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Galileo's law of free fall and modern science: historical and philosophical views

A lei da queda dos corpos de Galileu e a física moderna: aspetos históricos e filosóficos

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Abstract
The clearly recognized innovation in Galileo's work on free fall has been a stimulus and a challenge for the history and philosophy of science. This article will analyze the experimental and theoretical aspects of Galileo's work on free fall. It draws on several authors' results to justify the claim that the research model established by Galileo remains valid today (Sections 2 and 3). The article draws this parallel with current science by focusing on Galileo's method, way of considering scientific instruments, and practice of confrontation between theory and experiments. The Galilean mode of investigation can be interpreted from a variety of possible philosophical perspectives: Section 3 examines how relevant the so-called constructivist and conventionalist perspectives are to analysis of Galileo's innovations. Section 4 discusses Galileo's contribution to the mathematization of science and the Platonic character of his thought. Finally, the article attempts to show that Galileo's Platonism also involves experiments, as he conceives them.

Keywords
Inclined Plane. Mathematics. Platonism.

Resumo
A reconhecida inovação científica que caracteriza a investigação de Galileu sobre a queda dos corpos tem constituído um estímulo e um desafio para historiadores e filósofos da ciência. Neste artigo analisam-se vários aspetos desse trabalho de Galileu que, segundo alguns autores, conduziu a um modelo de investigação válido ainda hoje (parágrafos 2 e 3). Procura-se estabelecer o paralelismo com a ciência atual com base no método usado por Galileu, na sua forma de considerar os instrumentos científicos, e ainda na sua prática de confronto entre teoria e experiência. O modo de investigação galileana pode ser considerado sob diferentes perspetivas filosóficas: no parágrafo 3 examina-se a relevância das perspetivas construtivista e convencionalista na análise das inovações de Galileu. No parágrafo 4 discute-se a contribuição de Galileu para a

matematização da ciência e o caráter Platónico do seu pensamento. Finalmente, procura-se mostrar que o Platonismo de Galileu inclui também as experiências, tal como ele as concebia.

Palavras-chave
Plano inclinado. Matemática. Platonismo.

1. Introduction

From an epistemological point of view, mechanics plays a key role among the other domains of physics. Galileo's creation of a new perspective on mechanics has therefore been understood as a fundamental step in scientific knowledge; he replaced the old Aristotelian views with new conceptions of science and instituted the modern approach to the study of mechanical phenomena (Holton, 1962, p. 17-23). The treatise "On Local Motion" from *Two New Sciences* (Galilei, 1953, p. 144-145) aptly illustrates the emergence of a new mechanics in Galileo's work. In this book, as Stillman Drake (1910-1993) points out, "Galileo presented the mathematical theory of freely falling bodies, which he had worked out some thirty years earlier" (Drake, 1974, p. 129). Torretti also highlights the mathematical theory of free fall; he argues that Galileo, "despite the limitations and shortcomings, provided a paradigm of mathematical physics that inspired the next generations and in a general way is still alive today" (Torretti, 1999, p. 21). Gerald Holton too remarks on the innovation and relevance of Galileo's work in this area: "Others had known before Galileo that the Aristotelians were wrong about free fall, but it is to his credit that he proceeded to discover the details of the correct description of this motion and to make it part of a more general system of mechanics" (Holton, 1962, p. 27). Galileo' s treatment of problem of free fall allows us to understand the depth of his thought; it also reveals his merit in mathematics and his insight into scientific experience. Furthermore, this case of motion provides us with the opportunity for an epistemological analysis of Galileo's theoretical and experimental discovery that can be extended to other instances of scientific research. It is applicable to the case of electricity, for instance, which provides one of the most interesting examples of experimental science in the eighteenth century (Heilbron, 1979).

Galileo sought to give a rigorous mathematical description of the phenomenon of free fall. This point should be stressed, especially as the "popularly-offered reconstructions of Galileo's procedures in establishing his new science of motion are certainly mistaken with respect to the role of mathematics in them" (Drake, 1974, p. 130-131). Drake also states that "when we reconstruct Galileo's steps from his own rough notes, we find that mathematics was indeed his most fertile source of discovery" (p. 130). The importance of mathematics in Galileo's work extends well beyond the case of free fall, however. Besides being a scientific instrument, mathematics also decisively influenced his thinking.

