Models and Modeling in Science Education

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Modelling-based Teaching in Science Education

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Foreword

From my collegiate experiences with and reading Gilbert's and Justi's respective research publications, I cannot imagine any two science education colleagues who are more suited to and qualified for writing a book entitled *Modelling-Based Teaching in Science Education.* Gilbert and Justi have a vast experience over more than two decades, collectively and independently, working with secondary science teachers in schools to implement a range of new teaching approaches and alternative curricula designed to improve students' learning outcomes. Their research with classroom teachers that includes the use of models, analogies, visualisation, and variations of assessment has been published in journals and in edited books. While all these research findings are accessible, it is a great advantage to science educators that ideas and findings from their research activities have been brought together within the extant literature under one cover.

This text is well structured and maintains a clear focus on the nature of models, modelling, and modelling-based teaching, thereby illustrating consistently that models are not only the basis of much scientific practice but also can – and should – play similar roles in teaching and learning school science. In this text, Gilbert and Justi provide considerable evidence that modelling play a central role in teaching and learning science but they also, rightfully, recognise the limitations of such teaching and explain what teachers can do to address these limitations.

This is a scholarly text and one that is eminently readable for university academics and also teachers. References are sourced from a wide informing literature not only from science education but also the history and philosophy of science and psychology. In this way, the authors situate their work in the past and current literature that is well synthesised such that there is a logical connectedness from the start to the end of each chapter and also from the start to the end of the book.

I have conducted classroom research with doctoral students and fellow colleagues on models, primarily used in chemistry teaching and analogies and metaphors used in science teaching, and examined the importance of different representations and modes of representations that incorporate visualisation in teaching and learning science. Consequently, many of these chapters are of personal interest to me. Notwithstanding my personal interests, what Gilbert and Justi have managed to do really well is to frame their own work in the extant literature; identify key issues that ensure success, or otherwise, of a particular teaching approach with the aspects of modelling and modelling-based teaching; and provide suggestions and recommendations for effective teaching and learning. The last point especially is why I believe that *Modelling-Based Teaching in Science Education* would also be a valuable resource for teachers interested in this style of enriched teaching with models. Furthermore, what additional research work is needed to enhance classroom practice of modelling-based teaching has also been presented.

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Preface

The word ‘model’ in English is used in a wide variety of ways (OUP, 2008). A number of allied meanings are only found in everyday life:

- A garment made by a well-known designer. For example, a dress designed by Versace;
- A person who wears clothes to display them. For example, Kate Moss;
- A person who is a source of inspiration for a photographer or artist. For example, Joanna Hifferman and the painter Gustave Corbett;
- A person worthy of imitation. This is person who has achieved long-lasting heroic stature in a society. For example, Sir Edmund Hilary in New Zealand;
- An object worthy of imitation. This is an object that attracts emulators. For example, a vacuum cleaner designed by Sir James Dyson;
- An object that is smaller than the original. For example, the model of the Great Pyramid in Cairo Museum;
- A prototype of an object to be made in more durable material. For example, a clay model of a car made prior to its actual manufacture.

Other meanings are found both in everyday life and in science:

- A typical form or pattern. One example in each of the two contexts is: the basic layout of a passenger airliner; the array of glassware used in a chemical reaction;
- One object in a series of allied objects. One example in each of the two contexts is: a Mark 5 Volkswagen Gulf car, following on from Mark 1, 2, 3, 4; the electron cloud model of the atom, following on from the Thompson, the Rutherford, and the Bohr, models.

Yet other, overlapping, meanings have a particular status in science and technology:

- Objects that represent the original in a different scale aiming at supporting explanations and predictions about it. For example, a model of the HIV virus;

- A scientific description of something that is complex. For example, the Watson-Crick-Franklin model of DNA.

This wide range of meanings is very confusing to most people, particularly when they are learning or employing scientific ideas. In this book we are concerned with the wide range of scientific meanings contained in the latter two categories.

The great breadth and diversity of role of a model in science are captured in a typical (yet tautological!) definition of it as being a representation of things that are of interest to science. The formation and testing of models does play particular roles in science because they are concerned with the production of various types of explanation of the nature of the world-as-experienced. Thus ambition is far too demanding unless natural, complex, phenomena are simplified in some way. So this is done through the production and use of models. The particular importance of models and modelling in science is recognised, extensively if not always clearly, in the literature of the history and philosophy of science (for instance, in Hodson, 2009; Matthews, 2014).

Models can be placed into several types of category. Thus, although a model is always present in mental form in the mind of its inventor or subsequent user, it can take on one or more physical forms when placed in the public domain. These forms can be represented in a variety of media, for example, in the form of a gesture (e.g. of the relative position of objects), in a material form (e.g. a ball-and-stick representation of a crystal structure), in a visual form (e.g. as a diagram of a metabolic pathway), in a verbal form (e.g. an analogy for the structure of an atom based on that of the solar system), in a symbolic form (e.g. as a chemical equation), and in a virtual form (e.g. as a computer simulation). The range of entities that can be represented is wide: objects (e.g. of a virus), systems (e.g. of a blood circulation system), processes (e.g. of the liberation of energy from foodstuffs), events (e.g. of the attack of a white blood cell on a virus), ideas (e.g. of a vector of a force), and arrays of data about any of these entities.

