MODELING THEORY IN SCIENCE EDUCATION

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by

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To

Alexia Catherina and Gabriella Christiana

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PREFACE

Modeling theory is originally a theory *of* science, a theory about scientific theory and practice that emerged lately in the philosophy of science. It draws on the practice of prominent figures in the history of science, as well as on observation of modern day scientists at work (Bronowsky, 1953; Bunge, 1973; Giere, 1988; Harré, 1970; Hesse, 1970; Hestenes, 1992; Leatherdale, 1974; Nersessian, 1995; Wartofsky, 1968). The theory basically asserts that models are at the core of any scientific theory and that model construction and deployment are fundamental, if not the most fundamental, processes in scientific inquiry. This book is the culmination of over twenty years of work to deploy modeling theory *in* physics then science education with the prospect to turn it eventually into a theory *of* science education.

The last half-century has witnessed numerous calls and movements to reform the state of science education. A plethora of research articles has constantly shown that under conventional instruction of lecture and demonstration, students of all levels fail to develop a meaningful understanding of scientific theory and practice. Reformists have virtually all agreed that in order to change the state of things, a science student must become actively engaged in scientific inquiry, just like an apprentice does in any art or trade. With science perhaps as the most counter-intuitive trade of them all, science educators are being called upon to take special advantage of cognitive science, and particularly of the two-way stream that has been growing recently between cognition and philosophy of science. (Duschl, 1988; Duschl & Hamilton, 1992; Gentner & Stevens, 1983; Giere, 1992, 1994; Lakoff, 1987; Redish, 1994; Reif & Larkin, 1991). This call resonates well with our work on modeling theory.

As presented in this book, modeling theory in science education is grounded in a number of tenets about the nature of scientific knowledge and inquiry, as well as about learning processes in which students ought to become engaged in order to develop a meaningful understanding of science. The scientific perspective is offered in Chapter 1 of the book. It emphasizes the central role of models in putting together scientific theory and of modeling in conducting various forms of scientific inquiry. Related cognitive aspects are presented in part in the same chapter and are further developed from a pedagogical perspective in Chapter 3. The emphasis in the former chapter is on the need for students to develop experiential knowledge about physical realities, knowledge that comes about mainly as the result of interplay between people's own ideas about the physical world and particular patterns in this world.

Special attention is paid in our work to course content. This interest is driven by the conviction that knowledge organization is crucial for effective and efficient thought and inquiry. It is also implied by the fact that we are catering to science education standards and curricula that continue to be content-driven, which is justifiable as long as the drive for process is also there. Our focus with regard to content is primarily on models and modeling schemata in the manner discussed in Chapter 2. A scientific model is, for us, a conceptual system mapped, within the context of a specific theory, onto a specific pattern in the real world so as to reliably represent the pattern in question and serve specific functions in its regard. A model may serve an exploratory function (pattern description, explanation, post-diction and/or prediction), and/or an inventive function (control or change of existing physical systems to produce the pattern, and/or pattern reification into new physical systems and phenomena). Model constitution and function are laid out explicitly in Chapter 2 and extrapolated to the case of concepts in accordance with specific modeling schemata. A modeling schema serves students as an organizational tool for structuring models or related conceptions in a meaningful and productive way. It also provides teachers with reliable means for planning instruction and for the assessment of student learning and teaching practice.

A person's ideas about the physical world are spread across what we call a paradigmatic profile. Such a profile consists of a mix of paradigms, one of which is dominated by naïve realism. As discussed in Chapter 3, modeling theory in science education is set to help students through a paradigmatic evolution with reasonable expectations. Individual students are anticipated not to achieve a radical paradigm shift in the direction of scientific realism. Instead, they are moved to curtail naïve realism in their paradigmatic profiles and build up scientific realism to realistic levels. Meaningful paradigmatic evolution takes off from a threshold that is attainable by any student willing to invest the necessary effort. The threshold is defined in a given science course by the set of basic models in the scientific theory that is the object of the course. A basic model is a model that provides an affordable and efficient framework for students to develop fundamental tenets and conceptions (concepts, laws, and various theoretical statements) of the respective theory, as well as essential tools and skills of scientific inquiry.