2. Historical views on free fall and the inclined plane

It was surely mathematics that allowed Galileo to validate the hypothesis that free-fall motion could be studied using an inclined plane: that the laws of motion are the same in both cases. This idea provided Galileo with a way of establishing a relationship between theoretical and experimental approaches to the investigation of free fall; it represents a great advance in science. When Galileo developed his use of the inclined plane to study free fall, he broke new ground and initiated the long history of experimental science. He did so through the creation of one of his key strategies: that of working under conditions different from those that exist in nature in order to study natural phenomena.

Although the inclined plane is associated with the emergence of scientific experimentation, it belongs primarily to the history of mathematics from Antiquity to the Renaissance. Galileo's mathematical investigations of the inclined plane fit neatly into this sequence of studies that originates in Antiquity. It has been known since prehistoric times that inclined planes can be used to move heavy objects; Archimedes and other mathematicians of Antiquity theorized the inclined plane's mechanical advantages. However, only in the Renaissance was the problem rigorously solved by the law of the inclined plane obtained by Galileo. (Roux & Festa, 2008, p.1). The law of the inclined plane states that the ratio between a weight and the force needed to balance this weight on a given inclined plane is equal to the ratio between the length and the height of this plane. Galileo provided a demonstration of this law (p. 2). For Sophie Roux and Egidio Festa,

> The law of the inclined plane constitutes a significant advance of Galilean science. It will be used, for example, to demonstrate that the degrees of speed acquired on the planes, with different slopes but the same height, are equal when the mobile object arrives on the horizontal plane, and that their value depends only on the height of the plane. (p. 26)

Having been a subject of study for mechanics and mathematics for several centuries, the inclined plane has also become a matter of interest for historians and philosophers of science. It is often addressed in the context of Galileo’s study of free fall. In *The Science of Mechanics* (Mach, 1902), Ernst Mach (1838-1916) presents a historical overview of several studies on the inclined plane; he also provides epistemological considerations regarding the authors he includes. For instance, Mach deals with the case of Simon Stevin (Mach, 1902, p. 24-33) by stating that he “was the first who investigated the mechanical properties of the inclined plane” (p. 26) and stressing that his assumptions resulted from “a purely instinctive cognition” (p. 26). Mach also analyzes Galileo’s theoretical work on the subject (p. 128-143), referring to one of his fundamental hypotheses on the study of free fall:

> To form some notion of the relation which subsists between motion on an inclined plane and that of free descent, Galileo made the assumption that a body which falls through the height of an inclined plane attains the same final velocity as a body which falls through its length. (p. 134)

When describing Galileo’s methods and conclusions, Mach emphasizes that “Galileo, in this case, again, did not stop with the mere philosophical and logical discussion of his assumption, but tested it by comparison with experience” (Mach, 1902, p. 135). He later uses one of his well-known phrases to characterize Galileo’s way of doing science, which was “to gradually adapt his thoughts to the facts” (p. 140). He refers in similar terms to the question of experience and theory when developing his ideas about the economy of thought outside the context of Galileo’s work: “The comparison of theory and experience may be farther and farther extended, as our means of observation increase in refinement” (p. 490). In other words, Mach identifies procedures in Galileo’s scientific practice procedures that became fundamental to his own epistemology over two hundred years later.

Other authors have discussed the inclined plane in the context of Galileo's work. Stillman Drake, an authority on Galileo, retraces "his steps in the discovery of the law of free fall and its application to inclined planes from one of his letters and some manuscript notes" (Drake, 1974, p. 129-150). Drake reconstructs Galileo's geometric study by following the winding path he took, obstructed by mistakes concerning velocities and acceleration (p. 132-139). He notes that "the importance of acceleration in free fall probably did not become apparent to Galileo until Guidobaldo's objection to his theorems" (p. 139). Further on, however, he claims that "At any rate, Galileo did turn his attention to the question of acceleration … and successfully searched for a rule linking distances, speeds, and times in free fall (p. 139). He adds that the "discovery of this rule in turn was mathematical in character" (p. 139).

