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Understanding Scientific Inquiries of Galileo's Formulation for the Law of Free Falling Motion

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Abstract The purpose of this study is to gain a better understanding of the role of abstraction and idealization in Galileo's scientific inquiries into the law of free falling motion, and their importance in the history of science. Because there is no consensus on the use of the terms "abstraction" and "idealization" in the literature, it is necessary to distinguish between them at the outset. This paper will argue (1) for the importance of abstraction and idealization in physics and the theories and laws of physics constructed with abduction from observations and (2) that these theoretical laws of physics should be tested with deduction and induction thorough quasi-idealized entities rather than empirical results in the everyday world. Galileo's work is linked to thought experiments in natural science. Galileo, using thought experiments based on idealization, persuaded others that what had been proven true for a ball on an inclined plane would be equally true for a ball falling through a vacuum.

Keywords Abstraction · Idealization · The law of falling motion · Abduction · Thought experiment

1 Introduction

Galileo had shown that the acceleration of a falling body was constant, this had been an experimental finding, and it had not been deduced from any premises or from a metaphysical postulated justified by appeal to God's perfection and immutability. Newton postulated that there was an attractive force between any two material bodies (Trusted 1991, p. 96).

Though some have questioned the role of thought experiments in his scientific method, there is no doubt that Galileo's claims were innovative during his time. In *Two New*

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Sciences, for instance, Galileo presented familiar phenomena in an unfamiliar way in a way that seemed to contradict common sense and subvert existing knowledge (Gower 1997, p. 22). Cohen (1985) claims,

> To appreciate the full nature of Galileo's discoveries, we must understand the importance of abstract thinking, [and] its use by Galileo as a tool that in its ultimate polish was a much more revolutionary instrument for science than even the telescope. … Galileo showed how abstraction may be related to the world of experience, how from thinking about 'the nature of things,' one may derive laws related to direct observation. (pp. 86–87)

Although Galileo abandoned Aristotle's universe, which was systematically organized with hierarchies and purposes, he maintained the core of Aristotle's concept of natural motion with some modifications. Galileo's analysis of motion is based on two concepts of natural motion. One is natural accelerated motion toward the center of the earth, and the other is constant and uniform motion perpendicular to the motion toward the center of the earth. In the context these two motions, heavy matter moves toward the center of the earth as natural motion.

The purpose of this paper is to understand Galileo's scientific method by focusing not on why the heavy matter moves toward the center of the earth but on how it moves. To achieve this purpose, we address the following important research questions:

1. The distinction between abstraction and idealization.

In Galileo's free fall law, we address the following:

2. How Galileo proceeds into the theoretical world through mathematical abstraction to inquire how free falling motion as natural motion starting from rest proceeds.
3. What types of idealization strategies Galileo used to move into the idealized world from the empirical world for patterns of these mathematical laws.
4. How Galileo tried to justify the physical theory constructed in the theoretical world in the empirical world.

2 Abstraction and Idealization

Galileo insisted on the importance of the strategies of abstraction and idealization in his thought experiments. An important activity in constructing models and theories, abstraction comprises processes of forming general concepts out of individual instances.

Cartwright distinguishes between cases where abstraction, which is often called idealization, involves simplifying assumptions and dealing with abstract (and fictional) entities rather than dealing with concrete objects/situations and cases where idealization is performed on a concrete object/situation (Cartwright in Ladyman 2002, p. 259).

Nola (2004) succinctly notes the distinct differences between abstraction and idealization as follows:

> 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.* (p. 357)

For Nola, in idealization, *ontological* matter is ascribed to the *lacked* properties of the object, whereas in abstraction, we ascribe an *epistemic* matter to *ignored* properties. Moreover, abstraction means ignoring certain properties consciously for certain purposes. Because in order to compare and to classify the immense variety of shapes, structure and phenomena around us we cannot take all their features into account, but have to select a few significant ones. In this research, the meaning of abstraction is used in the following sense:

Abstraction In scientific activity, the notion of abstraction is essential and deliberately ignores certain features the object possesses in concrete circumstances, while other features remain in the background. In other words, scientific activities are processes of determining the precise detailed causes of natural phenomena by abstracting particular factors, selecting principal properties and materials, and subtracting peripheral properties and materials from the concrete circumstances based on scientists' intuitions for the construction of models or mathematical models, which scientists want to resolve some future problems. It is an epistemic matter, as when we ignore properties for reasons related to our theories and considerations.

Nola's idealization means considering the properties that the object does not definitely possess rather than deliberately ignoring certain features of the object.

