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A comparison between the nature of modelling in science and design and technology

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Abstract

This paper will compare the modelling likely to take place in science lessons with that likely to take place in design and technology lessons during Key Stage 3 by exploring three areas.

- 1. The nature of scientific activity in the real world and in school science. This will involve looking at the popular culture view of scientists and their activities, an informed lay view and that advanced by Thomas Kuhn. The intentions of science education will be stated and the role of the pupil as pupil as scientist within this as advanced by the constructivist school notably Rosalind Driver will be explored. Enabling pupils to understand the particulate nature of matter will be considered as a modelling exercise and the strategies for this explored. Parallels between this activity and the real world scientist activity will be drawn.*
- 2. The nature of design and technological activity in the real world and in school design and technology. The differences and similarities between instrumental and educational design and technology will be explored.*
- 3. The nature of modelling in school science and in school design and technology. Examples of the models produced by pupils in both school science and school design and technology will be discussed.*

The comparison will reveal that through a joint approach to modelling science and design and technology teachers can support each other's curriculum endeavours.

Two recent articles^{1,2} concerned with modelling in design and technology and my own interest in the use of scientific understanding in design technology^{3,4} have prompted me to look at the modelling that may be carried out in science lessons and compare this to the modelling that takes place in design and technology lessons.

To begin with a definition of a model is required. It can be defined as a simplified or idealised version of reality created for a purpose. From this it follows that modelling is the process of creating models which fulfill their intended purpose successfully.

To put modelling into an appropriate context it will be necessary to explore three areas:

- A) The nature of scientific activity in the 'real' world and in school science.
- B) The nature of design and technological activity in the 'real' world and in school design and technology.

C) The nature of modelling in school design and technology and school science.

A) The Nature of Scientific Activity in the 'Real' World and in School Science

i) Scientific activity in the real world

Let us begin by looking at the image of the scientist. The prevailing stereotype of the scientist, particularly among school pupils, is as follows: male, wearing a white coat and spectacles, obsessively interested in science, unworldly, and unaware of persons and events outside science⁵.

However representative of real scientists this image may, or may not be is open to question but it does contribute to a common culture view of the scientist and what he (as opposed to she) does. Scientists do experiments to find things out; sometimes they go wrong with disastrous results as in science fiction films (The Fly and The Blob) or as in real life (Chernobyl and Bhopal) although these may perhaps be better described as technological blunders rather than scientific ones. Nobody was trying to discover a new or elusive scientific truth when these disasters occurred but the media certainly talked about and blamed the scientists working at the establishments concerned.

An informed and perhaps sympathetic lay person's view of scientists and their work might be as follows: a scientist carries out lots of observations through activities called experiments. She/he sets up models that can be used to explain observed phenomena and predict future observations. The phenomena that are observed are those that are 'reliable' in that they can be observed by others who may or may not believe the explanatory model that the scientist wishes to invoke in explaining that phenomena. Eventually the models carry sufficient weight that they become embodied in scientific theories such as the atomic theory. The work of Thomas Kuhn⁶ has described the development and acceptance of a major scientific theory as establishing a paradigm in which the majority of the scientific community trust and work. When the scientific community builds a body of reliable data that cannot be explained in terms of models derived from the prevailing theory a scientific revolution occurs in which the old theory is discarded in favour of a newer theory which can accommodate this new data as well as that accommodated by the previous theory. This is the paradigm shift and like all revolutions is uncomfortable and involves power battles between conservatives who hold to the previous theory and radicals who advocate the need for a new theory. The revolutions in moving from Newtonian Physics to Einsteinian Physics and from classical physics to quantum physics are examples. Note these are rare occurrences and most of the time most scientists are simply gathering data that informs and conforms to the current paradigm.

ii) Scientific activity in the school science

We can suppose that the purpose of school science is to engage pupils in the methods of science so that they can know and understand a significant body of scientific knowledge, understand how science contributes to our understanding of the world and take an informed interest on those issues facing society that have a scientific dimension.

The work of Rosalind Driver (Children's Learning in Science Project based at Leeds University) has given great strength to the constructivist view of learning and insights into the nature of school science from the pupil's perspective. This view of learning requires the learner to construct his own meaning by reconciling new information with existing beliefs. This reconciliation is much more than simple remembering. It is quite possible for a learner to learn off by heart great chunks of information without understanding any of it or for that information making any difference to the set of beliefs by which the learner explains the world around him. Driver and her co-workers have described a phenomenon known as pupils' alternative frameworks. These are sets of beliefs held by pupils that are at variance with the accepted scientific view. Alternative frameworks for a variety of scientific explanations - electricity, energy, gravity, force dependant phenomena - are well documented across pupil populations in Western Europe, USA, Australia and New Zealand⁷. From a teaching point of view the most challenging feature of pupils alternative frameworks is that they are very resistant to change. It is only the pupil who can change her / his set of personal beliefs in response to new information. This requires both a willingness to do so and an awareness that an inconsistency exists. This is further complicated by the fact that many pupils have been shown to apply what is called 'local reasoning'. They are inconsistent in the way they apply their set of beliefs often to avoid any fundamental shift in position. So the question arises how can the scientific modelling required by science education be reconciled with pupils alternative frameworks?