Drake uses Galileo's original calculations (Drake, 1974, pp. 139-148) to show that his "first move after obtaining the law of free fall was to return to his investigations of motion along inclined planes and to test its applicability to them" (p. 139). Reproducing Galileo's procedure, he concludes that Galileo's calculations confirmed that the new law of free fall could consistently be applied to inclined planes (p. 142). At the end of his presentation of Galileo's work, seeking to respond to other historians of science, Drake presents some comments concerning the "profound difference between medieval and Galilean physics" (p. 149) and the illusion "of greater continuity between the fourteenth century and the seventeenth" (p. 149) than actually existed.

Fabien Chareix's approach to the free-fall problem differs from Drake's. Chareix emphasizes the importance of the inclined plane, stating that it constituted a major step forward in establishing the rules of movement under the dependence of gravity's physical properties (Chareix, 2007, p. 230). He further claims that Galileo was able to prove an important result. Using the properties of motion on the inclined plane he found that the speed reached at the end of a fall is proportional to two parameters: the acceleration and the duration of the movement (p. 231). Chareix considers that it is possible from this result to conclude that the final speed of a body moving on different inclined planes with the same height depends only on the height of the planes (not their length), and that this speed is the same as the body would have if it fell vertically. Chareix points out that Galileo published this conclusion in 1632's *Dialogue Concerning the Two Chief World Systems* (Chareix, 2007, p. 232).

Galileo's study of the inclined plane is well documented by Roux and Festa (2008), who place it in a history that spans Antiquity, the Middle Ages, and the Renaissance, and authors such as Heron, Pappus, Leonardo da Vinci, Jordanus, and Stevin. In Antiquity and the Renaissance, several scientists tried to solve the problem of the inclined plane, but it was Galileo who obtained a detailed demonstration of its law (Roux and Festa, 2008, p. 2). Roux and Festa refer to Galileo's studies of the preceding authors and seek to clarify "what Galileo may owe to his reading of his predecessors" (p. 21). However, they emphasize that analysis of the texts seems to confirm that "Galileo is in fact as far from the purely intuitive process of Heron, as from the geometric analysis of Pappus" (p. 21).

To assess the originality of Galileo's demonstration of the law of the inclined plane, Roux and Festa analyze in detail the works of the previous historical authors mentioned above (2008, p. 3-21). They conclude that Galileo's work "allows for a physically effective mathematical treatment of the problem of inclined plane" and that it "constitutes a significant advance of Galilean science" (p. 26). Galileo's results allow, for example, to demonstrate that the degrees of speed acquired on planes with different slopes but the same height are equal when the mobile object arrives on the horizontal plane, and that their value depends only on the height of the plane (p. 26). This means that the final velocity of a falling body along an inclined plane is strictly independent of the length of the plane; it depends only on its height—the height of the fall, in other words. Whatever the inclination of a plane, falling bodies pass through the same speeds at the same heights.

The studies of the authors just quoted allow us to establish Galileo's conclusions about movement on an inclined plane: in the absence of friction, the law of motion along any inclined plane is the same as that of falling from a vertical plane. In other words, the two motions are equivalent. The study of the movement of a body on an inclined plane therefore allows us to deduce the law of free fall. Galileo's theoretical investigation of falling along an inclined plane and its experimental application led to the law of free fall—the first law of variation between two physical quantities.

The equivalence between free-fall motion and motion along an inclined plane can be easily justified in today's physics through elementary-level arguments and calculations accessible to secondary school students (Sinonyi, 2012, p. 200-208). The inclined plane is now taught in high school to provide knowledge of kinematics and dynamics. Through this instrument, students learn about dynamics, Newton's second law, and the equivalence between falling perpendicularly and along the inclined plane.

3. Epistemological views of Galileo's studies on free fall

Galileo's work associates his inclined plane experiments with the theory of free fall. It constitutes a model of research in physics in which theory and experimentation interact and influence each other. This model has remained in use until the present day, although theoretical and experimental work are no longer carried out by the same researchers. However, collaboration and confrontation between theory and experiment play an important role in modern scientific development (Radder, 2009).

