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PICs, CAD & Creativity
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Abstract
This action research project grew out of a concern that electronics in schools does not generally foster creativity. Earlier work by the authors has suggested that incorporating microcontrollers (PICs) – small, low cost, programmable integrated circuits – in electronic products developed by pupils in design and technology could increase opportunities for pupils to make creative design decisions, because they enable pupils to make more decisions about the ways in which their design will act and respond.

Three schools have carried out a radical reappraisal of one unit of work, developing new units that foster greater opportunities for (and recognition of) pupil creativity by incorporating modern technology. The research question that all three schools sought to address was:

Does the use of programmable microcontrollers (PIC technology) and computer aided design (CAD) enable teachers to arrange electronics project work so that pupils are better able to make creative design decisions, as compared to pupils’ design decisions in previous electronics projects?

The preliminary analysis of the data presented here indicates that programmable technologies can help enhance the degree to which pupils make design decisions, but that other factors in the approach taken to reaching that decision are also important.

Key words
creativity, ECT, electronics, systems & control, systems, microcontroller, PIC, teaching approaches, action research

Introduction
This action research project grew out of a concern that electronics in schools does not generally foster creativity. There is research evidence (Spendlove, 2003) that pupils perceive design and technology as a whole as providing few opportunities for creativity, and electronics as particularly weak in this regard. The present authors conducted a further study (Steeg and Martin, 2005) that lent support to Spendlove’s concerns, but did suggest that incorporating microcontrollers (PICs) – small, low cost, programmable integrated circuits – in electronic products developed by pupils in design and technology could increase opportunities for pupils to make creative design decisions, because they enable pupils to make more decisions about the ways in which their design will act and respond.

When we first started to explore the issue of creativity in electronics, our belief was that a kind of hierarchy could be described. At the lowest level is what we characterised as ‘circuit and component electronics’ – in which pupils are introduced to a range of electronic components and a limited number of circuits. We saw ‘systems electronics’ (in which pupils are introduced to various electronic subsystems which can be combined to produce a wider range of complete circuits) as a ‘higher’ level, because of the wider range of choice available to novice pupils. At the top of our level scheme was ‘PIC-based electronics’, making use of programmable microcontrollers, because pupils here have even more opportunities to make design choices. Thus our hypothesis was: As the focus of work in electronics moves to a higher system level the scope for pupil creativity will increase.

Rutland (2002, 2003) developed a model of the factors influencing creativity in which three key features of a setting interact with individuals to promote, or not, creativity. These features are those associated with the domain practices in a particular field of knowledge in which design is taking place, those associated with the process of designing (labelled ‘creativity relevant factors’ in the diagram) and those associated with social and environmental factors that impinge on design.

Figure 1: Three feature model of factors influencing the creativity of the person (from Rutland 2002, p155)
Applying this to the teaching of electronics, we felt that as pupils move to higher system levels, the domain features of the task become much more accessible and the process features of the task become less technically demanding and allow thinking about what a product should do to rise above issues of how this might be achieved. As a result, the social and environmental features of the task also improve because the teacher will be freer in permitting or encouraging creative expression. The work reported here has challenged some aspects of these assumptions, but we argue that the overall hypothesis is both defensible and useful.

Creativity, design and technology and electronics

A variety of people and organisations have sought to ‘define’ creativity. The National Advisory Committee on Creative and Cultural Education, in their report to the UK government: ‘All Our Futures: Creativity, Culture and Education’ (NACCCE, 1999) suggest that creativity is:

‘Imaginative activity fashioned so as to produce outcomes that are both original and of value.’

We have used this definition as a starting point for this action research project.

It is perhaps worth saying what we believe creativity in electronics education is not. It is not creativity in electronics if the focus of pupils’ work is solely the appearance of the product (this might be very creative – but it isn’t creativity in the use of electronics). Similarly the introduction of teaching approaches that make use of aspects of the ‘creative arts’ (such as dance, poetry, drama, music and so on) may well lead to more creative teaching and improvements in pupil engagement and learning; but these are not, per se, improvements in creativity in pupils’ work with electronics (though they may well support this aim). Our focus is the development of pupil creativity in the use of electronics within the D&T curriculum.

