Understanding Galileo's Inquiries About the Law of Inertia

Jun-Young Oh, YooShin Kim, Chun-Hwey Kim, Byeong-Mee Min and Yeon-A Son

Abstract The purpose of this research is to gain a better understanding of the role of abstraction and idealization in Galileo's scientific inquiries about the law of inertia, which occupies an important position in the history of science. We argue that although the terms "abstraction" and "idealization" are variously described in the recent literature, the concepts must be adopted to highlight important epistemological problems. In particular, we illustrate the importance of abstraction and idealization for the formation of the law of inertia by establishing a distinction between two types of entities: quasi-ideal entities and idealized entities. These theoretical laws should therefore be justified, using deduction and induction, through quasi-idealized entities based on data from the everyday world.

1 Introduction

The notions of idealization and abstraction, which are commonly used in the thought processes of scientific knowledge construction, can be traced back to Galileo (Portides 2005). Nola (2004) argues that a clear distinction must be made between idealization and abstraction, so that the use of abstraction and idealization could be considered valid once the two notions are distinguished (Cartwright 1989; Suppe 1989; Portides 2005).

According to Nowak, "[in] brief, the Galilean breakthrough consisted in the introduction of the method of idealization in physics":

J.-Y. Oh (✉)
Hanyang University, Seoul 133-791, Republic of Korea
e-mail: jyoh3324@hanyang.ac.kr

Y. Kim
Pusan National University, Pusan 609-735, Republic of Korea

C.-H. Kim
Chungbuk National University, Cheongju 361-768, Republic of Korea

B.-M. Min · Y.-A. Son
Dankook University, Gyeonggi 448-701, Republic of Korea

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> The Galilean revolution consisted in making evident the misleading nature of the world image that the senses produce. We only see phenomena that are the joint effect of all the relevant influences. As a result, senses do not contribute in the slightest to the understanding of the facts. In order to understand phenomena the work of reason is necessary which selects some features of the objects through idealization and in their idealized models recognizes some other features of the empirical originals. These models differ a great deal from their sensory prototypes; what is more, they present images of hidden relationships that could not be grasped with the aid of experience at all. (Nowak 1994, in Nola 2004, p. 350).

The hidden causes of observable events cannot, by definition, be perceived by our senses but can be revealed by idealization and abstraction. Therefore, to understand important scientific cognitive processes, the exploration of how idealization takes place in science is mandatory. The case of Galileo is central: he used a dyadic approach, combining the composition of idealizations for theories or models and the generation of observation-based predictions, about which we can only make approximations using our theories or models. The present study focuses on this dyad.

First of all we will present the development of a typical scientific inquiry based on different level worlds. We will then describe in detail Galileo's discovery of the Law of Inertia. How did Galileo use the abstraction and idealization strategies in formulating the law of inertia? The answer can be found by showing how Galileo went beyond Aristotle's scope of observation through the use of thought experiments. Moreover, how did Galileo justify the law of inertia that he formulated? Answering this question will allow us to show how the proof of his conclusion was also produced through thought experiments. A final question also arises in relation to heliocentrism: How did Galileo's strategies concerning Copernicus' work support the heliocentric hypothesis?

2 Background

2.1 Abstraction and Idealization

Modern philosophy of science distinguishes between abstraction and idealization. As an important activity in constructing models and theories, abstraction comprises processes of forming general concepts out of individual instances.

Psillos describes abstraction as the removal of certain characteristics, properties, or features of an object or system that are not related to the aspects of behavior of the object under investigation (Psillos 2007, p. 6). According to Cartwright, in the case of abstraction, we subtract concrete facts about objects, including perhaps the details of their material composition, and—of particular importance—we eliminate interfering causes (Cartwright, in Ladyman 2002, p. 260). By contrast, Cartwright defines idealizationas the theoretical and experimental manipulation of concrete situations to minimize or eliminate the effects of certain features of an object. For example, we obtain a frictionless plane through idealizing the real surface, and then we re-introduce the appropriate mathematical concept, the friction coefficient.

Bhaskar (1979/1998) interprets abstraction as follows:

> Abstraction according to its traditional meaning is focusing upon certain aspects of something to the (momentary) neglect of others. It is a process of focusing on some feature(s) of something(s) while others remain in the background (Bhaskar 1979/1998, p. 170).