The crucial importance of scientific instruments also emerges from Galileo's work. Other mathematicians and physicists had studied the inclined plane, but Galileo's study went beyond knowledge of its properties. For Galileo, the inclined plane became a scientific instrument as well as an object of study. This instrument allowed him to establish the rules of movement "placed under the dependence of physical properties of gravity" (Chareix, 2007, p. 230).

In his experiments Galileo used a small ball that moved along the inclined plane and found a way to measure time during its movement (Torretti, 1999, p. 24). To achieve better experimental conditions, he sought to eliminate the friction inherent in the motion of a body in an environment: the existence of friction prevented the understanding of the phenomenon of motion as he conceived it. To eliminate or reduce friction, Galileo would have had to make the surfaces of the ball and the inclined plane as smooth and uniform as possible. When studying motion in the void, Galileo "immediately and consciously places himself outside of reality. An absolutely smooth plane, an absolutely spherical sphere, both absolutely hard: they are things that are not found in physical reality" (Koyré, 1939, p. 36). In trying to eliminate friction, Galileo

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chose to study a phenomenon even further away from physical reality. However, we know that this choice was guided by the idea that friction would disrupt the nature of free-fall motion as he conceived it. Experiments in the following centuries would follow similar strategies.

All the natural sciences currently work according to this pattern of studying phenomena under laboratory conditions. These conditions must be chosen in such a way that the measurement possibilities are optimized. For this, it is necessary to isolate the phenomenon under investigation from parasitic phenomena that undermine the observation of what is essential. Experimental situations created to study a natural phenomenon are therefore often very different from situations in nature. In other words, many scientific experiments depart from reality as it presents itself to us. Although they are supposedly aimed at understanding natural phenomena, they are often carried out under circumstances very different from those that exist without the mediation of science. Although the techniques currently used to optimize experimental conditions are often technologically sophisticated, they are based on the same idea that led Galileo to modify the conditions of his free-fall experiments.

The Galilean way of proceeding in his study of free fall represents a foundational act for science. Galileo went beyond the speculations of Antiquity and the Middle Ages; instead of questioning the causes of free fall, he sought to establish its rules. He initially took as a model of free fall the uniformly accelerated motion that he had already discussed from a mathematical point of view (Holton, 1962, p. 27-28). He then established suitable experimental conditions and found a way to measure space and time over the course of motion. Finally, he sought to provide a rigorous mathematical description of the phenomenon of free fall. Taken together, these various steps represent a style of explorative research that uses both experimental and mathematical means. This style of research led to the foundation of modern physics. Any physics researcher would be able to recognize in Galileo's work on free fall a pattern of scientific inquiry practiced from his time to the present.

Successive historical revisions were made to the facts concerning Galileo's work, as we have seen. The philosophy of science has also presented different perspectives on the Galilean way of investigating nature. Various philosophical schools invoke reason and empirical evidence in different ways in their analysis of the evolution of scientific knowledge. Furthermore, philosopher-scientists seeking to contribute to a global view of science have introduced new epistemological concepts which they applied to the history of science. These philosopher-scientists include Ernst Mach, Henri Poincaré (1854-1912), and Gaston Bachelard (1884-1962).

In *La Formation de l'Esprit Scientifique* (Bachelard, 1967), Bachelard develops his epistemology around the central idea that all scientific knowledge must be reconstructed at every moment. This conception could be applied to Galileo's work; his theoretical and experimental innovations fit the idea that "science makes its objects instead of finding them ready-made" (Bachelard, 1967, p. 71). The idea of construction can provide arguments to justify the complexity of scientific theories and experiments.