Applying the NACCCCE definition of creativity to electronics in schools suggests that creativity in electronics education must engage each pupil’s imagination and lead to work in electronics that, for the pupil at least, is original and has personal value. One of our premises has been that a minimum precondition for such creativity to flourish is that pupils are engaged in designing and making electronic systems where they have been encouraged to consider, and make their own design decisions. Barlex (2005) has suggested that pupils design decisions can be represented as belonging to five interconnected domains:

- What the electronic system is for.
- The needs and wants it will meet (who it is for).
- The materials and components they will use.
- How the system will behave electronically.
- Its appearance and other non-electronic aspects.

This set of decisions and the interrelations between them are captured by the design decision pentagon shown in Figure 2.

![Design decision pentagon (Barlex, 2005)](Image)

Creative engagement in electronics proceeds in step with the development of knowledge and skills. A picture of the required inputs for creative activity is captured nicely by the (electronic logic) diagram shown in Figure 3.

![Required inputs for creativity (Barlex 2003)](Image)
This diagram summarises work done by the Nuffield D&T project that identified four features that all have to be in place for pupils to act creatively:

- The activity has to be supported by a significant stimulus – usually one that is strongly visual.
- The activity has to be presented in a context to which pupils can relate.
- An attitude of continuous reflection needs to be encouraged.
- Focused teaching is necessary to provide underpinning knowledge understanding and skills.

However, subsequent work with pupils showed that while these might be necessary they were not sufficient. Critically there needed to be some risk associated with the activity in terms of the originality of the outcome as far as the pupil is concerned. But the risk must be proportionate to the knowledge, skills and maturity of the pupils and be managed effectively by the teacher.

In recent years a number of ICT-based systems have been developed specifically for electronics education which, properly used, support risk-taking without recklessness, because they allow pupils to relatively quickly model and investigate a wide range of possible ideas. These include:

- Circuit modelling and simulation software (so that pupils can check a circuit or a PCB layout quickly before taking up time to build it).
- Software and hardware to allow them to use programmable microcontrollers ("PICs") in electronic products. These have three important advantages. Firstly, pupils are able to program them to carry out different tasks (allowing a wider range of design choices), simulate their behaviour on screen (allowing for rapid testing of ideas), and edit the program until the behaviour is as required. Secondly, because the circuits involved are generally simpler and standard, there is less chance of non-working circuits. And thirdly pupils can modify the program controlling the system even after the circuit has been made (extending opportunities for enhancement). In short, with PIC systems a small amount of technical understanding provides a wealth of design opportunity (in contrast to traditional approaches to electronics teaching where a huge amount of technical understanding was required to achieve even a small amount of design work).
- CAD and CAM software and equipment, so that pupils can model and edit ideas for product design.

These relatively recent developments give teachers the opportunity to include more creative aspects into work in schools, because they provide a technological 'safety net'.

Research Design

The funding of this work through a Creativity Action Research Award (CARA) led inevitably to the adoption of an action research approach to the research. The action research framework adopted by CARA is based on Welch (1998), summarised by the following six steps:

Step 1: Focusing your Inquiry
Step 2: Formulating a Question
Step 3: Review of Literature
Step 4a: Collecting Data
Step 4b: Ethical Issues
Step 5: Analyzing Data
Step 6: Reporting Results

The action research approach adopted in the three schools has been to carry out a radical reappraisal of one Unit of work, and to develop a new scheme of work addressing many of the same learning objectives as previously, but ensuring that modern technology and greater opportunities for (and recognition of) pupil creativity are incorporated. The research question that all three schools sought to address was:

Does the use of programmable microcontrollers ("PIC technology") and computer aided design (CAD) enable teachers to arrange electronics project work so that pupils are better able to make creative design decisions, as compared to pupils’ design decisions in previous electronics projects?

There are considerable differences between the details in each school (see overleaf), but it has proved possible to adopt a similar research approach and to develop some pupil support materials which have been adapted to the specific requirements of each school.

Prior to the introduction of the new Unit, staff and pupils at each of the schools were interviewed in groups to explore their beliefs and feelings about creativity in general, in a variety of school areas and specifically in electronics. The interviews were recorded and transcribed, and provide a valuable insight into pupil and staff thinking and experience.

