Boston Studies in the Philosophy and History of Science

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Boston Studies in the Philosophy and History of Science looks into and reflects on interactions between epistemological and historical dimensions in an effort to understand the scientific enterprise from every viewpoint.

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Jochen Büttner

Swinging and Rolling

Unveiling Galileo's unorthodox path from a challenging problem to a new science

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…post diuturnas mentis agitationes…
Galileo Galilei – Discorsi (1638)

Foreword

The Historical Epistemology of Mechanics

The Historical Epistemology of Mechanics studies the long-term development of mechanical knowledge. Mechanical knowledge concerns material bodies in time and space, their motions, and the forces that cause or resist such motions. Mechanical knowledge enables us to predict how bodies change their position with time as long as we know their current state and the forces acting upon them. Mechanical knowledge of this kind played a special role in the process of transformation from natural philosophy to modern science. Natural philosophy from its very inception in the works of Aristotle constructed conceptual systems to represent pictures of the world as a whole. But, in contrast to such global intentions, the origins of mechanical knowledge have to be sought in the much more down-to-earth practical activities of achieving the specific tasks of everyday life.

Over a long historical period, the development of mechanical knowledge and its transmission from one generation to the next remained an inherent dimension of such activities, unrelated to any cognitive endeavors aimed at constructing a mechanical worldview. It was only after the first attempts in classical antiquity to include mechanical knowledge in the conceptual systems of natural philosophy that its assimilation to them and the corresponding accommodation of such systems to mechanical concepts led to conflicts between mechanical knowledge and knowledge about nature as a whole. It was only after the growing body of mechanical knowledge became a vital resource of early modern societies that mechanical knowledge within its own conceptual systematization started to compete with natural philosophy by constructing its own worldviews. This finally resulted in early modern times in what has been called the "mechanization of the world picture."

The main goal of the series under the heading *The Historical Epistemology of Mechanics*, conceived in analogy to the four-volume set on *The Genesis of General Relativity*, is to explain the development and diffusion of mechanical knowledge in terms of historical-epistemological concepts. The studies presented within the series are based on a research project centered at the Max Planck Institute for the History of Science in Berlin. While the emphasis of the research has been on the period of the Scientific Revolution, the analysis also takes into account the long-term development of mechanical knowledge without which neither its emergence nor the consequences of this period can be adequately understood. Just as the reconstruction of the relativity revolution in *The Genesis of General Relativity* takes Einstein's work as the point of reference for a thorough contextualization of his achievements, the reconstruction of the transformation of mechanical knowledge during the Scientific Revolution similarly refers to Galileo's work as a point of departure for outlining a historical epistemology of mechanics.

The development of an adequate theoretical framework provides a common basis for the investigations constituting *The Historical Epistemology of Mechanics*. The longevity of mechanics makes it particularly clear that large domains of human knowledge accumulated by experience are not simply lost when theories are revised, even if this knowledge does not explicitly appear in such theories. Thus, formal logic is of little use for a description of the multilayered architecture of scientific knowledge that allows both the continuous and the discontinuous aspects of the transmission of mechanical knowledge to be accounted for. In order to explain structural transformations of systems of knowledge, it is furthermore necessary to take into account the collective character and the historical specificity of the knowledge being transmitted and transformed as well as to employ sophisticated models for reconstructing processes of knowledge development. Concepts such as "mental model," "shared knowledge," "challenging object," and "knowledge reorganization" have turned out in our work to be pivotal for such explanations.

We conceive of mental models as knowledge representation structures based on default logic, which allow inferences to be drawn from prior experiences about complex objects and processes even when only incomplete information on them is available. Mental models relevant to the history of mechanics belong either to generally shared knowledge or to the shared knowledge of specific groups. Accordingly, they can be related either to intuitive, to practical, or to theoretical knowledge. They are, in any case, characterized by a remarkable longevity—even across historical breaks—as becomes clear when considering examples such as the mental models of an atom, of a balance, of the center of gravity, or of positional weight. Their persistence in shaping the shared knowledge documented by the historical sources becomes particularly apparent in the consistency of the terminology used, a consistency that offers one important element for an empirical control in the reconstruction of mental models and their historical development. The concept of mental model is particularly suited to study the role of practical knowledge for the transformation of mechanics in the early modern period. Conceiving a body in terms of the intuitive mental model of gravitation, for instance, implies that a heavy body falls down in "natural motion" if its motion is not inhibited or deflected by a force, that it makes an impact when it falls, that the force of this impact is the larger the longer it falls, but also—at a later stage of development—that the body has a weight that can be measured by a balance. Whenever the question of a quantitative measure of impact arises—as it does in the early modern period—this model of intuitive and practical knowledge could be and was further extended in reaction to new experiences with the challenging objects of contemporary technology.