If a teacher sets up any of the significant and accepted scientific models for explaining the physical world there is the immediate problem that it is at such variance with a pupils alternative view that it will be rejected out of hand with minimal consideration. Some would argue (see for example M Arnold and R Millar⁸) that children should be allowed to postulate their own models and explore them for inconsistencies. With appropriate guidance they will move to an accepted scientific view and although this looks as if it will take longer than a more didactic or expository form of teaching, if fundamental concepts are developed in this way during primary and early secondary school, then later progress will be much faster and we will not be in the current position of 70% of fifteen year olds experiencing difficulty in interpreting the circuit diagram for a simple torch⁹, others, myself included, take a less extreme view and would introduce the models but give pupils sufficient time and a wide range of activities related to the models, including those perhaps not normally associated with science education - dance, music, drama, creative writing, making flip books, small group discussion - for the pupils to establish such an

ownership of a model that they can use the model to confront the inadequacies of their current (alternative) set of beliefs.

Let us look at one of the most fundamental models used by scientists - the particle model of matter. This model starts by postulating that all matter - solid, liquid and gas - is made of particles. Such particles are so infinitesimally small that a single particle cannot be seen using the most powerful light microscope. [At a rough estimate there would be about one million, million, million, million such particles in a tablespoon of water i.e., 1,000,000,000,000,000,000,000,000,] A further condition of the model is that the particles of a single substance are all alike - same mass, same size; but different from the particles of all other single substances. Now at first sight this does not seem a very useful way of looking at the world. It certainly requires a large dose of imagination and mental effort to begin to take it seriously; after all it does sound preposterous. The strength of this model lies in its powers to explain everyday phenomena, make predictions and to be developed to explain more complex phenomena. The model is so powerful that it is, as far as most scientists are concerned, not a model but a statement about what the world is really like i.e. it is a theory.

The development of this theory has its roots in Ancient Greece; it has had periods of acceptance and rejection. As recently as 1906, Boltzmann, a scientist of great repute and historical significance who believed strongly in the particle model of matter committed suicide because the model was under such strong attack. Many texts trace the development of this model but this is not strictly relevant to what follows. Those particularly interested are recommended to consult Mellor¹⁰.

Let us try to use this model to explain the properties of solids, liquids and gases. First we must establish the observed nature of these: solids have a fixed volume but no fixed shape - they take up the shape of their container, are incompressible and form into droplets quite unaided. Gases have no fixed shape or volume, they spontaneously spread out to fill the available space and are compressible.

Now we can imagine a solid, liquid and gas as being made up of these minute particles so that the arrangement we envisage explains the properties that we observe to be true? If we can, then surely this is imaging and modelling worthy of any design and technology lesson?

A model like Figure 1 emerges¹¹. We can extend this model in trying to explain what happens when a solid interacts with a liquid and a solution is formed. To do this we need to have a clear and agreed set of observations related to dissolving. A simple demonstration helps; a small crystal of potassium permanganate is placed in the centre of a dish of water. Potassium permanganate is chosen because it is soluble and coloured. The purple colour spreads out from the crystal into the water even though there is no stirring. A model like Figure 2 emerges.¹¹ Figure 3 is an English teacher's attempt to engage pupils

with the model by helping them to write creatively about it.¹²

iii) Comparing 'real' world and school science

Given the resistance to change of alternative frameworks it is tempting to argue that as children progress in their scientific understanding they go through a series of personal paradigm shifts that eventually lead them to a publicly acceptable set of scientific beliefs (that required by the National Curriculum perhaps). Given also that responding to a paradigm shift is an uncomfortable and agonising experience for the professional scientist (most of whom do not, most of the time, actively seek out data to challenge the prevailing paradigm anyway) we should not be too surprised that many children go to great lengths to avoid such shifts in allegiance. It is becoming increasingly apparent that helping children to reconcile inconsistencies in their beliefs and the way they are used to explain the observed world would be an important role for the science teacher as she/he guides pupils to the publicly accepted view. I will return to a modelling perspective on this later.

B) The Nature of Design and Technological Activity in the 'Real' World and in School Design and Technology

i) Design and Technology in the 'real' world

It is the outcomes of design and technological activity that are significant in 'real' world design and technological activity. The procedural competances that are developed and utilised by those producing the outcomes are insignificant compared to the outcomes themselves. The motivation for the endeavour is the production of an outcome that is seen as responding to an opportunity or meeting a need.

