1.4 Learning Science Through Models and Modelling

JOHN K. GILBERT and CAROLYN J. BOULTER
The University of Reading, UK

A model can be defined as a representation of an idea, an object, an event, a process or a system. The role of models and modelling in the learning of science is worthy of a distinctive focus for a number of reasons. Firstly, the terms are used ubiquitously in science education to describe representations ranging from an individual’s transient ideas to grand objects found in museums. The range of things represented, the scope and degree of the changes brought about in the formation of representations, and the wide-ranging existential nature of the resulting models ensure that the meanings of the processes involved are clouded with uncertainty. Secondly, by being more perceptually accessible than theories, models play a key role in the conduct of scientific inquiry. They more readily permit the consequences of theories to be deduced and tested by experiment. The widespread desire to provide science education which is more obviously related to the conduct of science suggests that the nature of models and modelling must be directly addressed. Thirdly, the cognitive psychology representation of learning, including that in science education, is predicated on the formation and development of models by an individual within the context of a social group (Harré & Gillett 1994). An understanding of learning in science education thus necessarily involves an understanding of the nature of models and modelling. Fourthly, models play a substantial role in everyday classroom teaching and this role should be further explored.

The main aims of this chapter are to discuss the word ‘model’ when used in science education and to show how models can and do contribute to learning in classrooms and other contexts. The first section of this chapter examines the relationships between the words ‘model’, ‘theory’ and ‘concept’. The second section describes the nature of learning in ‘situations’, ‘narratives’ and ‘models’. Having provided a framework for the remainder of the chapter, the third and fourth sections, respectively, examine the use of models and narratives in the classroom, and in other contexts involving computers, television and museums. The penultimate section identifies three forms of argumentation and illustrates how each governs the roles played by different types of models in science education. The chapter concludes with a summary and suggestions for further research.

Chapter Consultant: Shawn Glynn (University of Georgia, USA)

MODEL, THEORY AND CONCEPT

A model of a target (that which is to be represented) is produced from a source (some other object, event or idea) by the use of metaphor in which the target is seen, if only initially for the sake of argument and for a short time, as being very similar to the source. Taking the interactive view of metaphor (Black 1962), the elements of which the source is composed are projected onto the target. Those which seem to have an evident value in representing the target are altered to fit the special circumstances of the target by the drawing of analogy (Hesse 1966; Thagard 1992).

Model and Theory

Nagel (1987) has attempted to clarify the distinction between model and theory by stating that there are:

... three components in a theory: (1) an abstract calculus that is the logical skeleton of the explanatory system, and that 'implicitly defines' the basic notions of the system; (2) a set of rules that in effect assign an empirical content to the abstract calculus by relating it to the concrete materials of observation and experiment; and (3) an interpretation or model for the abstract calculus, which supplies some flesh for the skeletal structure in terms of more or less familiar ... visualizable materials. (p. 90)

A model thus can be viewed as an intermediary between the abstractions of theory and the concrete actions of experiment, therefore helping to make predictions, guide inquiry, summarise data, justify outcomes and facilitate communication. Nagel (1987, p. 110) suggests that, on some occasions, one theory and an attendant model, together, can serve as a model for the development of another theory plus model. For example, Newton's laws and the attendant billiard ball model were the sources from which the kinetic theory and model of gases was derived. Here a model is established at the same time as the theory. On other occasions, just the theory is established by analogy to an existing theory. Nagel (1987, p. 111) quotes the case of Maxwell's recognition of the similarity between the structure of the mathematics of gravitation theory and those of the theory of heat conduction; the accompanying model evolved later. Harré (1978) has discussed the relationship between a theory, the process of production of a model, and the model itself, in respect of a modern version of the Darwin-Wallace Theory of Natural Selection. These relationships deserve greater elaboration.

There have been some recent inquiries into the relationship between models and theories as perceived by students. From an interview-based study of understanding of the word 'theory' among 30 pairs each of 9-, 12- and 16-year-old students in the UK (Scott, Driver, Leach & Millar 1993), it can be inferred that models: are used from an early age; act as a way of understanding theories more clearly; form a bridge between theory and behaviour by enabling predictions to be generated
and empirically tested; and can be transferred between contexts. The evidence is that students construct a narrative about the nature of science which is different from that of their teachers; inevitably, the notion of what a model is forms part of this divergence.