More generally, we conceive of challenging objects as historically specific material objects, processes, or practices entering the range of application of a system of knowledge without the system being capable of providing a canonical explanation for them. Examples run from mechanical devices challenging Aristotelian dynamics, via artillery challenging early modern theories of motion, to black-body radiation challenging classical radiation theory. In reaction to such challenges, knowledge systems are typically further elaborated, occasionally to the extent that they give rise to internal tensions and even inconsistencies. Such explorations of their limits may then become starting points for their reorganization where often previously marginal insights take on a central role in an emerging new system of knowledge. Such processes of reorganization may be exemplified by the emergence of theoretical mechanics from Aristotelian natural philosophy in ancient Greece, the transformation of preclassical into classical mechanics in early modern times, or the emergence of quantum theory from classical physics at the turn of the last century.

The investigations constituting *The Historical Epistemology of Mechanics* build on this theoretical framework, centering on the role of shared knowledge, of challenging objects, and of knowledge re-organization. The first study, Matthias Schemmel's *The English Galileo: Thomas Harriot's Work on Motion as an Example of Preclassical Mechanics*, investigates the shared knowledge of preclassical mechanics by relating the work of Thomas Harriot on motion, documented by a wealth of manuscripts, to that of Galileo and other contemporaries. Harriot and Galileo indeed exploited the same shared knowledge resources in order to approach the same challenging objects. The study of Harriot's parallel work thus allows the exploration of the structure of the shared knowledge of early modern mechanics to perceive possible alternative histories and to distinguish between individual peculiarities and shared structures of early modern mechanical reasoning. The second study of the series, Matteo Valleriani's *Galileo Engineer*, looks more closely at the role of Galileo as a practical mathematician and engineer-scientist. It focuses on his intellectual development in the frame of the interaction between natural philosophy and the challenging objects provided by technological developments. It analyzes Galileo's contribution to the practical science of machines as well as his role as a teacher involved in the contemporary art of war. The results of this analysis highlight Galileo's profile as a military engineer. The book develops a model according to which new scientific knowledge was generated on the basis of the interaction between theoretical knowledge—basically Aristotelian—and the practical knowledge Galileo shared with his contemporaries. Galileo's work is reinterpreted in its entirety against the background of a historiographical investigation concerning the early modern figure of the engineer-scientist.

This third contribution to this series, Jochen Büttner's study *Swinging and Rolling: Unveiling Galileo's unorthodox path from a challenging problem to a new science of motion*, looks more closely at the reorganization of mechanical knowledge that took place in the course of Galileo's research process. This process pursued within a network of exchanges with his contemporaries and documented by a vast collection of research notes is reconstructed in minute detail. It is shown that a problem arising from the encounter of two challenging objects, the pendulum and the inclined plane, motivated and shaped Galileo's thinking and became a mainspring for the formation of Galileo's comprehensive theory of naturally accelerated motion. Tensions between the existing frameworks and the new insights engendered by his investigation of the relation between the swinging of pendulums and the rolling of balls along inclined caused Galileo to reorganize his knowledge, thus effectively creating his new science of motion, a milestone of the transition from preclassical to classical mechanics.

The fourth upcoming and conclusive volume will articulate more extensively the theoretical foundations of a historical epistemology of mechanics, still with a focus on preclassical mechanics, its prehistory, and its contexts. The framework presented in this volume makes it possible to reconstruct the long-term development of mechanical knowledge from its anthropological origins via the formation of a mechanical worldview to the transformations of classical mechanics in modern physics. It also investigates the societal conditions fostering the integration of this knowledge in the emergence and expansion of preclassical mechanics and the far-reaching consequences it had on the development of physical knowledge.