In other words, abstraction allows us to omit less relevant details, as we understand them, and thus to increase our capacity to identify an object's essential features. Hypotheses about idealizations can not be obtained by induction, by simple enumeration, or by the methods of agreement and difference. The scientist must intuit which properties of phenomena form the proper basis for idealization and which properties may be ignored (Losee 2001, p. 49).

Nola (2004) succinctly differentiates between abstraction and idealization as follows:

> The term "idealization" will be used differently. In the case of abstraction, an object is still a real object with property P, but we ignore property P for certain purposes, such as whether it is a property with which our theory deals. But in the case of idealization, we do not merely ignore a property; we regard P as a property that the object *definitely does not possess*. (Nola 2004, p. 357).

According to Nola, in idealization we do not ascribe ontological status to the removed properties of the object, whereas in abstraction we ascribe an ontological status to removed properties. Moreover, abstraction means consciously ignoring certain properties for certain purposes.

Nola's idealization means considering the properties that the object does not definitely possess rather than simply ignoring certain features of the object deliberately. Generalizing for an infinite amount of unobservable data based on a finite amount of observed data, instead of ignoring certain features, is an important example of formal idealization.

In our research concerning Galileo's work, abstraction and idealization are distinguished as follows:

> **Abstraction**: In scientific activity, the notion of abstraction is essential. Abstraction allows the scientists to focus on an object's particular properties—and their operations—through isolation, controlling and removing any other properties present in the concrete circumstances.
>
> **Idealization**: Idealization is the consideration of properties that the object definitely does not possess in a physical system, using Galileo's thought experiments; the notion of abstraction, by contrast, deliberately ignores certain features the object possesses in concrete circumstances, while others remain in the background

By extrapolating from a series of phenomena, we formulate an idealization. For example, the concept of free fall in a vacuum can be obtained through extrapolation based on the observations of the behavior of a falling object in a series of fluids of decreasing density. Creative imagination plays an important role in obtaining results by means of idealization.

Abduction and Retroduction: The abductive process simultaneously infers the rule and the case from a known fact (i.e., the result) that requires explanation. Abduction is an expansive cognitive process in the sense that it yields a novel hypothesis (amplitude). How can abduction be a form of inference distinct from deduction and induction (as the unfettered play of amusement or as a response to a surprising fact) and also a form of recursive analysis that includes deduction and induction? Referring to the concept of abduction as amusement and to that of recursive analysis as retroduction can eliminate much of the confusion surrounding abduction.

The distinction between the pre-trial and post-trial evaluations of hypotheses is included in the H-D method. For example, Whewell required the use of a hypothetical theory to "explain phenomena which we have observed" and "foretell phenomena which have not yet been observed", indicating that these phenomena are "of a kind different from those which were contemplated in the formulation of our hypothesis" (Whewell 1847, pp. 62–65).

According to Rescher (1978), Peirce sees qualitative induction as an evolutionary process of variation and selection. Two component processes are involved here, as we have seen:

1. Hypothesis production or abduction: the purely conjectural proliferation of a plethora of alternative explanatory hypotheses that are relatively plausible.
2. Hypothesis testing or retroduction: the elimination of hypotheses on the basis of observational data (Rescher 1978, p. 8).

The result of the overall process is that science proceeds by the repeated elimination of rival hypotheses in favor of one preferred candidate. Each stage of the abduction-retroduction cycle reduces a cluster of conjectural hypotheses to an accepted theory.

2.2 The World According to Galileo's Scientific Inquiry Procedure

In this section, we propose a model of the scientific inquiry process which is useful to interpret the one adopted by Galileo. We stratify the ontological world into four layers—the empirical world, the event world, the theoretical world, and the idealized world—to analyze Galileo's scientific inquiry.

The empirical world: The empirical world may be roughly defined in relation to the other worlds. The empirical world is the world perceived through the sense organs of a cognizing subject who accommodates the stimulations of the external world. In this world, the cognizing subject is in a state of ignorance with regard to the regularities among perceptions, but these regularities, the features of events in this world, are grasped by the cognizing subject via perception of the external world and are produced through arranging and individuating them.