The notion that science reconstructs nature by seeking to describe and understand it is characteristic of epistemological and sociological approaches that are generally considered to be constructivist or constructionist. It is useful to refer to construction in connection with Galileo's work, but this article will not provide an in-depth discussion of constructivism. The notion of scientific constructionism, established during the 1930s by Ludwick Fleck (1896–1961), has been used by philosophers of science from different schools of thought. Several authors describe the varieties and ambiguities of constructivist ideas in different epistemological or sociological approaches. Alexander Riegler addresses "various strands of empirical insights and philosophical reflections" (Riegler, 2012, p. 235-266) that "have led and are still leading to the formulations of a number of constructivisms" (p. 237). He stresses that "constructivism is not a homogeneous paradigm" (p. 237). Reigler describes Mach's phenomenological perspective as a precursor of constructivism (p. 238); on Reigler's account, Mach's constructivism is based in the idea that the growth of knowledge is nothing more than the adaptation of thoughts to facts. He claims that it "was on this basis that Mach developed the concept of the 'economy of thoughts,' which emphasizes the importance of compressing experiences into laws" (p. 238).

Riegler's study raises a relevant and even fundamental question regarding whether the constructions considered within the scope of scientific inquiry constitute "an adequate representation of reality" (Riegler, 2012, p. 242). The idea of a nature reconstructed by scientific knowledge may indeed seem incompatible with philosophical positions of realism and the realist commitment to the mind-independent existence of the world investigated by science.

From the point of view of realism, the same question arises with any interpretation of Galileo's work.

Ian Hacking is quite critical of constructionism. He argues that although it appeared to be a truly liberating idea in many contexts, social constructionism has become merely orthodox. One of his criticisms is that "most of the (social) construction/constructing works do not exhibit anything resembling a construction. Construction has become a dead metaphor" (Hacking, 1999, p. 49). However, "most writers never reflect on the metaphor in 'construction'" (p. 50). Hacking's critiques of social constructivism are pertinent. They can also be applied to the natural sciences, where the idea of construction could become a "dead metaphor" that replaces the complexity of knowledge processes with a simple label. However, the construction of knowledge is a suggestive idea in the learning process; it can be implemented through historical contexts and specific contents that give it life. The idea has naturally interested some science teachers who have adopted the perspective of knowledge construction in their teaching practices (Driver et al., 1994). The concept of construction as used by Bachelard and other philosophers of science can also be seen as an useful epistemological tool. It can be used for analyzing the transformation of knowledge brought about by Galileo's experiments and theoretical work as well as other experiments and theories of modern physics. Nevertheless, the idea that scientific knowledge is reconstructed cannot be a single and global explanation for such a complex process.

Philosophers of science have found other ways to characterize the complexity of scientific knowledge. One such characterization is the idea of convention, established by Henri Poincaré in the context of geometry (Poincaré, 1982, p. 65) and later generalized to mechanics (p. 106). The idea of convention has been the subject of extensive controversy that we cannot explore in detail here. However, given that the word "convention" raises even more strong objections than "construction," it is important to refer to some of Heinzmann and Stump's arguments (Heinzmann and Stump, 2021). These arguments justify Poincaré's conventionalist ideas developed in *La Science et l'Hypothèse* (Poincaré, 1902): "The principles of mechanics certainly have, according to Poincaré, an empirical origin, but they nonetheless surpass the bounds of strict empiricism" (Heinzmann and Stump, 2021). Heinzmann and Stump also describe the process that, according to Poincaré's thinking, leads to the transformation of an empirical law into a principle of physics: "From the phenomenon we move by physical induction to the experimental result and, thanks to differential equations, to the laws and the general hypotheses which, by a common decision of the scientific community, can be elevated finally to a principle" (Heinzmann and Stump, 2021). These observations concern the principles of physics and characterize a different time than Galileo's. They nonetheless refer to a problem that is already present in his work: the relationship between experiments and theoretical laws. The problem has gained in significance with the development of the means and instruments of theory and experience, and with the growth in the scope and applications of scientific results. The current controversies surrounding the theory-experiment problem approach the issue essentially from the perspective of the social functioning of science (Franklin and Slobodan, 2021). However, the ideas that emerge in the field of philosophy or epistemology, such as those of Mach, Poincaré, or Bachelard, continue to be useful for a critical analysis of theory and experiment in science and their relationships. Ideas about Galileo's Platonism have also been valuable tools in this analysis.