Berlin, Germany Jürgen Renn

Preface

In 1994, the Max Planck Institute for the History of Science was founded in Berlin. In the following year, while I was still studying physics and philosophy at the Freie Universität, I was given the opportunity to start working there as a student assistant in the department of Jürgen Renn. At that time, in a pioneering attempt, an online edition of Galileo's so-called *Notes on Motion* was being prepared in a joint effort of the department together with the Istituto e Museo di Storia della Scienza and with the Biblioteca Nazionale Centrale, both situated in Florence. I was assigned the task of overseeing and completing what, at the time, appeared to be merely some last remaining nonissues before the edition could go online. As can easily be imagined, this turned out to be a misjudgment, and before long, I found myself deeply and profoundly immersed in studying the content of the manuscript. This, paired with the intellectual stimulus coming from the historical epistemology as it was and still is practiced in Department I of the Max Planck Institute for the History of Science, triggered my academic transformation into a historian of science. This transformation, in a sense, was completed in 2009 when I defended my Ph.D. thesis *Galileo's Challenges: The Origin and Early Conceptual Development of Galileo's Theory of Naturally Accelerated Motion on Inclined Planes* at the Humboldt University in Berlin. It is this thesis, in thoroughly revised form, which more than a decade after it was initially conceived I present to a wider audience for the first time in the form of this book.

Due to the long time that has passed since I first directed my attention to studying Galileo's working notes, the list of persons that I owe gratitude and thanks has grown beyond comprehension while, at the same time, memory also begins to fade. Hence, first of all, I would like to thank all those friends and colleagues who greatly deserve thanks but who I unavoidably and also inexcusably will forget to mention here. Jürgen Renn acted as advisor for the dissertation which resulted in this book, and I thank him for this. Much more importantly, however, as my teacher he had great impact on my intellectual formation and as mentor supported and encouraged me in many ways for which I am extremely grateful. Gerd Graßhoff provided council on the first steps of my investigations into Galileo's science of motion, and I much appreciate the direction this gave to my later studies. For my work on Galileo's

Notes on Motion, I have been allowed to use data compiled and edited by a working group at the Max Planck Institute for the History of Science. I would like to thank the members of this group, in particular Simone Rieger and the late Peter Damerow for courteously making this material available to me. Lindy Divarci, publication manager at the institute, has been of great help in getting this book published. Her always friendly support is much appreciated. I am much obliged to Sarah Kühne for taking on the major task of language editing the manuscript.

I would like to thank all my colleagues at the institute for supporting me in so many different ways and plainly for being excellent colleagues. Special thanks goes to Matteo Valleriani, long-time colleague and friend, whose incredible aptitude for keeping up a good spirit against all adversity has more than once helped me to not hang my head and to take things somewhat more lightly in times of difficulty. I would like to thank the many colleagues with whom I have had the opportunity to share my thoughts on Galileo. Their feedback, whether at conferences, in direct discussions or in written exchanges has provided important stimuli that have contributed in shaping and occasionally first provoked the thoughts that I present here. Special thanks to Christian Barth, Philipp Strauß, and Martin Klein on account of keeping me entertained while revising this manuscript.

I fancy that no non-historian of science ever had to listen to so many details about Galileo, as Jochen Schneider, former research coordinator at the Max Planck Institute for the History of Science. I thank him for his patience and his acute responses, not at all restricted to questions regarding Galileo and not the least for teaching and still playing Go with me. I would like to thank Norbert Palz, for being a great friend and for granting me refuge in his office space when I needed a change of scene while writing this manuscript; Peggy Haines for being a role model in responsible scholarship and for her faith in my capabilities, unsupported but unswerving; and my mother for her patience with her son and for her continued support of me and my family. I want to commemorate my father who sympathetically and always reassuringly accompanied my transformation from the physicist I was trained to be into a historian of science but who sadly didn't live to see it completed. Last but not least, I want to thank my wife Sonja, my daughter Toni, and, my son Mattes. If it weren't for them, this book would certainly have been completed much earlier. Yet of all the reasons that may have delayed publication, this is the one, which I can without hesitation state, has made my life and certainly also this book better.

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Jochen Büttner

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