Enhancing Students' Understanding of the Nature of Science

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INTRODUCTION

Underlying the nature of science is the concept of model. Modelling is a fundamental aspect of 'doing' science (Gilbert 1991). An enhanced appreciation of the nature of science, therefore, inherently involves an understanding of the role and the nature of models. Teaching science is a 'matter of conveying mental models of science' (Bliss 1995: 166). Mental models refer to students' personal knowledge while conceptual models refer to scientifically accepted knowledge.

WHAT ARE MODELS IN SCIENCE?

A model, generally, might be considered to be the representation or the outcome of the creative transfer of some aspects of the source of the model (from where it is derived) to that which is being described, that is, to the target of the model. For instance, the source of the orbiting electron-central nucleus model of the atom (i.e. the Bohr-Rutherford model) is the solar system which consists of planets orbiting a central sun. The development of science consists of the construction of models and the consequent development of theories.

All models start as (private) mental models. Some mental models in science will, through description and extensive use, survive to become publicly available conceptual models. Ingham & Gilbert (1991: 193) quote Black (1962) as classifying models into five types:

- Scale models, which are 'likenesses of material objects, systems or processes, whether real or imaginary, that preserve relative proportions'.

- Analogue models, which represent 'some material object, system or process, designed to produce as faithfully as possible in some new medium the structure or web of relationship in the original'.

- Mathematical models, which are of situations 'that can be summarised in, or represented by, a mathematical equation' .

- Theoretical models, which involve 'the production of some concretised representation of a phenomenon, which can be applied to the study of the phenomenon without making theoretical assumptions about it.'

- Archetype models, which are 'a systematic repertoire of ideas by means of which a given thinker describes, by analogical extensions, some domain to which these ideas do not immediately and literally apply.'

Finegold & Smit (1993: 19), following a literature survey, suggested the following features of the nature of models:

- Models are constructions of the human mind and are temporary by nature.

- Models in science are analogues of things and processes.

- The two main uses of models in science are heuristic — to simplify a phenomenon or make it easier to deal with, and explanatory — to explain the unknown mechanism which is responsible for the phenomenon.

- The models utilized in physics are not pictures of the underlying reality but are viewed as representations of real entities.

- An important role is played by models in the acquisition of knowledge about nature.

- A clear distinction is made between a model and a theory. Ideally, a theory should contain the description of a plausible model, modelled on some thing, material, or process which is already well understood.

THE USEFULNESS OF MODELS

Craik (1943: 13) has stressed the power and usefulness of models in thinking:

> *If the organism carries a 'small-scale model' of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and future, and in every way to react in a much fuller, safer, and more competent manner to the emergencies which face it.*

The term physical intuition is used to describe the ability to construct mental models. The cognitive development of the student can be described as the development of mental modelling abilities. Mental models are both a method of representing and a way of organizing knowledge.

Models help the scientist to predict, describe and explain natural phenomena, particles, and structures. The descriptions are never complete and different models can be used to describe the same entity. Physicists can define a 'gravitational field', but does a gravitational field have any reality beyond its definition? Is it something physical or is it a mathematical fiction? The distinction is not as clear-cut as it may seem. There is a feeling that something can be 'understood' if it can be pictured as, say, wheels and levers fitting together. The development of twentieth century science has involved a movement away from visualisable models towards abstract mathematical models. At the microscopic level 'physical reality' cannot be directly perceived by the senses. As a consequence, it is not intrinsically knowable (in the same sense) as macroscopic reality. It can, however, be approached at an inferential level using measurements from macroscopic instruments. Physical models based upon macroscopic experience suggest analogies. Mathematical models can be suggested by physical models (and vice-versa). These usually represent a further simplification for mathematical convenience.

Research into students' conceptions of models

Research on students' conceptions of the nature of models has found that students need more experience and discussion on the nature and roles of models (Duit 1991; Grosslight, Unger & Jay 1991). Gentner & Gentner (1983), for instance, presented students with the 'moving-crowd' and the 'flowing-fluid' models for electric current. They found that different aspects of electrical behaviour were best understood by the most apposite analogy. Similarly, Black & Solomon (1987) found that taught analogies or models did not greatly help students in answering typical examination questions, but that students were better able to deal with novel situations. Arnold & Millar (1996) reported favourable findings in explicitly using a water model to teach basic thermodynamics. Harrison & Treagust (1996), in investigating students' mental models of atoms, found that students can mistakenly regard analogical models as being literal representations of reality. There is also the problem of 'worn-out models' interfering with the acquisition of new ones. The Bohr model of the atom is introduced by analogy to the solar system, but the model of orbits that is acquired can get in the way of the later incorporation of more advanced concepts of quantum physics (Mashhadi 1995).

The student's mental model of a system may be incomplete, confused, and subject to sudden change. It may not even be internally consistent. However, the possession of a model enables the student to save mental effort in coming to terms with a problem. The model summarizes the student's beliefs about a system, however unjustified they may be in scientific terms. The aim of the model is to enable predictions to be made about the likely future behaviour of a system. The student is unlikely to be concerned about aspects of the model that do not make sense. Teaching and learning involves the construction by the student of mental models for entities not perceived directly, e.g. light (quanta of light), electric current (electrons), particles of matter (atoms). This modelling process is complex as it requires students to construct and use certain entities (these may be sets of objects or systems), describe these entities in exact ways using certain parameters (e.g. mass, volume, temperature change), and account for the processes of interaction between the parameters by describing relationships between them (using inventions such as force, heat, and electric current). Perhaps, not surprisingly, the building of such complex models requires considerable effort and time from the student.

In summary, the nature of models should be taught explicitly when students are taught about non-observable phenomena (e.g. light, atomic structure) and where there is a tendency for the model to be confused with reality. Students' understanding of science is enhanced when they appreciate the strengths, the limitations, and the very nature of models.

CONCLUSION

The *tabula rasa* or 'blank slate' picture of the student has been replaced by the recognition that students are actively engaged in the construction of their own learning and understanding. On the basis of their everyday experience, people develop naive theories or alternative conceptions that can provide not only descriptions of, but causal explanations of, phenomena. These alternative conceptions significantly influence student learning. Research into student thinking has underscored the need for students to have a greater self-awareness of their own models, to make predictions based on them and to make comparisons between their own and accepted scientific models in order to enhance their scientific imagination.

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