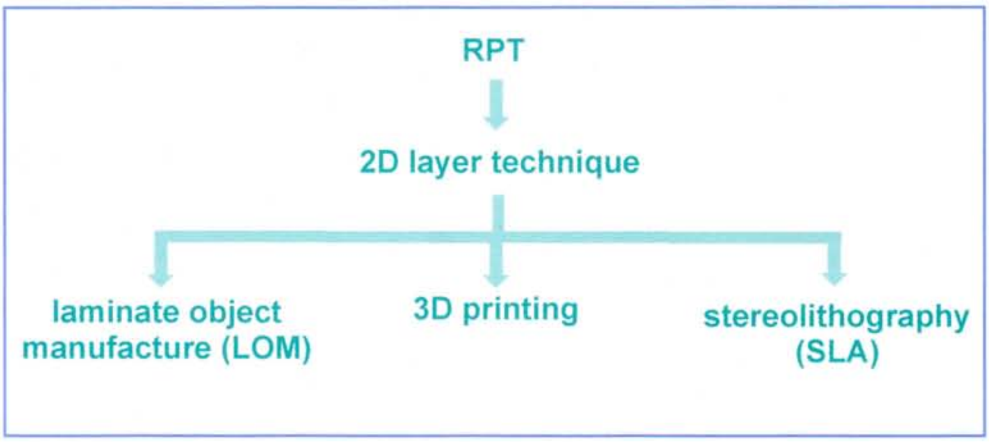


Figure 4: The 3 principal RPTs.

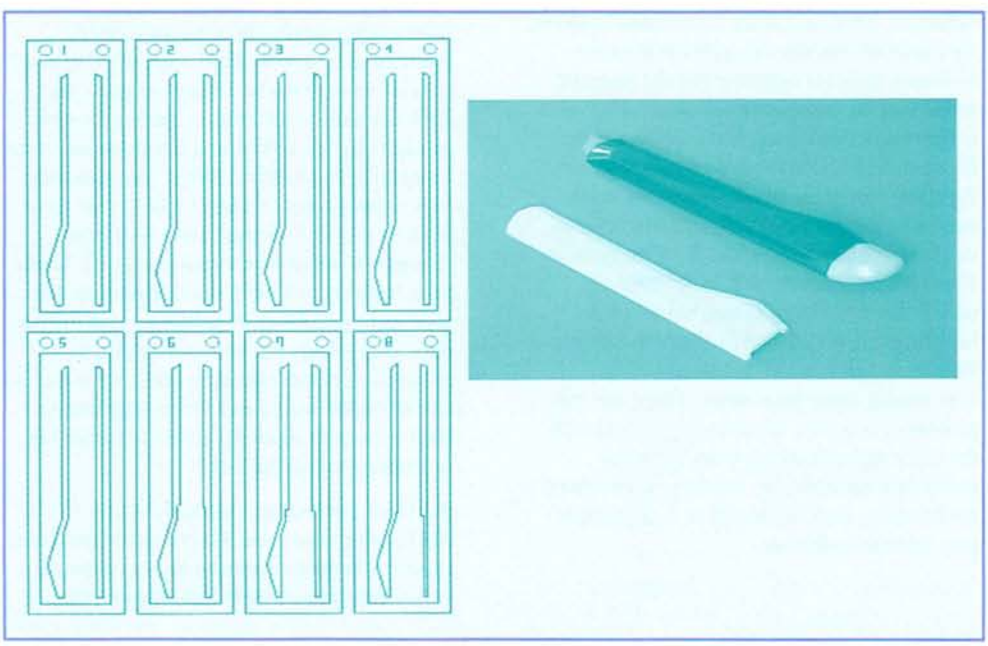


Figure 5: Laminate object manufacture.