4. Galileo's platonism, mathematics, and experiments

According to Giorgio Matteoli (2019), the thesis regarding Galileo's Platonism was first formulated in the Marburg school by Paul Natorp (1854-1924). For Natorp, Galileo was the "true founder of the modern idea of law, meant as a mathematical necessary connection between phenomena" (Matteoli, 2019, p. 71). Matteoli adds, however, that it "is only with Cassirer, who took inspiration from his teacher, that Galileo's Platonism thesis was refined and systematized in the wider framework of the history of science" (p. 71). Ernst Cassirer (1874-1945) was the first "to develop a detailed reading of the scientific revolution as a whole in terms of the 'Platonic' idea that the thoroughgoing application of mathematics to nature (the so-called mathematization of nature) is the central and overarching achievement of this revolution" (Friedman, 2022). For Cassirer, in accordance with the philosophical principles of Marburg neo-Kantianism, philosophy as epistemology "has the articulation and elaboration of the structure of modern mathematical natural science as its primary task. Cassirer claims that it was Galileo who first grasped the essential structure of the 'synthetic process wherein mathematical models of nature are successively refined and corrected without limit'" (Friedman, 2022).

Galileo's Platonism is often associated with his conceptions of mathematics. However, as De Caro writes, "throughout the history of philosophy, the category of 'Platonism' has been used all too commonly … Cassirer, for example, identify 16 different types of Platonism represented in that period. Merely defining Galileo as a Platonist would therefore be of very little interest, if one were not able to specify precisely what precise sense should be attributed to the label 'Platonism' in that context" (De Caro, 2017, p. 87).

The Galileo's Platonism thesis has influenced historians of science including Alexandre Koyré. Koyré sees mathematics as having a "commanding position in Physics" for Galileo (Koyré, 1943, p. 420). Galileo's ideas about the importance of mathematics in research into physics were acquired from a young age, he writes. Galileo gained these notions alongside Francesco Buonoamici and Jacopo Mazzoni, who used the role played by mathematics to draw a line between Platonists and Aristotelians (p. 420-421). Different conceptions concerning the role and nature of mathematics are, in fact, "the principal subject of opposition between Aristotle and Plato" (p. 420). Galileo, however, goes well beyond his Platonic-inspired philosophy. He carries out, "under the obvious and unmistakable influence of the 'superhuman Archimedes' a determined attempt to apply the principles of 'mathematical philosophy' to this physics" (p. 417). As a result of this attempt, a "new and original concept of motion had to be formed and developed. It is this new concept that we owe Galileo" (p. 417). In *Galilean Studies*, Koyré addresses the influence of Archimedes on Galileo's thought in more detail (Koyré, 1939, p. 28-38). He states that Galileo's physics is "Archimedean": a "deductive and abstract mathematical physics." This statement encapsulates Koyré's idea that the issue at stake regarding the role of mathematics in Galileo's thought is not only its *use* in physics but also its presence in the *structure* of the discipline (Koyré, 1943, p. 421). Koyré notes that "these are the discussions to which Galileo alludes continuously in the course of his dialogues" (p. 421-422).

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De Caro cites Koyré, referring to the philosophical interpretation of the mathematization of nature: "According to Koyré … the Platonists were those who gave a realist interpretation, i.e. an anti-instrumentalist one, of mathematized science" (De Caro, 2017, p. 85). He points out that in "Machamer's words: if a thinker believed in the descriptive power of mathematics, he was a Platonist" (p. 85). De Caro clarifies that this, "however, evidently is not a methodological characterization, but an ontological one: if mathematics correctly describes reality, it is because reality is inherently mathematical. And, indeed, if the Platonic interpretation of Galilean science has value, it is because—in addition to the methodological level—it also considers the epistemological and ontological ones" (p. 86).

Many authors mention the relevance of mathematics in Galileo's work. However, there are different views on how his mathematical practice is related to his natural philosophy (Machamer and Miller, 2021). Machamer and Miller refer to a wide range of publications on Galileo. They ask if he can be considered "a mathematical Platonist (Jardine 1976; Koyré 1978), an experimentalist (Settle 1967; Settle 1983; Settle 1992; Palmieri 2008), an Aristotelian emphasizing experience (Geymonat 1954), a precursor of modern positivist science (Drake 1978), or an Archimedean (Machamer 1998a), who might have used a revised Scholastic method of proof (Wallace 1992; Miller 2018). Or did he have no method and just fly like an eagle in the way that geniuses do (Feyerabend 1975)" (Machamer and Miller, 2021).