The theoretical world: The theoretical world comprises the description of causal forces and mechanisms operating on objects outside the cognizing subject. The elements of the theoretical world, therefore, correspond to the elements of the external world of the cognizing subject. Although certain objects exist, the causal forces of those objects may not come into effect because of inappropriate conditions and consequently may not produce suitably detectable results. The theoretical world may not exactly reflect the external world but approximately conforms to it. Theories always aspire to describe the external world satisfactorily.

> **The idealized world**: The idealized world is composed of idealized entities that are mental constructions of the scientist, produced by idealization and based on objects in the event world. A vacuum is an ideal entity, and free fall in a vacuum is the ideal behavior of an ideal entity. Idealization requires creative imagination rather than a simple enumeration-induction and consistence-difference method.

We argue that experiments involving idealization are at the core of Galileo's arguments against the Aristotelians. In our study, the idealized world belongs to the theoretical world. The theoretical model is a set of idealized objects and idealized relations among them, obeying idealized laws (Nola 2004, p. 360).

In Galileo's writings, thought experiments and real experiments are deeply intertwined and often indistinguishable. Some of his experiments proved to be only imaginary (Cohen 1950/1993; Cushing 1998; Dijksterhius 1986, pp. 81–84). All of these experiments amount to the same thing—idealized experiments—in contrast to real experiments in the modern sense of the term (Galili 2009). Here, we can see that Galileo's thought experiments constitute a significant strategy of connecting and coordinating real experiments and theoretical models involving idealized entities.

Recently, Fernández-González (2013, p. 1727), proposed an ideal level and a quasi-ideal level for both physics and chemistry:

> Idealized entities are thus archetypes of real world objects. Unlike Plato's ideal entities, which are eternal and immutable, idealized objects are mental constructions of the scientist, based on real objects. Quasi-ideal entities are those real world entities whose characteristics most closely approximate those of idealized entities since they are created with that intention (e.g., the balls used by Galileo that imitate geometrical spheres). This quasi-ideal world is an almost perfect reflection of the ideal world. Thus, if the level of precision required is not very high, a quasi-ideal system can behave as though it were ideal. Actually, the ideal world is part of the theoretical world, where complex structures such as theories and models reside.

By using thought experiments, Galileo was able to extend the scope of the concept of experience without distorting its validity. These thought experiments enabled him to discover things about motion that could not be discovered using common experience and simple inference (Gower 1997, pp. 31–32). For Galileo, thought experiments secured a link between the real experiments that led him to his belief in the principles of a new science of motion and the common experiences that he would need to appeal to in order to justify those principles to his readers (Gower 1997, p. 33). A scientific inference based on abstraction and idealization for the generation of hypotheses involves the deduction-induction method for justification of the hypothesis (see Magnani 2001, 2009; Oh 2012, 2014) and for the evaluation of hypotheses.

In this study we are considering three distinct worlds: the empirical world is separate from the idealized world, which is embedded in the theoretical world, thus giving the appearance of two worlds. We locate the theoretical world, including the idealized world, at the highest level and describe its members as theoretical entities (theories, models) and idealized entities. We call those entities situated at the highest level of the empirical world, close to the idealized world, quasi-idealized entities.

2.3 Galileo's Scientific Inquiry Procedure about the Law of Inertia

The generation and formulation of hypotheses based on abstraction and idealization.

In the present study we are analyzing the generation of hypotheses through abstraction and idealization. The processes of abstraction and idealization are as follows: first, we formulate new hypotheses through prevailing knowledge about a theoretical physical world, a process known as "abduction". We then make use of an idealization strategy based on thought experiments to generate an idealized physical world (see Fig. 1).

The arrows directed upward symbolize the generation or formulation of hypotheses, and the arrow downward symbolizes the verification or justification of the generated hypotheses. The dotted arrows mark the border between the theoretical world (or conceptual world) and the event world.

The relationship between the ideal world and the quasi-ideal world is somewhat closer. The quasi-ideal world is the closest approximate reflection of the ideal world, but the quasi-ideal world has no meaning without the existence of the ideal world, which is its referent.

