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Making connections: students using science understanding of electric circuits in design and technology

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Abstract

The requirements of the National Curriculum note the importance of using science (and mathematics) in design and technology activity: 'pupils should be given opportunities to apply skills, knowledge and understanding from the programmes of study of other subjects, where appropriate, including art, mathematics and science.'¹ Although it is difficult to disagree with this requirement, the nature of the links are not clear. In particular, there is little evidence from classroom research that indicates how students use and build upon their scientific understanding. Our work indicates that there are some difficult problems for both students and teachers;^{2,3} and, despite discussions in the design and technology education literature,^{4,5} there is as yet little empirical evidence of how students use science understanding in technology activities. We argue here for more research on this issue and analyses of the requirements of design and technology tasks.

As part of our research into problem solving in technology education at Key Stage 3 in schools in England (*Problem Solving in Technology Education: a case of situated cognition?* funded by the UK Economic and Social Research Council, grant number R00023445), we have carried out some pilot work investigating students' use and understanding of related scientific and technological concepts. Some of this work has involved the design and make of products that use electronic circuits, such as a lapel badge and a moisture detector. In this paper we present some of the issues involved in students using and developing that understanding of scientific and technological concepts.

The task context: a moisture detector

The design and make of devices such as a moisture detector were included in the National Curriculum Order for design and technology for KS 3, as is the associated technological systems concepts of 'input', 'process' and 'output'.⁶ The evidence we report here is taken from an example of this kind of design and make task. In the case study of this task we observed students carrying out the project in two parts: assembling a circuit, designed by the teacher, that would detect moisture; and designing and

making a styrene box to house the circuit and allow for the removal of the battery. The project occupied seven weeks with two sessions of 1hr 40 min per week, each session being taught by a different teacher, one of whom [A] concentrated on the design and construction of the box, while the other [B] taught the functioning and construction of the circuit. (This division occurred because of timetable constraints.) Initially the students had to choose a context for their sensor and most elected to make a water level detector - for a bath or sink, or a (lack of) moisture detector for a plant pot. Although both aspects of the construction raise issues related to conceptual knowledge, for this paper we concentrate only on the circuit assembly and testing tasks.

The steps that the students had to undertake to complete the assembly of the circuit were:

- learn to recognise the components;
- draw the standard circuit diagram - copied from the board;
- observe the process of etching (to understand the production of the circuit board);
- drill the circuit board and strip the wire ends;
- solder in the transistors and resistors;

- connect the probe wires, switch, LED and battery snap;
- test the circuit and correct faults if necessary;
- modify the circuit for the situation they had chosen - changing the output; altering the circuit to detect lack of moisture;
- test the circuit again and correcting faults if necessary.

Students were given a standard circuit, that assumed a 'make contact' as the input and a LED as output, which they had to modify if they were doing a plant pot moisture detector ('break contact' as input), or buzzer as output.

Knowledge requirements of the task

The planning of a technology project requires teachers to take account of the conceptual knowledge that the students already have and to build on it adding new knowledge that can be used in future work. In this study the teachers expected the student outcomes to be:

to learn a greater understanding of electronics because the new National Curriculum at KS 4 was hinting some time ago that electronics was something that we need to be teaching children and we were not doing that so we need to alert and raise the awareness toward electronics so that we can introduce them in Year 9 to the 555 chip which will do so many things, and then on to do with other things to do with electronics for them to understand the world is an electronic world.[Teacher A]

For these teachers the dilemma was to know what knowledge they could assume the students already had, which came substantially from their Middle school experience (students entered this school at Year 8). The National Curriculum now gives no guidance on what particular aspects of science might be important, and does not help in co-ordinating the science and design and technology Programmes of Study (e.g. voltage is not taught in science until KS4, but could be used in D&T KS3 to understand a moisture detector). The knowledge requirements of a moisture detector project, to enable students to assemble the circuit, test it and to diagnose faults, are:

- ideas of polarity, in order to correctly orientate the transistor and LED with respect

to the battery output (and that the resistor has no polarity);

- the idea of a complete circuit, for correct alignment of components across gaps in the circuit and diagnosis of faults;
- the idea of conductivity through solids, to be able to check joints and detect faults and short circuits.

In order to follow the teacher's instructions for the assembly the students also needed to be able to:

- recognise the components and relate them to the symbols on the circuit diagram;
- relate the circuit diagram to the PCB circuit;
- use the PCB drill, wire strippers and soldering iron.

In addition to the science ideas, students needed to be able to understand the technological concepts of 'input' and 'output', and how they related to the design of their particular device. (See Table 1 for the design variations.)

Students' learning of the concepts

We investigated this learning by observing students as they designed and made their moisture detector, and interviewing them with it present, as well as with some simple circuits (to test their science ideas in the way they experienced them in 'science lessons'). They were also asked to select conductors from a sample of objects, generalise about conductors, identify the polarity of an LED and explain why solder rather than glue was used in the circuit. Here we will focus on three issues that arise from these data.

Prior understanding

All the students said that they had previous experience of electrical circuits using batteries to make bulbs light. When we gave them batteries, bulbs and holders, leads and a switch, eight students out of eleven were able to make a bulb light. They also knew that adding a second battery would make the bulb light more brightly. Those students who could make the bulb light could also draw a circuit diagram to represent what they had done. In addition they could also correctly identify materials that would conduct and generalise that metals were conductors. We could assume

then that the majority of the class had a basic understanding, in the context of a science lesson, of:

- a complete circuit;
- a metal conductor being needed for an electric current to flow to operate a device such as a bulb.