During the new Unit progress was monitored by shorter informal visits, interviews and discussions. During the final week of the Unit staff and pupils were again interviewed to evaluate their views on the new approach, and in particular the extent to which it has supported creativity, and how it could be improved.
In addition, at the end of the Unit, pupils in all the schools were asked to complete a questionnaire (very similar to the one used in Steeg and Martin, 2005) that asked them to evaluate the extent to which they were able to make design choices in various aspects of the Unit. This paper reports preliminary results from the analysis of the questionnaire data. A fuller account will be published when the analysis is complete.

The Kingsway School, Stockport
The new Unit was used with Y10 pupils as part of their Design and Technology: Electronic Products GCSE.

In previous years at this point in the GCSE course the pupils have done a project based on ‘traditional’ electronics technology with quite a constrained brief – a toothbrushing timer. Their design choices were limited to:

- minor modifications of the component values (to change the timing period);
- the colour and decoration of the case.

This Unit was replaced with a completely different one, making use of PIC technology and exploiting the flexibility that this allows. The scenario used was a point of sale display system. The pupils were able to make their own choice of the product that was being promoted and the associated graphics. The approach adopted was to provide the pupils with a pre-designed and made PIC ‘core’ board on a PCB (so that they did not have excessive complexity to deal with in this their first encounter with PICs) but where they had almost total freedom to add (on a separate prototyping board) their own choice of input sensors and output devices. In addition, they were able to make decisions on how the point of sale system would behave because they were writing their own control program for the PIC. So, with the new Unit, pupils were able to make their own design decisions about:

- the artwork for the presentation and the positioning on this of input sensors and output devices;
- the types of output devices they would use;
- what happens at an output (or range of outputs) when the user activates an input;
- what types of components they would use as sensors (inputs).

A main finding from the interviews was that the teachers’ perception was that the pupils felt that the new approach was a significant improvement, especially in the area of creativity, because they were able to make the kinds of design decisions outlined above. However, there were problems with the approach used for prototyping the electronic system. Pupils were generally able to make sensible choices of input sensors and output devices, consistent with their overall designs. Where they found considerable difficulty was in reliably transferring their subsystem designs to the prototyping breadboard and testing that these worked. They were hindered by components falling out of the breadboard, especially in the intervals between lessons.

The consequence of this was that some pupils became frustrated and discouraged. Our interim conclusion is that the overall approach is promising, but that a different technology will need to be developed to allow pupils the same design freedom in selecting input sensors and output devices, without the manipulation problems encountered in the present approach.

The Queen Katherine School, Kendal
The new Unit of work was piloted with Y8, with a view to incorporation in the design and technology KS3 scheme of work for all pupils at the school.

The brief that the pupils were given was to design and make a ‘mood light’ (suitable as decorative lighting for e.g. a bedroom).

The key new features of the Unit were:

- making use of PICs (in the form of a pre-constructed kit) so that the pupils have much more choice about how their product operates;
- using an attractive range of modern plastics to produce products with high aesthetic appeal;
- some use of CAD and CAM to shape the plastic and wood used for the body of the lights;
- introducing them to a range of attractive modern high intensity LEDs, including ‘rainbow LEDs’ that cycle through the colours of the rainbow;
- the pupils worked in teams of four, and were encouraged to make use of this to discuss and evaluate ideas and to support each other.

The work with PICs was new to the pupils, and so was kept relatively simple. All the pupils were able (in some cases with extra guidance from the teacher) to program the PICs in the way they wanted to give interesting lighting effects.

The design ideas that the teams developed were attractive, interesting and makable. They showed a considerably higher level of creativity than might be expected of Y8 pupils, and were of a standard that would be more typical of GCSE projects. All the mood lights were completed within the time allocated for the Unit, though this did involve some work during lunchtimes.
Key points made during follow-up interviews were that the balance of discussing the project in the teams of four, working in pairs and working individually was about right and led to better ideas, and had helped with both creativity and the development of knowledge and practical skills. The work with the PICs was new and challenging but the pupils were able to program their systems in a variety of ways to behave how they wanted. The use of attractive colourful acrylic added a lot to the project, because it meant that the pupils could see that the materials available had the potential to enable them to produce aesthetically pleasing lamps.

**Birkdale High School, Dewsbury**

Of the three schools in the partnership Birkdale experienced the most difficult conditions being a school in special measures working with a markedly deprived catchment.