Following Kuhn (1970), we also believe that Galileo observed the same phenomena through different paradigms. In fact, observation is theory-dependent because, when we observe phenomena, we are influenced by what we already "know" and by

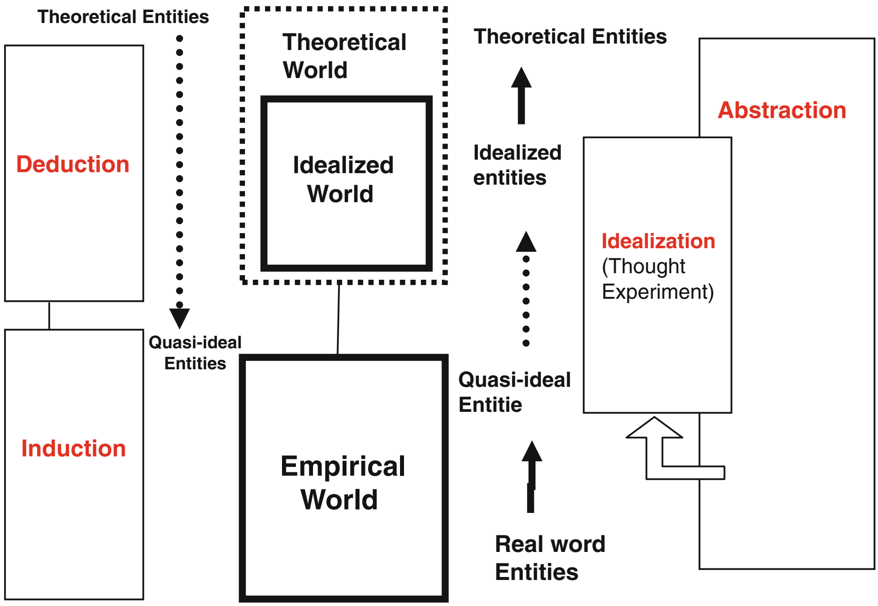

Fig. 1 Galileo's scientific inquiry procedure about the law of free falling motion

background thoughts. Galileo poured all his efforts into developing the heliocentric theory and he accepted Aristotle's theory about the natural motion of the essential elements of the universe. Also the influence of Neo-Platonism in his abductive inferences can be easily detected.

The testing and verification of hypotheses based on deduction-induction

Deduction: Grosseteste and Roger Bacon (Losee 2001, p. 49) improved the Method of Composition by suggesting the deduction of consequences (quasi-ideal entities in the event world) that were not initially included in the data in order to induce explanatory principles (theoretical entities in the theoretical world).

Induction through Experimental Confirmation: Grosseteste and Roger Bacon (Losee 2001, p. 50) also added to the method of resolution and composition a third stage in which the conclusions reached are further tested experimentally (quasi-ideal entities in the event world). In fact, only quasi-ideal entities in the event world appear in experimental situations. Because of the range of possible forces at work, it is difficult to construct scientific experimental situations in which natural phenomena can be explored, so to speak, in their entirety.

3 Galileo's Formulation and Justification of the Law of Inertia

Logic, considered as a tool assisting the search for truth, had different meanings for Simplicio (Aristotle) and Salviati (Galileo). Simplicio regarded Aristotelian logic itself as the absolute authority and the correct tool for finding truths. In contrast, Salviati believed that the true logic that reveals natural knowledge resides in the proofs of mathematics and geometry, which are the "languages of Nature". Garrison (1986) referred to this activity of explaining the empirical world using the ideal world as "secondary idealization". This is the Galilean solution to the problem of generalization that has become common in the physical sciences (see Chalmers 1990, p. 35).

3.1 Galileo's Strategies for Formulating the Law of Inertia

First Stage: abstraction based on abductive strategies

Salviati: […] Now tell me, what do you consider to be the cause of the ball moving spontaneously on the downward inclined plane, but only by force on the one tilted upward?

Simplicio: That the tendency of heavy bodies is to move toward the center of the Earth and to move upward from its circumference only with force; now the downward surface is that which gets closer to the center, while the upward one gets farther away (Galilei 1967, p. 148).

However, if an external force is not continuously added to the horizontal surface, the moving object eventually stops. Feyerabend (1975) argued that Galileo ascribed a special position to motions that are neither natural nor forced:

> It must be assumed that the "neutral" motions, which Galileo discusses in his early dynamical writings, may be forever or at least for periods comparable to the age of historical records. And they must be regarded as "natural," in the entirely new and revolutionary sense that neither an outer nor an inner motor is needed to keep them going (Feyerabend 1975, p. 95).