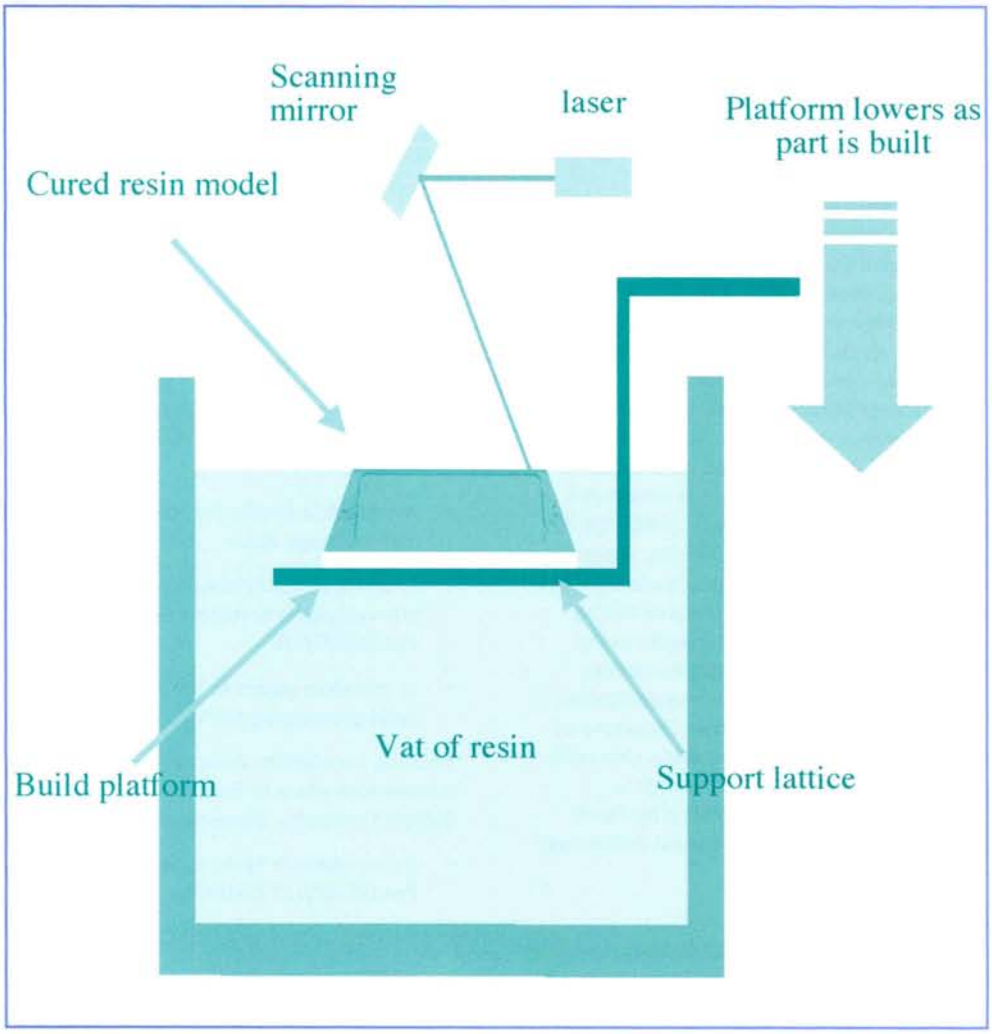


Figure 6: SLA process.

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rapid prototyping techniques employed result in physical outcomes that are quite different in nature and purpose. What follows is a brief introduction to each method.

Laminate object manufacture (LOM)

This system involves the transfer of CAD data to a laser or plotter cutter which then creates layers in the modelling medium (card/sheet plastic). The layers are subsequently bonded together to create the 3D prototype. The model can then be finished off using a variety of techniques to produce a more durable prototype for visualization/form checking etc. A relatively inexpensive school based system based around the use of a plotter/cutter is already available from Boxford Ltd.

3D printing

The ability to produce 3D prototypes using a deposition system similar to that of the inkjet printer is a rapidly developing area of RPT. Instead of ink, the modelling medium, which varies depending on the system (starch/plaster based powder and thermo-polymers being two examples), is deposited layer by layer to produce a three dimensional form. Prototypes produced by this method can lack durability and quality of definition, but they do provide immediate feedback to the designer on the validity of a concept. The raw materials used in this process are relatively cheap and all the indications are that such systems may soon become affordable to the education community.