For the purposes of this book, we define modelling as the dynamic process of producing, using, modifying, and abandoning the models in science. In the light of the wide range of meaning that the word ‘model’ has acquired, summarised above, it does seem that modelling is a core process in all human thinking and, as such, a vitally important focus for education.

In general, education has three broad aims. First, it is concerned with the transmission of socially valued knowledge across the generations such that the knowledge acquired by earlier generations is not lost. Second, it seeks to pass on the thinking skills that have produced that knowledge. Third, it supports the production of new knowledge through the use of these skills. The thinking skills involved in the conduct of science in particular are manifested in the processes that lead to scientific knowledge. Models and modelling, therefore, must play important roles in science education if the latter is to be ‘authentic’, that is to reflect how science has been and should be conducted (Gilbert, 2004).

The importance of models and modelling in the nature of thinking and in the history and philosophy of science has long been a matter of contention (for instance, by Giere, 1988). However, its saliency in discussions about science education has only gradually risen in the few decades or so. This process has several roots. The first was in the study of the meanings that students had for single words commonly used in science: the so-called misconceptions or alternative conceptions movement (Gilbert & Watts, 1983). This initially focused on the meanings held by students of individual words (for example, force, heat, light, energy). It gradually expanded to the study of how these meanings interacted, leading to understanding of complex phenomena by their integration into models, for example, of everyday movement, of the cooling of liquids, of the production of shades of colour, and of energy conservation (Gilbert & Boulter, 2000). The second root was the gradually emerging emphasis in curricula of the study of the nature and processes of scientific enquiry (Abd-El-Khalick, 2012). This perhaps occurred to some extent because of the need to provide a basis for the unification between the separate sciences – mainly physics, chemistry, biology, earth science – when these are amalgamated into ‘general’ or ‘integrated’ science courses in compulsory-age schooling. Models, being central to the history and philosophy of all the sciences, were seen as able to do this. The third role was the need to improve accessibility to the ideas of science, in the face of evidence that curricula had become overloaded with content, fragmented in structure, and too abstract, and divorced from phenomena of interest to students (Cerini, Murray, & Reiss, 2003). The outcome of these problems has lead to widespread student disengagement with the sciences. Particular models, applicable across diverse areas of content, were seen not only as potentially providing access to complex phenomena that are relevant to students’ interests, as providing the basis for the integration of individual facts, and hence able to effect a simplification of the curriculum that made learning easier. The fourth root has been the advent of desktop computers with very large memory stores. These provide access to highly interactive ‘modelling systems’, thus enabling enquiry work focused on models and modelling to readily take place (Edelson, 2001).

This book has three purposes. First, it draws together, evaluates, and integrates the findings of the diverse literatures that have contributed to current knowledge of the overall field of modelling in science education. Second, it justifies the central contribution of modelling to science curricula. Third, it identifies the research and development work still needed for that contribution to be realised in classroom practice.

As such, the book has six overlapping audiences:

- Curriculum designers, for it is they who have the best opportunity to signal the importance of modelling to teachers;
- Public examiners, for it is they who define what knowledge of modelling can be validly and reliably assessed;
- Textbook designers, for it is they who translate the intentions of curriculum designers and public examiners into forms readily grasped by students (and their teachers!);
- Teacher educators, for it is they who have the best opportunity to introduce pre- and in-service teachers to the potentialities and realities of modelling;

- Advanced students of science education and curriculum design, for they have the opportunity to study the ontological and epistemological bases of modelling;
- Science education researchers, for they have the task of filling the gaps in our understanding of modelling.

The book has 12 Chapters. They are successively concerned with:

1. The challenges that science education currently faces, together with the assertion that an education in and about modelling can help meet these challenges.
2. The notion of 'model' and the knowledge and skills that contribute to the production and validation of models.
3. The notion of 'authentic learning in science' together with an evaluation of how modelling can contribute to that authenticity.
4. An exploration of the meaning of 'modelling-based teaching' together with the presentation of an approach based on the 'Model of Modelling'.
5. As the meanings of the words 'concept' and 'model' are often confused in the literature, an exploration of the scope and limitations of both is conducted.
6. The use of argumentation in the acts of creating and validating models.
7. The contribution that 'visualisation' makes to the creation of models.
8. The central role of analogies in modelling-based teaching.
9. The way that modelling contributes to the core curricular aims of 'understanding the scientific enterprise'.
10. The structure of a learning progression for modelling.
11. The professional development of teachers needed to implement modelling-based teaching.
12. A review of the lacks of definitive knowledge needed for the universal implementation of modelling-based teaching together with suggestions about how this situation might be addressed.

We decided to write this book because, although we have jointly and singly written about models and modelling for over 20 years, we felt to need construct an overarching view of the field. At the same time, the place of 'modelling' in national mandatory curricula was being progressively strengthened and we felt that science educators in general would value such an overview. Although based in different continents and having very different professional commitments, we did manage to meet at least twice in each of the 3 years that it took us to write. Nothing could have been achieved without e-mail, Skype, and the generous support of our professional friends, especially Ana Sofia Afonso, David Treagust, Izabella Martins, Matthew Newberry, Maurice Cheng, Nilmara Mozzer, Paula Mendonça, and Poliana Maia. We view the outcome as 'work in progress', for Chap. 12 sums up the serious gaps in knowledge that currently exist. Having toiled through many hundreds of papers, we would respectfully suggest that future authors define their terms and write with an eye to classroom implications.

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Contents