In an exchange between Simplicio and Salviati, two characters in his Dialogues, Galileo argues that because a smooth ball projected down an incline would accelerate and continually increase its speed and because one projected up an incline would decelerate and continuously slow down until it stopped, then a ball projected along a horizontal surface would continue to move along this surface with undiminished speed. In some passages, Galileo seemed to consider natural, or inertial, motion to be a form of motion that neither rises nor falls but that always remains equidistant from the center of the Earth (McMullin 1985).

Aristotle had held that Earth could not be moving because if it were, objects such as birds, falling stones, and clouds would be left behind as Earth moved along its way. Galileo defused this objection to the sun-centered idea with experiments that almost single-handedly overturned the Aristotelian view of physics. In particular, he used experiments with rolling balls to demonstrate that a moving object remains in motion. This insight explained why objects that share Earth's motion through space—such as birds, falling stones, and clouds—should stay with Earth rather than falling behind as Aristotle had argued. Thus, Galileo formulated the inertial law of the terrestrial world from Aristotle's celestial natural motion through what it is now called rule-forming abduction.

Abduction: Rule-forming "Abstraction"

Aristotle divided motion into the "natural" motions and the "violent" motions. Natural motions were those motions that objects naturally made: objects on Earth fell towards the center of the Earth. Heavenly objects naturally moved in circles. Violent motion was *anything* other than this. Therefore, picking up a rock was considered a violent motion.

> Because motions in the horizontal plane with no friction are not going down and going up based on the natural motion of Aristotle, it is possible for the motion of rolling to continue. If the hypothesis that neutral motion without any friction at the same distance from the center of the Earth is equal to natural motion in the celestial world is correct, and if the objects hold some speeds, then an object projected along a horizontal surface equidistant from the center of the Earth will continue to move along this surface with undiminished speed (theoretical entities). Therefore, there are good reasons to believe that an object projected along a horizontal surface equidistant from the center of the Earth will continue to move along this surface with undiminished speed.

In addition, the notion of eternal straight motion, another hypothesis in the horizontal plane, was eliminated based on Aristotle's finite universe **(Retroduction)**.

Galileo contradicted the strict separation between the celestial and terrestrial worlds of Aristotle. In addition, he developed them into a claim that natural motions ofthe vertical rise and fall in the terrestrial world are the same movement as the circular movement in the celestial world. Because Galileo cannot deviate completely from Aristotle's views regarding celestial motion in perfect circles, his inertial motion was circular rather than the linear inertial motion of Newton.

Second Stage: idealization based on thought experiments

"The removal of friction by thought experiments: This produces ideal objects that act in conditions that are also ideal".

If the hypothesis that an object experiences friction on a flat surface is correct and if the flat surface is infinite and an object is pushed with the same force on a surface that is increasingly smooth, then what motion will the object follow?

(But) In fact, the object stopping further away on an increasingly smooth flat surface (quasi-ideal entities) and eventually moving infinitely farther away is possible as an ideal limit value. Therefore, in an idealized situation (idealized entities) that ignores air resistance, the flat surface can be made smoother and smoother until eventually the object continues without stopping.

We believe that Galileo imagined a smooth flat surface becoming smoother and smoother as a quasi-ideal entity in an experimental situation, with the surface finally becoming frictionless. He regarded this plane as an ideal entity. As an example of such an entity, he cited the surface of a smooth water plane, and he saw the infinite frictionless plane as an idealized entity. He, thus, advanced his idealization strategy through two types of entities: idealized and quasi-idealized.

For idealized entities, no friction exists between objects and surfaces. If all resisting effects could be removed, the object would continue in a steady state of motion indefinitely in a theoretical world. Theoretical entities (models or theories) in a theoretical world consist of idealized entities. Galileo is close to the law of inertia in the Newtonian sense, but this point does not imply that Galileo reached the law of inertia in the Newtonian sense, only that he developed an idealization strategy through creating quasi-ideal entities.

Under his idealization strategy, if a plane and an object are both highly polished, the object, given the same initial speed, will slide farther before coming to rest. On a smooth layer of ice (the closest approximation of an idealized entity and therefore a quasi-ideal entity in the event world), the object will slide farther still. Galileo reasoned that if all resisting effects could be removed, the object (an idealized entity) would continue in a state of motion indefinitely (a theoretical entity).