Stereolithography (SLA)

This technique, first developed in the 1980s, is currently the most widely used method of rapid prototyping. Model quality can be high and as a result they are often used to produce silicon rubber tools from which facsimile models are cast. These are subsequently put to a variety of uses including design verification, functional testing and market research. SLA models are built onto a platform within a tank of photo-sensitive liquid resin using a combination of laser, photochemistry and software technologies. Appropriate software is used to slice the three dimensional CAD model into thin layers, typically 0.1 mm thick. This information is used to control a laser beam, which passes over the tank. Where the laser beam strikes, the resin is instantaneously

cured to a solid that matches the CAD model lamina. This process is repeated layer by layer, building the three dimensional model from the bottom up. The process is illustrated below.

Rapid prototyping in schools

Unfortunately from the point of view of the education community, most of these technologies are oriented towards industry and mass production making them, for the time being at least, prohibitively expensive. However, developments in contemporary design and manufacture have clear implications for the direction of the design and technology curriculum. The National Curriculum suggests that the subject should 'prepare pupils to participate in tomorrow's rapidly changing technologies' (DfEE/QCA, 1999), and the pupil competencies, drawn up as part of the CAD/CAM in Schools Initiative have highlighted the importance of raising pupil awareness of modern manufacturing methodologies. As design and technology educators we need to seek out opportunities that allow pupils to develop an awareness of leading edge professional practice. One such opportunity presented itself through a collaborative project coordinated by Geoff Armitage at the REACT Regional Technology Centre in Rotherham.

Project outline

This was a collaborative undertaking aimed at introducing school pupils to the principles and practices of rapid prototyping, the latest incarnation of a project that had been running in a variety of forms since 1997. The earliest phase was the product of a partnership between the College of Arts and Technology, the Chamber of Commerce, Training and Enterprise and the Metropolitan Borough Council, all based in Rotherham. It began with vocational focus across a number of subject areas intended to promote collaboration between education and industry and enhance links between schools and FE colleges. In Phase 2 the focus shifted more clearly to the design and technology curriculum and included an introduction to the first generation Pro/DESKTOP software, CNC systems and online manufacturing.

The current phase, initiated in September 2000, the point at which Sheffield Hallam University became involved, aimed to consolidate work done in Phase 2 and extend the manufacturing experience for pupils into rapid prototyping.

The emphasis shifted to supporting 'gifted and talented' pupils as Geoff Armitage, the project director, highlighted the need to bring pupils into manufacturing who may not otherwise have considered it a career option.

Phase 3 – work in progress

The project linked six schools from the Rotherham area with the REACT Regional Technology Centre and the authors at Sheffield Hallam University. Each school identified 13 to 15 pupils to work on the project.

The collaborative venture had the following objectives:

- to provide teachers and pupils with access to facilities and expertise beyond the resources of the average school
- to develop teacher and pupil competence and understanding of CAD/CAM in the wider context
- to provide a facility for schools to network and exchange ideas
- to develop school based projects that allowed pupils to make effective use of Pro/DESKTOP
- to introduce pupils to the principles of rapid prototyping (RP).

Training for teachers from the participating schools took place in January at Sheffield Hallam University where topics included:

- an introduction to the updated version of Pro/DESKTOP (2000i^2)
- the relative merits of 3D CNC manufacturing and rapid prototyping technologies, including stereolithography, laminate object manufacture and thermal polymerisation
- post processing and file size optimisation for on-line manufacture
- SLA model verification
- activity planning – including progression through Key Stages 3 to 5.

School-based developments

In discussion with the project director at REACT, a number of potential school based activities emerged. For pupils at Key Stage 3, specified requirements were that the activity would:

- be appropriate to Key Stage 3
- lend itself to conceptual development using Pro/DESKTOP
- be physically small to keep production costs at an affordable level
- result in STL files that were small enough to transfer quickly over the Internet.

At Key Stages 4 and 5, much of the project work was already underway. Where this was the case, it was decided that the best way

Figure 7: Pupil visit to REACT.

forward was to support the development of individual project work by providing SLA models as a basis for constructing working prototype models for GCSE and A'/AS' Level examination submission.