There is also no historical consensus on the question of Galileo's contribution to the mathematization of science. As mentioned in the introduction to this article, Torretti believes that Galileo "provided a paradigm of mathematical physics that inspired the next generations" (1978, p. 21). Drake also values Galileo's mathematical discoveries, stating that they "consist in the perception that a certain mathematical relationship holds for physical phenomena considered" (1974, p. 130) and that the study of free fall represents an "approach to a valid mathematical physics in the modern sense" (p. 149). In opposition to these claims, Marco Panza argues that although kinematics must be,

> According to Galileo, a mathematical science, it does not introduce its objects as mathematical ones. Rather it is founded on a mathematical characterization of physical phenomena. Once again, Galilean

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science of motion results from an application of mathematics to the study of motion and not from a process of mathematization. (Panza, 2002, p. 267)

The modern relationship between physics and mathematics has a long history that began before Galileo with the fourteenth-century schools of Oxford and Paris (Dalmedico and Peiffer, 1986, p. 209). However, Galileo's investigation of free fall led him to establish a mathematical relationship between space and time over the course of motion, a relationship he expressed using the theory of proportions. This solution meant that the evolution of the free fall phenomenon took place in the general domain of mathematical quantities that simultaneously regroups the time and space intervals. In other words, Galileo thought of it as a functional relationship (Dalmedico and Peiffer, 1986, p. 212). The functional relationship between two physical quantities was therefore the mathematical instrument invented by Galileo when he had the "perception that a certain mathematical relationship holds for physical phenomena" (Drake, 1974, p. 149). The existence of functional relationships between physical quantities was significant in the development of mathematics. In the seventeenth century, for example, the fact that the study of movements was a privileged subject meant that most of the functions introduced were studied as curves, considered as trajectories of points in movement (Dalmedico and Peiffer, 1986, p. 212).

The different conceptions of Galileo's relationship with mathematics can be justified by the fact that "no research has so far been devoted to the cognitive mechanisms underlying Galileo's mathematization of nature" (Palmieri, 2003, p. 229). For Palmieri, "a cognitive history perspective might complement current historiographical approaches, thus appealing to a broader, cross-disciplinary audience" (pp. 229-230). In developing his study, Palmieri refers to "Galileo's alleged use of thought experiments" (p. 232); he claims that the themes of the mathematization of nature and thought experiments are correlated in Alexandre Koyré's thesis concerning Galileo's Platonism (p. 232).

Some texts from *Galilean Studies* (Koyré, 1939) may shed light on the issue. As already mentioned, Koyré claims that Galileo "immediately and consciously places himself outside of reality. An absolutely smooth plane, an absolutely spherical sphere, both absolutely hard: they are things that are not found in physical reality (Koyré, 1939, p. 36). When dealing later with the law of falling bodies, Koyré asks if an experiment is not nearly always for Galileo a mental experiment (p. 173). These and other statements that appear throughout *Galilean Studies* seem to corroborate the idea that there is a correlation between Galileo's conceptions of the mathematization of nature and of scientific experiments. In other words, if for Galileo the mathematical study of nature consisted of a Platonic approach to the real world, the same was true of experiments as he conceived them.

Conclusion

Historians and philosophers of science recognize the importance of Galileo's theoretical and experimental research into falling bodies. It has not been possible to establish a consensus on some aspects of Galileo's thought, however, such as the significance of mathematics in his work. Galileo's experiments have also generated controversy among historians and philosophers. The intention throughout this study has been to demonstrate the lack of consensus between their various interpretations of Galileo's work.

This article presented various philosophical approaches, such as constructionism, conventionalism, and Platonism. These approaches allow different but not totally incompatible readings of Galileo's work, and in particular its relationship with mathematics.

Finally, the article argued that the presentation of Galileo's experimental procedure, based on the thought of Alexandre Koyré, provides a useful clue to understanding what experiments have represented in science from Galileo to the present day.

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