We believe that Galileo imagined a smooth, flat surface becoming smoother and smoother as a quasi-ideal entity in an experimental situation, with the surface finally becoming frictionless. He regarded this plane as an ideal entity. As an example of such an entity, he cited the surface of a smooth water plane, and he saw the infinite frictionless plane as an idealized entity. He,thus, advanced his idealization strategy through two types of entities: idealized and quasi-idealized.

3.2 The Process of Justification

Such inertia has been applied in the tower argument, which supports the Copernican theory of the Earth's motion (Finocchiaro, 2010) and is consequently proved: although a ship on a smooth sea is motionless, once an external force strikes it, the ship will move around the surface of the Earth continuously. Of course, no resistance and no external force are present.

According to Cohen (1985), in Galileo's experimental test the essence of what is called both the mathematico-experimental and hypothetico-deductive method in symbolic terms is displayed:

> What Galileo did was to deduce *B* from *A*; he next tested *B*, and then concluded that *A* holds. It should be noted, however, that this method does not include a guarantee of *A*. For instance, it might happen that *B* could also be that deduced from A'. Additionally, it is assumed that the process of deducing *B* from *A* is correct. Traditionally, this means correctness of logical deduction. Galileo's method is to derive *B* from *A* by aid of mathematics. Because *B* is derived from *A* by mathematics and then tested by experiments, the method can also be called mathematico-deductive. In the seventeenth century, the term "mathematical-experimental" was also used. This method is called "hypothetico-deductive" because we wish to test hypothesis *A* but cannot do so by experiment. (Galileo's use of this method in relation to the hypothesis $V \propto t$ and the testable deduction $D \propto t^2$ may be found on pp. 88 ff. supra.) (Cohen 1985, p. 207).

> **Deduction**: If the falling body speed (V) of an object is proportional to falling time (t) and, ignoring air resistance, if the object is in free fall without an initial velocity, then it is mathematically induced that the fall distance (D) is proportional to a square of the time (t^2).

> **Induction**: As mathematically predicted, the result showed that V is proportional to $t(\mathrm{t}^2)$. Thus, the hypothesis that the falling time of an object in free fall, ignoring air resistance, is proportional to the square of the falling time is supported.

Third Stage:

"The Deduction-Induction Cycle"

In Galileo study, it was by an experiment that, in parabolic motion of an object that was dropped from a mast on a ship like the following, the horizontal motion components of an object that is mathematically induced equals the velocity of the ship. In other words, Galileo realized for the first time that physical quantity that has a direction, that is, vector, can be decomposed into components that are at a right angle to one another.

One of the arguments against the heliocentric hypothesis of Copernicus was the tower argument. How did Galileo counter it? Galileo's study experimentally proves that, from the parabolic motion of an object dropped from the mast of a moving ship, the speed of the boat is, in fact, a mathematically derivable element of the constant horizontal motion of the object.

(If) the law of inertia (a theoretical entity), which states that all objects that are not provided with a force for motion have inertia in motion, is correct, (and) if an object is dropped from the mast of a ship that moves at a constant speed and has no air resistance (quasi-ideal entities), (then) the object must fall directly below the mast due to the mathematically derived horizontal velocity of the object.

Several well-known passages in Galileo's *Dialogue Concerning the Two Chief World Systems* relate to this:

> Salviati: Now as to that stone which is on top of mast; does it not move, carried by the ship, both of them going along the circumference of a circle about its center? Consequently, is there not in it an ineradicable motion, all external impediments being removed? And is not this motion as fast as that of the ship? (Galilei 1967, p. 148).

> Salviati: […] for you yourself have already granted the resistance to be against motion which increases the distance from the center, and the tendency to be toward motion which approaches the center. From this it follows necessarily that the moving body has neither a resistance nor a propensity to motion which does not approach toward or depart from the center, and in consequence no cause for diminution in the property impressed upon it. (Inertial law: Theoretical entities) (Galilei 1967, p. 149)

> Salviati […] it may be seen that, at most, the falling body might drop behind if it were made of light material and the air did not follow the ship's motion, but if the air were moving with equal speed, no imaginable difference could be found in this or in any other experiment you please (*Expected Results: Quasi-ideal entities*) […] Now, in this example, if no difference whatever appears, what is it that you claim to see in the stone falling from the top of the tower, where the rotational movement is not adventitious and accidental to the stone, but natural and eternal, and where the air as punctiliously follows the motion of the Earth as the tower does that of the terrestrial globe? (*Support of the Heliocentric hypothesis*). (Galilei 1967, p. 154, emphasis added).