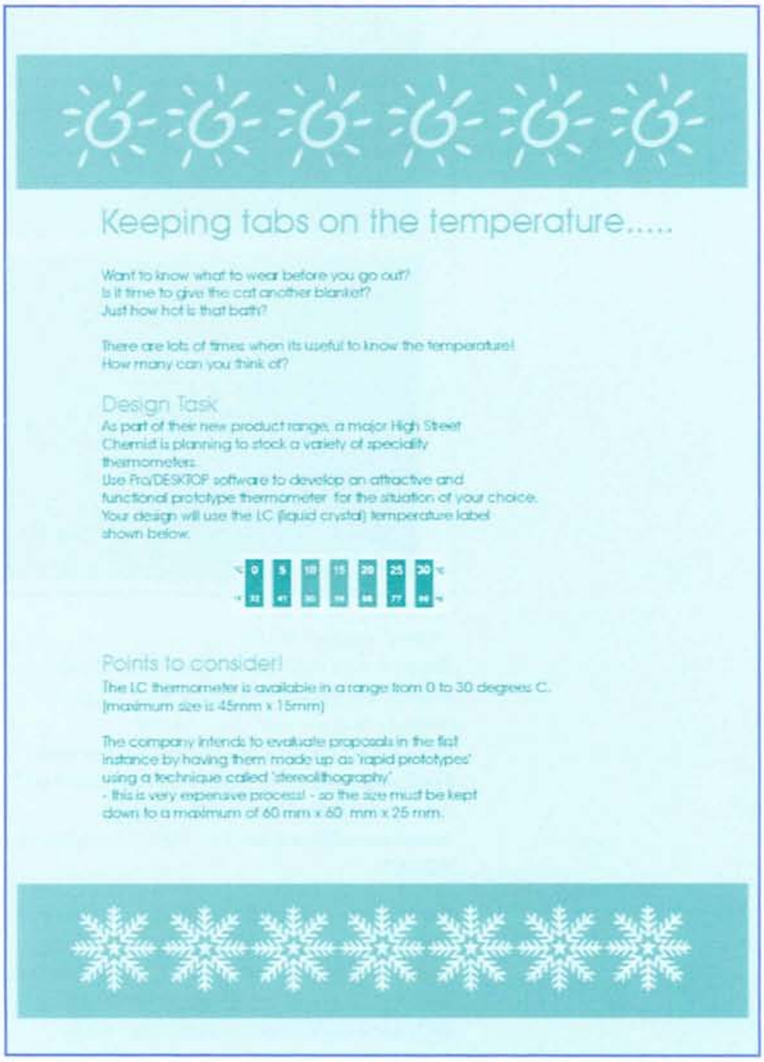
The visits

Following the university based training, teachers and pupils from across Key Stages 3 to 5 visited REACT to learn more about rapid prototyping technologies and observe the SLA modelling process in action. The format of the visit varied from school to school, depending on the age range of the pupils involved. Some of the pupils at Key Stage 3 were working on a project developed in collaboration with the authors at SHU (see following section for details). Pupils at Key Stage 4 and 5 were able to relate the techniques to their individual project work and the additional expertise on hand provided a sounding board for their ideas.

The Key Stage 3 project – 'keeping tabs on the temperature'

This project, incorporating the use of a 'smart' material, was intended to encourage pupils to use Pro/DESKTOP as a conceptual design tool. Pupils were asked to develop an addition to the product range of a major High Street chemist by developing a new concept for a speciality thermometer. Pro/DESKTOP software was to be used to develop an attractive and functional prototype for the situation of their choice. The prototype had to incorporate a thermochromic liquid crystal temperature label. As the final design was to be e-mailed to the rapid prototyping centre for manufacture as an SLA model, quite stringent constraints were placed on the overall size.

Figure 8: The 'Keeping Tabs on the Temperature' brief.



Keeping tabs on the temperature.....

Want to know what to wear before you go out?
Is it time to give the cat another blanket?
Just how hot is that bath?

There are lots of times when its useful to know the temperature!
How many can you think of?