Students' use of scientific understanding

The students needed to use their knowledge of circuits and conductors when they came to test the circuit that they had assembled. A power pack was used rather than a 9-volt battery and students had to connect it to the circuit using crocodile clips on the battery snap. With their circuit switch in the 'on' position they then touched the bare ends of the probe wires together and looked for the LED to glow. If this was successful they moistened their finger and thumb and held the probes wires a small distance apart, with damp fingers. When the LED failed to light with direct contact of the probes, students did not seem to realise that this indicated a fault in their assembly, because they still moved on to test the circuit with damp fingers. There was little evidence of the students using their understanding of the functioning of the basic circuit to detect faults. When faced with failure they simply tried, ritualistically, the testing procedure for a second and even a third time before seeking help from the teacher. In fact some of the difficulty stemmed from lack of familiarity with the power pack. Errors included failing to switch it on, not realising that the cut out had been triggered, and not understanding that the polarity of the output needed to be matched to the correct terminals of the battery snap. Even when this was correctly done, the switch built into their own circuit needed to be on and students did not always recognise the 'on' position. We saw little evidence that the students tried to find faults for themselves, with the exception of one boy, easily the most confident in the class, who could be seen examining joints of leads and components on the PCB and checking them against his circuit diagram. The teacher seemed to accept his own role as fault finder and simply identified a potential fault and sent the student to correct it (e.g. a loose connection or a component in the wrong position), with little or no explanation as to why this was affecting the function. As a result, when the students began

to modify their circuits, by changing the outputs or moving components, and then needed to test the modification, they still resorted to asking the teacher for help if the circuit did not work. The teacher, who had in earlier lessons assumed (correctly) that the students did understand the basic ideas, failed at this stage to encourage the *use* of the concepts. This was perhaps because doing the fault finding himself was quicker and easier than helping the students to understand for themselves (understandable in the rush to finish projects).

Explanations of circuits

With Teacher B, students spent a considerable time passively listening and copying from the board. Table 2 shows the time spent and the topics dealt with. The diagram that they copied was intended to assist with assembly of the circuit and we observed students consulting it as they were doing so. They did not have to make any notes of the session in which the functioning of the circuit was explained. The teacher did not attempt to draw on the students' knowledge and only rarely asked questions. When he did so, the answers came from the two boys [P and R] who had the greatest prior understanding (from our interviews).

By the end of the project all the students had assembled a circuit which worked, and modified it to suit their design. Some had done this fairly independently, others had achieved it with considerable help from friends or the teacher. Yet our observations and interviews suggested that probably none understood how the circuit worked, although they could now name the components. Student responses to the question "What have you learned?" illustrated this:

P: I know how to put the circuit board together I know how it works I suppose, I didn't know what any of the components did.

N: Just learned the names of all the components and this teaches you how to build a circuit and which sort of things are resistors; and how it all works and which is the input and output and that sort of thing.

One comment, from a student with a good understanding of circuits and experience of using electronic kits at home, is more revealing.

R: I know that electricity goes from positive to negative and that when it meets a resistor only a certain amount of electricity can go through so that's diverted and I know the transistor is a switch preventing or allowing the electricity to go through, but I'm not sure how having all that put together makes a moisture sensor.

Clearly the project had met the aims of the teachers in increasing the students' awareness of what electronics can do, and in future projects many of them should be able to recognise the components. However, they did not learn how the circuit worked, on which the teacher spent so much time and, perhaps more importantly, they did not learn what to do when a circuit would not work. Nor could the students describe the circuit in terms of 'input', 'process' and 'output'. Although output was correctly identified in student interviews at the end of the project, few could identify the 'input', confusing it with the battery function or the probe wires attached to the circuit.

In this project the science knowledge that the students brought to the workshop was largely inert. It could have been made useful if, instead of concentrating on the operation of the circuit at a level of understanding that was beyond most Year 8 students, the teacher had used the time to relate their understanding of a basic circuit (continuity, short circuits and polarity) to the testing and fault finding of their assembly. This could have provided useful knowledge to carry forward to future projects. (This approach reflects the distinction that Plant makes when he discusses the 'know how' of technology and the 'know why' of science.⁷)

The issues for teachers

The National Curriculum gives teachers an impossible task, by expecting links between science and design and technology to be

made, but providing little analysis or support to ensure it can be done. Any teacher trying to encourage links needs to be clear about the following:

- what knowledge we assume students bring with them, how we find out the extent of that knowledge, and how we activate it for use;
- what knowledge we want to teach, ensuring that it is really necessary for the task;
- what we should leave out; we need to consider what explanations the students will need to use in their project and focus on those effectively.

To be able to answer the questions implied above, we need more awareness in the classroom and more research, particularly to see the role for design and technology in making largely inert knowledge from science useful.

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Product	Inputs	Outputs
Plant pot detector	rigid rods - break contact	buzzer; LED/bulb
Bath-level indicator	rigid rods - make contact	as above
Washing line rain detector	concentric parallel grid - make contact	as above

Table 1: Design choices in the design of a moisture detector

Session	Time spent (min)	Teaching content
2	17 34	Giving out and naming circuit components. Copying the circuit diagram including an explanation of the transistor drawing.
4	24 18	Identifying the components, function of components, learning circuit symbols. Function and use of solder, how to solder.
6	17 4	Explanation of how the circuit works in terms of electron flow. Action of battery, resistor and LED. How to modify circuit to meet own design needs.
10	3 2 4 3	Function and action of resistor. Description of system as <i>input</i> , <i>control</i> [not <i>process</i>], <i>output</i> . Function of the transistor in detecting moisture. How to modify the circuit to meet needs of their design.

Table 2. Time spent teaching understanding of the circuit by Teacher B.