A particular modeling program presented in Chapter 4 is designed to help students to achieve the target paradigmatic evolution. The program concentrates on the common denominator among all scientific disciplines: model-laden theory and inquiry. Implicit in the program is the recognition that students at the college and pre-college levels cannot be brought to develop scientific theory and inquiry with uncompromising rigor. The compromise is however significantly reduced through didactic transposition of the content of scientific theory, a transposition that revolves around the set of basic models in the theory. Appropriate activities are designed for students to develop these and other models from different rational and empirical perspectives, along with the fundamental tools and skills that are necessary for various forms of scientific inquiry. Activities are associated with particular norms and guidelines for a variety of assessment and evaluation processes that allow students to reflect on their own ideas and regulate them in an insightful manner.

The program is implemented in structured learning cycles described in Chapter 5. A learning cycle is, for us, a five-phase modeling cycle. The five phases are exploration, model adduction, model formulation, model deployment, and paradigmatic synthesis. Each cycle is devoted to the development of a specific model along with particular modeling processes that can best be developed in the context of the model in question. A cycle takes off with subsidiary models, i.e., counterpart models that have limited viability by comparison to the target model that students develop, intuitively sometimes, by correspondence to familiar situations. A cycle proceeds through student-centered investigative activities that allow groups of students progressively to refine their subsidiary models until they take the form of the target model. The entire process is teacher-mediated so as to bring to the surface various student ideas, especially those that are at odds with science, and to help students to mutually ascertain their ideas and regulate them in the light of empirical evidence and in conformity with scientific theory and practice.

Modeling instruction as presented in this book has been systematically corroborated, mostly within the context of secondary school and university physics courses, and primarily in U.S.A. and Lebanon (Halloun, 1984, 1994, 1996, 1998a, 2001b, 2004; Halloun & Hestenes, 1987; Wells, Hestenes & Swackhamer, 1995). Discussion is often illustrated with examples from Newtonian mechanics, examples that are within the scope of virtually any science teacher and chosen so as to keep an affordable storyline across various chapters. Modeling theory as presented in this book is now being deployed into other scientific fields and educational levels. Early results are consistent with what we have been able to achieve in the context of physics. They show that the theory in question actually fosters the paradigmatic evolution we are calling for, and that it brings about an equitable learning experience that narrows significantly the traditional gap between students at opposite ends of the competence spectrum, i.e., those students that enter a science course with high competence and those that do so with low competence.

This book is the culmination of over twenty years of work. It presents aspects of modeling theory that have repeatedly demonstrated their value when deployed in physics education, and lately in science education. The book is intended primarily for researchers and graduate students in science education. It can serve as well as a major reference work for in-service and pre-service science teachers who want to go into their classroom not to promote canned texts but to foster the sort of meaningful understanding of science called for in this book. Interested educators are invited to contribute to our drive to turn modeling theory into a theory of science education. This still requires hard work at the level of theoretical foundations and structure of the prospective theory, as well as further systematic deployment and corroboration in a variety of scientific disciplines and educational levels. Meanwhile, one cannot but acknowledge that, given the intricacy of our endeavor and especially the seemingly endless list of hard to control cognitive and affective factors involved in any learning process, we may never get to a theory of science education that is as rigorous and as viable as a scientific theory. Nevertheless, this author is determined to bring modeling theory in science education to as high an efficacy level as any educational theory can possibly achieve.

Numerous people have contributed in one way or another to the appearance of this book. I am above all indebted to my family for putting up with my long days of isolation while writing the book. I am grateful to Professor Bill Cobern for his trust, and to Kluwer's staff for their kind cooperation in bringing this work to press. Special acknowledgments are due to the modeling research team headed by Professor David Hestenes at Arizona State University and to many other colleagues around the world with whom I keep exchanging ideas about modeling theory in science and science education. I am especially grateful to the numerous teachers and professors who have been diligently implementing modeling instruction in their classes and providing me with valuable feedback, and to their students and mine who have endured with us the hardship of bringing this work to its current state. In a sense, colleagues and students have all been part of this work. Their contributions are acknowledged throughout this book with collective attribution of work and points of view. Still, because ideas might have come about without consultation with any or some of these people, no one but myself should be held responsible for the way modeling theory is presented in this book.