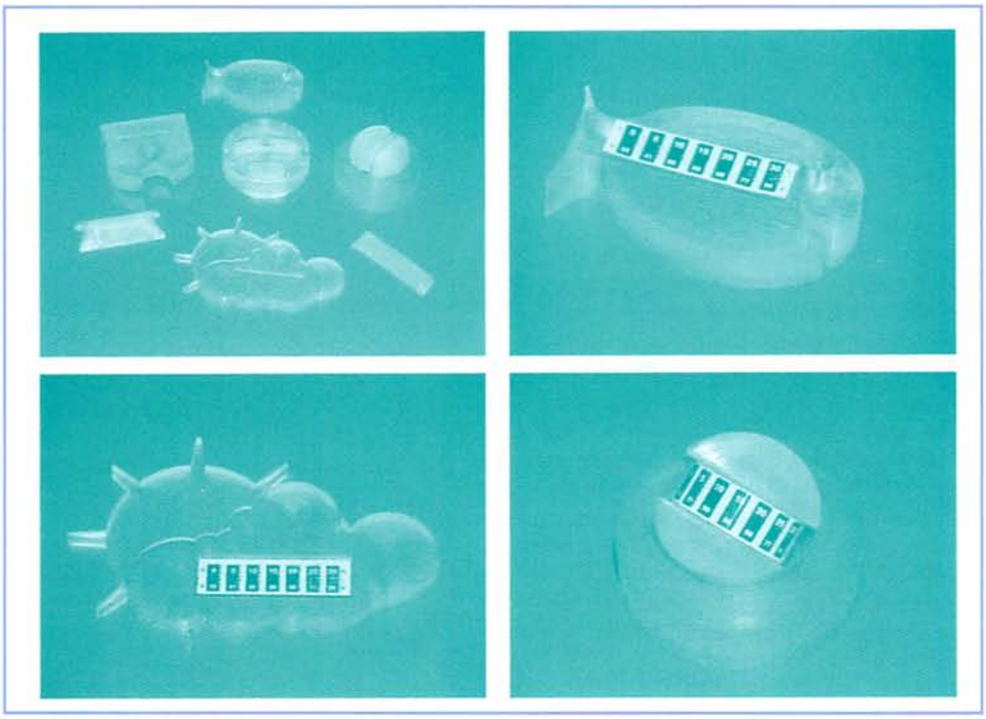
Design Task
As part of their new product range, a major High Street Chemist is planning to stock a variety of speciality thermometers.
Use Pro/DESKTOP software to develop an attractive and functional prototype thermometer for the situation of your choice.
Your design will use the LC (liquid crystal) temperature label shown below.

Points to consider!
The LC thermometer is available in a range from 0 to 30 degrees C.
(maximum size is 45mm x 15mm)

The company intends to evaluate proposals in the first instance by having them made up as 'rapid prototypes' using a technique called 'stereolithography'
- this is very expensive process! - so the size must be kept down to a maximum of 60 mm x 60 mm x 25 mm.

Figure 9: Pro/DESKTOP thermometer prototypes.

Figure 10: SLA models of thermometers.



School-based work

Back in their schools, over the next three months the pupils embarked on a range of projects that allowed them to use Pro/DESKTOP as a conceptual design tool. Final solutions were produced, exported as stl files and verified on screen using stl visualiser software prior to being e-mailed to REACT.

Outcomes – Key Stage 3

There are currently two projects in progress. Pupils at Kimberworth School, Rotherham are working on a rule manipulator for children with hand coordination disabilities while pupils at Oakwood School, Rotherham are working on the thermometer project. For most of the pupils involved this was their first opportunity to use the Pro/DESKTOP software and consequently considerable training was required before they were able to tackle the design projects, a time consuming process! At the present time, neither school has yet reached the SLA manufacturing stage although both expect to in the very near future.

Prior to using it in school, the thermometer project was trialled with teachers involved in the initiative and with trainee teachers at

Figure 11: Pupils designing with Pro/DESKTOP.