Model and Concept

Like ‘model’, the notion of ‘concept’ is widely used in science education, again without a generally-agreed operational definition of the word. Carroll (1962) suggests that, for any individual, a particular concept is: an abstract generalisation which emerges from experiences with more than one example of an event or object; evaluated in terms of its relative adequacy for an individual’s purpose; constantly being revised by that individual; governed in nature by the specific experiences which led to its formulation; and one of many that can exist for a particular object or event in a population of people.

The formation of a concept is difficult to justify by use of the language of representation. The target of the concept, or what is to be represented in the formation of the concept, involves the elements perceived to be common to a range of objects or events. Yet how can these regularities be recognised without the use of the concept itself? How can experience exist without being recognised as such through the use of the concept? Two possibilities exist for the source of the concept (i.e., that from which the representation is derived). It can be another concept, which is seen to act as a metaphor through which experience is recognised and acted upon. Or the source can lie within the many possible elements of a crudely-perceived experience, which are compared with each other until positive elements of analogy of convincing strength are identified. Even within a seemingly common and homogeneous social environment (e.g., a well-disciplined and purposeful school classroom), the concept formed by a given student on a specific taught topic will deviate both from the socially-sanctioned concept that the teacher is trying to teach and from those formed by other students, thus giving rise to so-called ‘alternative conceptions’ (Gilbert & Watts 1983). Concepts seem to involve the formation of propositions, and models make use of images.

LEARNING IN SITUATIONS, NARRATIVES AND MODELS

A broad view of constructivism has been influential in perceptions of teaching, learning and research in science education over the past decade or so. In the ‘situated cognition’ version of constructivism:

... learning is a process of enculturation or individual participation in socially organised practices, through which specialized local knowledge, rituals, practice and vocabulary are developed. The foundation of actions in local interactions with the environment is no longer an extraneous
problem but the essential resource which makes knowledge possible and actions meaningful. (Hennessy 1993, p. 2)

Within this approach, learning takes place in particular situations. But what constitutes a 'situation'? Rodrigues and Bell (1995) point out that, in the science education literature, the word 'context' can mean a variety of things, such as 'the classroom', the 'learning environment' or the 'relevance of an activity'. However, what is important in their view is the personal meaning attached to new or established knowledge when used to understand the external, physical situation. A situation, then, is a specific external environment which is turned into a context at a particular time by the mental activity of an individual, often acting within a group.

When a situation is used deliberately for an educational activity, the four factors of where it takes place, the focus of the activity, the educational purposes being addressed, and the people involved remain the same throughout the activity. It allows for an event to take place. The language which is used within the confines of an event is the text of the event. An analysis for participation in the text of an event can show who said what to whom, how that person responded, and what followed next. A text carries a series of narratives, or stories composed by one or more people for others to pay attention to. A text consists of a series of interwoven narratives, such as those produced by the teacher as the demands of the curriculum are being presented to the students, or those being produced by individual students as they ascribe their own meanings to what is going on. The text of an educational event, usually spoken but often with a substantial written component and sometimes an element of physical action, can be analysed to reveal some of the narratives being produced. This set of relationships is summarised in Figure 1.

Models play a major part in the narratives of science education. It is possible to differentiate between target systems (which exist in common experience and are to be represented), mental models (personal, private, representations of a target), expressed models (which are expressed by an individual through action, speech or writing), consensus models (expressed models which have been subjected to testing by a social group, such as ones drawn from the science community, and which have been agreed by some as having some merit), and teaching models (specially-constructed models used to aid the understanding of a consensus model).

The great value of many models is that they enable ideas, objects, events, processes or systems – which are complex, on a different scale to that which is normally perceived, abstract, or some combination of these – to be rendered either visible or more-readily visualised. This is done by simplifying the target (selecting only some entities and relations between them for representation), perhaps altering the scale and using a medium which is widely accessible. As a given model is initially produced for a specific purpose, the selection (and hence the suppression) of features in the target for representation is highly specific.
In science education, students often encounter one or more distinctive situations, such as the conventional classroom, computers, educational television (usually in the form of videotape), museums (as well as zoos and galleries) or the external natural environment. Each student will construct a narrative for each event in a given situation. If the events which a student encounters are intended by the teacher to have a similar or related subject content, then the narratives constructed in the various situations will interact with each other in the production of an extended narrative of the phenomenon being studied. Models, of whatever type, which are produced, expressed or encountered in one situation, serve as the basis
International Handbook of Science Education
Fraser, B.; Tobin, K. (Eds.)
1998, XXX, 1271 p. 11 illus. In 2 volumes, not available separately., Hardcover