An opportunity is linked to the notions that design and technology may be innovation driven or market led. It may involve the production of a new product as in the case of the "walkman". This did not exist before 1975 and no part of the human race was excessively deprived because of this. Technical developments in earphones rendered a walkman possible and intelligent marketing rendered the walkman an object of desire. Now it (and a variety of clones) are produced and sold in millions world wide. Or an opportunity may involve developing a product that exists already. The safety razor has existed since the early twentieth century. It clearly meets a need but the development of a variety of 'innovative' forms over the past thirty years is in response to market pressures from competing manufacturers.

A need is linked to the notion that design and technology is beginning in that it responds to needs by developing products that meet those needs. Some designers such as Papanek¹³ have argued that design and technology has failed by being innovation driven and market led and that the only honourable function for design technologists is to identify 'real' needs, on a global scale, and to use their talents to meet these. Papanek polarises the distinction by

asking questions like 'If two thirds of the world is hungry how can any sane person spend his time developing convenience food for the over fed?'

ii) Design and Technology in school

Although pupils produce outcomes (artefacts, systems and environments) as the most obvious 'end product' of design and technology in schools in trying to meet needs and grasp opportunities it is the intentions (meeting the need or grasping the opportunity) and the procedural competances developed and utilised in response to those intentions that are significant. Current models of good practice require that the pupil has significant responsibility for the nature and quality of the response she / he makes and that she / he is required to reflect on and evaluate both the nature and quality of her / his response. Without product there can be no design and technology process but it is the process that is educationally significant although it is the nature of the product at varying stages within the process that reveals much about the process.

C) The Nature of Modelling in School Design and Technology and School Science

i) Modelling as a pupil design/technologist

It is all too easy to see the end result of the modelling activity, 'the models', as the most significant part of the activity. They are only significant to the extent that a) they help the designer, be they pupil or professional, develop a clearer picture of that which she / he is designing and b) that in the case of education they reveal to the teacher the mental processes of the pupil in coming to grips with the design task. While it is convenient to classify the models in terms of their form it is important for the teacher to see them for what they are in educational terms - insights into pupil thinking. Modelling as used by pupils in schools may lead to the following outcomes:

2D representations on paper

These include progression from 'rough' exploratory sketching of overall concept, through part details and assembly considerations to full rendering of finished form and working drawing allowing making by someone else.

3D representations

These include simple paper, card, straw, lolly stick, paper fastener explorations of mechanisms and structures as well as the use of kits such as Lego and Fischer Technic. Similarly explorations of overall form can be developed using simple materials without any attempt to achieve final finish as opposed to detailed block modelling which is the 3D equivalent of a rendered drawing.

Symbolic representations

These come in the form of mathematical formulae, calculations, concept diagrams and graphs. They can be used to calculate details of mechanical

arrangements, geometric drawing may be used to plot loci of moving parts. Displacement v time and velocity v time graphs may be considered in developing the correct profiles for cams. Vector diagrams may be constructed to reveal the nature and size of forces in frameworks.

Computer simulations

These can be used:

- to explore a variety of finishes or decorative schemes - paint programmes,
- to explore a variety of forms - 3D modellers,
- to animate a mechanism, e.g crank and con rod, and explore variations on key variables - animation programmes,
- to generate working drawings - such as CAD packages.

Whatever form the model takes, it is important that it moves the pupil towards a clearer detailing of the design proposal.

ii) Modelling as a pupil scientist

Using the mind's eye to conjure the particle picture is an activity that can be described by the APU model for design and technological activity Figure 4 (taken with permission from APU Design and Technological Activity A Framework for Assessment¹⁴); where the iterative process of developing a detailed design proposal can be seen as paralleling the iterative process of acquiring ownership of a scientific model; one that means something to the learner and is moving towards that which is deemed acceptable in terms of prevailing scientific views. Note that the model only becomes examinable when it comes out of the head and appears in concrete form. Engaging pupils with expressing themselves about the particulate nature of matter can lead to a variety of interesting outcomes - flic books models and creative writing.¹⁵ (See Figure 5 for examples) None of these are prescribed outcomes, each pupil in a class set such tasks will produce their own unique responses. As in the case of the pupil as designer what is important about the model is that it moves the pupil towards clearer detail, in this case a clearer appreciation of the atomic model.

In conclusion I believe that I have shown that teachers of science and design and technology share both an opportunity and a responsibility to involve pupils in modelling - an activity that is central to both disciplines. A consideration of a joint approach to this as opposed to who is covering what content might provide an interesting strategy for co-operation between science and design and technology in the school curriculum.

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