Induction through Experimental Confirmation and Expansion:

(If) the law of inertia (a theoretical entity), which states that all objects that are not provided with a force for motion have inertia in motion, is correct, (and) if an object is dropped from the mast of a ship that moves at a constant speed and has no air resistance (quasi-ideal entities), (then) the object must fall directly below the mast due to the mathematically derived horizontal velocity of the object.

Following the steps above deduction, Induction,

(And) as expected, the object that was dropped from the mast of a moving ship fell directly below the mast of the ship (quasi-ideal entities). (Therefore), the hypothesis that all objects that are not provided with a force for motion have inertia in motion is supported.

One of the questions left unanswered by the Copernican system of the universe was the following: if the Earth rotates, then why does a ball dropped from a tall tower fall directly below instead of some distance away from the tower? Galileo's response was that the ball shared the Earth's rotation and continued this motion in a horizontal direction even while it was falling down. This response reflects the principle of inertia, according to which all motions maintain their status as long as there is no external interference (Cushing 1998). The same logic that explains why the ball falls directly below the tower on a rotating Earth also explains why a ball falls directly below the mast on a moving ship. Galileo's principle of inertia did not deviate from Aristotle's view that a circular motion is complete and natural, however. The orbit of an inertial motion is a circle because the ball falling from the tower shares the Earth's rotational motion.

According to Cohen (1985), Galileo intended to prove his restricted inertia through this well-known fact:

> It is precisely this point which Galileo wished to prove because he now can explain that a stone let fall from a ship will continue to move around the Earth as the ship moves, and so will fall from the top of the mast to the foot of the mast (Cohen 1985, p. 121).

Galileo recognized this constant motion as a uniform circular motion. The planets absolutely must follow a circular orbit at a constant speed. This is because any change in motion meant that there was a continued application of force affecting the planets, or as Kepler said, a magnetic-like force affecting them. Galileo thought, according to his own law of inertia, that the orbits of the planets must be circular and that no change could occur in the speed of planetary motion (Parisi 2001, pp. 23–24).

Galilean relativity theory says that within the inertial frame, system, uniform motion, and stationary state cannot be distinguished. This means that the absolute space of Aristotle does not exist. In a famous passage from his *Two Chief World Systems*, Galileo says:

> Salviati: How many propositions I have noted in Aristotle that are not only wrong, but wrong in such a way that their diametrical opposites are true, as happens in this instance! But keeping to our purpose, I believe that Simplicio is convinced that from seeing the rock always fall in the same place, nothing can be guessed about the motion or stability of the ship (Galilei 1967, pp. 153–154)

This experiment provided the basis for an interesting and important objection to the Copernican heliocentric hypothesis of the Earth's motion, especially to the Earth's daily axial rotation.

4 Discussion

The "thought experiments" by which Galileo destroyed the Aristotelian dogma that moving objects stop eventually and heavier objects fall faster than lighter objects are classic and typical examples in the field of the science of motion. These experiments are certainly prototypical examples and thus feature prominently in all contemporary studies concerning scientific thought experiments (Brown 1991, 2000; Gendler 1998; Norton 1996). Galileo's thought experiments take two-fold roles for the formation and justification of theory. Galileo started with an analysis of idealized conditions that experience could never provide. Where Aristotle had begun with experience, Galileo began with the idealized case, of which the actual is only an imperfect embodiment. Having defined the ideal, he could then understand the limitations that material conditions entailed. If we start from experience, we are more likely to end up with Aristotle's mechanics, a highly sophisticated analysis of experience. Fundamental to Aristotle's discussion was the principle that all of the objects we encounter on the Earth are made up of some combination of "four elements": air, Earth, fire, and water. The celestial bodies are made of a "fifth element": "aether." The natural motion of a body composed of aether is circular, so that the observed circular motion of the heavenly bodies is their natural motion, just as motion upward or downward in a straight line is the natural motion for a terrestrial object.