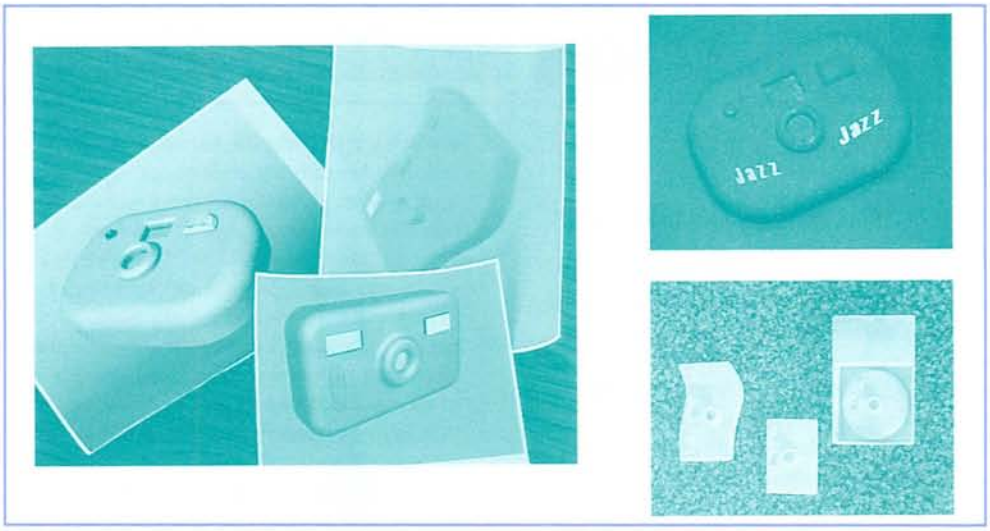


Figure 12: Camera outcomes.

Sheffield Hallam University. Once familiar with the software both teachers and trainee teachers found that they could create, adapt and develop dynamic design ideas quickly and easily. A variety of on-screen solutions resulted, some of which were selected for manufacture using the SLA process and e-mailed to REACT.

Outcomes – Key Stages 4 and 5

Inevitably, in such a period of transition there will be considerable crossover between old and new ways of working. The pupils were using Pro/DESKTOP to develop concepts, but their design thinking was to some extent being constrained by the ways in which they had become accustomed to working in design and technology. The pupils, governed by their formative experience of more rudimentary 2D and 3D manufacturing methods appeared to be unable to break out of a mindset that only allowed them to visualise a product in two and a half dimensions! The result was a number of proposals that made only limited use of the potential of the process.

At Key Stage 4 the redesign of a pocket camera was undertaken. Pro/DESKTOP was employed as a design and development tool with the final design being exported in stl file format. Prototypes were manufactured in 3D using school-based CAM machines and detail applied using Stika Scan.

At Key Stage 5, pupils worked on a range of individual projects for the external examinations. Virtual models were created in Pro/DESKTOP and the main components e-mailed to REACT in stl file format and manufactured using the SLA process. Back in school, pupils employed more traditional techniques to add detail and 'finish' to the models. In the example illustrated, bought in