The school was already running a Year 8 ‘Alarm’ project based on a non-programmable systems approach and making use of systems based design software. The school decided to use this as a ‘reference’ project and provide two groups of pupils with the opportunity to revisit the alarm context with a PIC-based circuit. Work with PICs was new to both the pupils and the teachers, the latter being a significant issue, as the school operates a system in Year 7 and Year 8 where pupils are taught by the same teacher across all disciplines in technology – so any new teaching approach needs to be assimilated by all D&T teachers, whatever their material specialism.

The first lesson of the reference project involved a hands-on product analysis of a wide range of different types of alarm, to encourage a diversity of selection. The pupils were given an open-brief to select a suitable application for their own use. The applications selected by the pupils ranged from ‘drawer detective’-type alarms and window alarms to simple doorbells. The use of a standard (transistor driven) circuit board in the reference project, meant that pupils could still achieve personalised outcomes by selecting input and output devices, without the need to make twenty-odd individual PCBs per class.

The PIC project used a standard PICAXE alarm circuit, with hardware customisation limited to using either an LDR as a motion (or opening detection) sensor or a switch for the input, and either an LED or buzzer for the output. PIC programming was a carried out using PIC Logicator 2005, the teaching of which proved to be a significant challenge to some members of the D&T team and the learning a challenge to some pupils involved. Interestingly the interviews revealed that pupils had had flowchart based programming experience (i.e. similar to PIC-Logicator) in ICT, but the connection had not been made.

Within the six weeks available for each project, pupils on the reference project were able to design and manufacture a simple card enclosure for their product using 2D CAD software and a card cutter. Pupils on the PIC project required significant time to learn to use the software package, so a standard enclosure was provided (although some of the more capable pupils were able to design their own).

Pupil interviews suggested that they felt the PIC project was ‘harder’ but that they enjoyed it more; when pupils were pressed on this apparent anomaly, it was clear that doing the PIC project made them feel more ‘grown-up’ because the hardware was more complex and they recognised that it was more like ‘real life’ electronics. They also recognised and appreciated the fact that, although the input and output components were similar in the two projects, the PIC-based system gave them greater choice over what the alarm actually did.

**Conclusions**

The introduction to this paper describes a systems hierarchy and a hypothesis that as the focus of work in ECT moves to a higher system level, the scope for pupil creativity will increase. While we continue to believe that this hypothesis has validity, we have come to recognise that including PICs in electronics project work does not, of itself, enhance pupil creativity. PICs have only become available for use in schools in the last few years whereas in typical (traditional) electronics work teachers, using either a circuit and component or a systems approach, have tended to restrict pupil design decisions (and hence, in our analysis, creativity) in order, quite sensibly, to ensure that they produced working systems. For these ‘historical’ reasons there is a tendency for teachers of electronics to continue to adopt a rather prescriptive approach, even though PICs provide the potential for a more creative approach.

The most important focus of the present work has been to develop and evaluate Units of work at the three schools that exploit the increased opportunities for pupil creativity offered by PICs, and by CAD/CAM. We feel that considerable progress has been achieved, and this owes a great deal to the teachers’ willingness to try new approaches.

It was noticeable that in the preliminary interviews, conducted prior to embarking on the new Units, the pupils perceived ‘creativity’ as referring solely to the visual and aesthetic aspects of product design. In the post-Unit interviews many of the pupils, when asked about creativity, referred to the work with PICs (as well as aesthetic aspects of their work).
Reflecting on the work in the different schools:

• We feel that the work at The Kingsway School has greatly expanded opportunities for creativity, and was recognised by pupils as having done so. The one significant problem was that the prototyping system used led to confusion and frustration. We are already considering ways in which this technical problem can best be overcome and will report the results when the Unit of work has been modified and repeated.

• The Unit developed at The Queen Katherine School has worked well and was very positively received by pupils and staff. The use of project teams was particularly significant and pupils felt that this was an important factor in supporting creativity. A good balance of decision-making in all the key areas of the ‘design pentagon’ (see Figure 2) was achieved, without over facing the pupils with too much new knowledge and skills.

• The development of PIC-based work at Birkdale School provided significant challenges both to pupils and for staff development. There were very real fears that the unit being developed would be too demanding for the pupils. In the event the pupils responded very positively to work that they perceived to be more ‘real’ even though they found it harder. The implications of this are being considered by the department.

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Footnote

Information about Creativity Action Research Awards (CARA) is available at: www.creative-partnerships.com/cara

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