Galileo also proposed the application of geometry to the study of terrestrial motions, such as the inertial motion based on abstraction and idealization in this study, through which he implied, ultimately, that Earth becomes a celestial body in a Copernican system. What shocked Aristotelians was that Galileo attempted to apply mathematical schemas to the terrestrial material cases, formerly only applicable to the explanations of the perfect celestial movements, believing that this rule was hidden in the "imperfect" Earth. Galileo thought that imperfection was the basis of reality. The imperfection of a fall of a body began the starting point of dynamics, and the spots sparkling around Jupiter as well as the solar spots on the surface of the sun demonstrated the possibility of the heliocentric theory. With Galileo, matter suddenly existed as "itself." He changed the question of "why" into "how".

According to Aristotle, without an applied external force, an object will move linearly upward or downward in accordance with its natural tendency to reach its original position. Aristotle thought that each of the basic elements had an original location as one of its properties and that movement stopped when an element had reached its original place. Although Galileo accepted Aristotle's theory of natural motion, he argued that a circular motion, that is, the natural celestial motion, could be induced on the ground by a violent motion, such as that caused by the application of a significant pushing or pulling force on the object. The primary weakness of Aristotle's approach was that it was, so to speak, too empirical. This weakness explains why he was unable to produce a mathematical theory of nature. Galileo's major achievement was to dare to describe the world although we do *not* experience it. He stated laws in a way that was outside of direct experience and, therefore, could not be verified by any single observation, but that was mathematically simple. Thus, he opened the road to a mathematical analysis that breaks down the complexity of actual phenomena into single elements. The scientific experiment is different from standard experiences in that it is guided by a mathematical theory that poses a question and is able to interpret the answer. It thereby transforms the given "nature" into a manageable "reality". Aristotle wanted to preserve Nature, to save the phenomena; his fault was in making too much use of common sense. Galileo dissects Nature, teaching us to produce new phenomena and to defy common sense with the help of mathematics (Von Weizsäcker 1996, pp. 104–105).

A more Platonic attitude can elevate the role of reason in the construction of idealized scientific models, beyond Aristotelian common-sense experience. Aristotle was able to express, in an abstract and consistent manner, many spontaneous perceptions concerning the universe that had existed for centuries before he gave them a logical and verbal rationale. In many cases, these were precisely the perceptions that since the 17th century, elementary education has increasingly banished from the Western mind. Today, the view of Nature held by most sophisticated adults shows few significant parallels to that held by Aristotle or even by the members of primitive collectives, yet views held by many non-Western peoples do parallel Aristotelian perspective with surprising frequency (Kuhn 1970, p. 95).

5 Conclusions

Post-positivist philosophers such as Kuhn, Feyerabend, and Dudley Shapere argued that the alleged distinction between theory and observation was to some extent illusory and untenable. The theory-ladenness of observation plays an important role in Galileo's justification of the heliocentric hypothesis by mechanics through thought experiments and thanks to astronomical observations through the telescope.

First of all the present study introduced abduction and idealization as processes devoted to the generation of new hypotheses. Koyrė (1978) regarded Galileo's new approach in building mathematical models of motion as the victory of a Platonic and abstract idealizing approach to science over that of Aristotle and medieval Aristotelians, who appealed to experience: "[F] or the contemporaries and pupils of Galileo, as well as Galileo himself, the Galilean philosophy of Nature, appeared as a return to Plato, a victory of Plato over Aristotle" (pp. 68–74). As Plato's student, Aristotle could have come close to understanding the principle of inertia, but he mainly focused on observation, turning away from Platonic idealizations such as those concerning eternity, vacuum, and the perfect, frictionless surfaces. He thereby lost the opportunity of discovering the concept of inertia (Potter 2009, pp. 82–83).

Today's teaching of science reflects yesterday's philosophy of science: several decades ago, empiricism dominated educational thought. It was taught that the scientist basically learns from experience by collecting data and generalizing or finding regularities in the data. The theoretical level is now more important even if we have to remember that the most important scientific theories did not fall from the sky: the views of discovery expounded in this article reflect the naturalistic turn in philosophy of science favored by the analysis of Galileo's thought experiments,strongly based on abstraction and idealization.

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