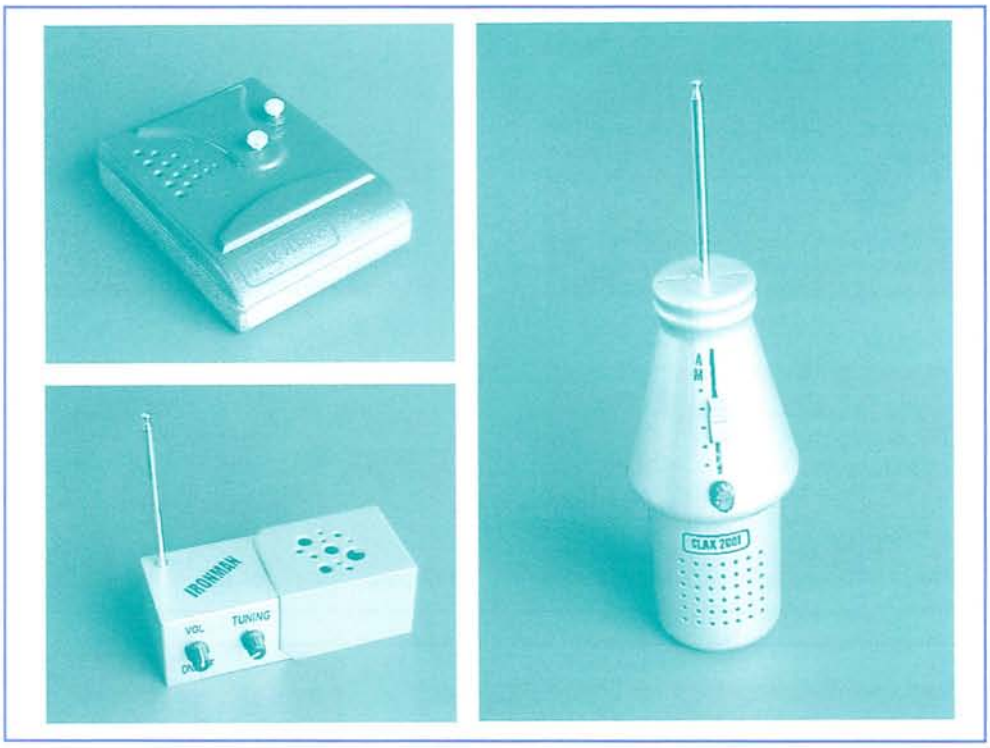


Figure 13: Radio project (SLA models).

electrical components were added to create a working radio.

There are other issues to be considered at this point – it is all too easy when using Pro/DESKTOP to make quite dramatic conceptual changes on screen with only a few clicks of the mouse, but somewhat more difficult to remember to keep a record of these changes! An easy way of recording progress is to keep a digital record on computer by regularly saving and re-naming files. How should this work then be presented for external examination – is a hard copy necessary or should pupils be allowed to present work in a digital format?

Another important issue is that of assessment. Given the high level of importance attached to assessment and monitoring of performance, how do we assess work of this nature – particularly where pupils have been fortunate enough to have access to techniques such as SLA modelling. Clearly, their physical involvement in making the models will not have been significant, but to be successful their designing would have to be informed by a clear understanding of manufacturability and functionality.

Further developments

As discussed earlier, the rapid introduction of 3D modelling software of the calibre of Pro/DESKTOP has raised many issues. The best way to integrate the software with its attendant design strategies into existing curriculum frameworks and its impact on pupil creativity are just two of the areas that are being hotly debated. However, the potential benefits are plain to see. The initiative has given the subject a welcome boost in a number of ways. David Prest, in his keynote speech to the Warwick CAD/CAM conference highlighted the fact that Senior Management Teams and parents were beginning to take notice of the subject again after what has been seen by many as a period in the doldrums. Anecdotal evidence suggests that pupil enthusiasm is sky high. Links with those in professional practice are becoming more meaningful as teachers, pupils and professional designers have begun to share a common language. In a good example of the new spirit of collaboration, a CAD/CAM competition for schools, organised recently by the Sheffield Advisory Service and the Engineering Employers Federation generated tremendous interest among those industrialists present who formed the judging panel. Speaking to the group of teachers and pupils, Colin Jacklin a chief engineer at Bombadier Corporation, an emerging global leader in the fields of aerospace and transportation, expressed first astonishment and then delight at what the pupils had begun to achieve with the new resources. He spoke of a new, computer aided design process and how pupils were being given an excellent introduction to it through the initiative.

In the education community, where change can be frustratingly slow, it is pleasing to see that the CAD/CAM in Schools Initiative appears to be bucking the trend. Now, given the speed and enthusiasm with which many

teachers and pupils have embraced the new developments, the obvious question is where to next? Having given pupils access to professional standard software and the associated design strategies, the question becomes, in our view, rhetorical. We should perhaps be seeking out opportunities that offer students access to similar resources in manufacturing terms.

Of course, given the high capital costs presently attached to rapid prototyping that even established manufacturing companies find difficult to meet, it would be naïve to suggest that we can install such facilities in every school. We could, however, encourage local education authorities, teachers, advisers and representatives from industry to build collaborative opportunities similar to the one we have described in this article. Where first hand opportunities simply can't be found there is still plenty of potential in raising pupil awareness through the introduction of audio-visual resources from the growing list available on the topic of contemporary design and manufacturing processes – pupils can for example visit the REACT webcam to see the SLA process in action at any time.

Finally, there is one further exciting development that the authors can foresee – as capital costs fall, it may even be possible to establish rapid prototyping 'service centres' to be shared by the education community in the near future. Watch this space!

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