The movement of free fall through a vacuum is an extrapolation from the observed behavior of bodies dropped in a series of fluids of decreasing density. This concept of free fall in a vacuum is an idealization, like a frictionless plane. One important consequence of this use of idealization is the emphasis on the role of creative imagination in the method of resolution. Hypotheses about idealizations cannot be obtained by induction, simple enumeration, or by the methods of agreement and difference. It is necessary for the scientist to intuit which properties of the phenomenon are the proper bases for idealization, and which properties may be ignored (Losee 2001, p. 49). Idealization is used in this paper in the following sense:

Idealization Idealization is the consideration of properties that the object definitely does not possess in a physical system (as, for example, in Galileo's thought experiments), through extrapolation from a series of phenomena while other properties remain in the background. This is an ontological matter, as when one claims that an object lacks certain properties when it is idealized. We are no longer considering actual objects, but idealized objects. This is because we consider the objects to lack some properties necessary for an actual object.

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 process in the sense that it yields novel hypotheses (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 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 evaluation 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 they 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, 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. Testing hypothesis 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.

2.1 Differential Levels Entities for Scientific Inquiry Procedure

Recently, Fernández-González proposed an ideal level and a quasi-ideal level for 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. (Fernández-González 2013, italics mine)

In this research, I consider three distinct worlds. The empirical world and the idealized world, which are embedded in the theoretical world, are seen as two worlds. I locate the theoretical world, including the idealized world, at the highest level and describe its

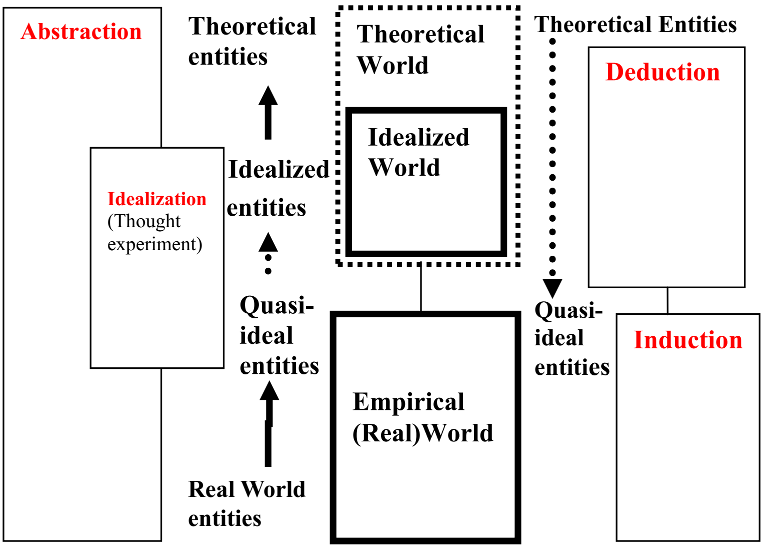

Fig. 1 Galileo's scientific inquiry procedure about the law of free falling motion

members as theoretical entities (theories, models) and idealized entities. Those entities situated at the highest level of the empirical world, close to the idealized world, are called quasi-idealized entities (see Fig. 1).

The arrows directed upward symbolize the generation or formulation of hypotheses. The arrow directed 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 reference.

3 Conceptual Organizations of Galilean Free Fall Motion

Galileo mathematically abstracted that in a free fall motion starting from rest, in which the speed undergoes the same change in every equal interval of time, the motion is in a straight line (sometimes called uniformly accelerated motion); then, through thought experiment, Galileo concluded that free fall is a case of this uniformly accelerated motion. In the absence of any air resistance, the motion of a freely falling body, as well as motion on an inclined plane, will always be accelerated according to this law. He then showed by actual experiment that motion on an inclined plane exemplifies this law.

3.1 Generation of Laws or Principles and the Process of Their Validation

Premises or assumptions for the law of free falling motion are as follows:

1. According Aristotle's famous principles, nature always works in the simplest way possible, or in the most economical fashion.
2. As Democritus claimed, all physical objects are composed of tiny invisible particles called atoms.

Galileo acknowledged Aristotle's natural motion, and focused on understanding how objects move, under the assumption that all free falling movements, including those in natural motion on an inclined plane, do not experience resistance.

3.1.1 First Stage: Mathematical Abstraction

Using Aristotle's principle that nature always moves in simple and economical rules and Plato's simple mathematical claim, we examined whether the speed of a free falling object increases in proportion to the time it takes to fall or the distance fallen.

According to Cohen (1985), the idea of proportionality between the falling speed and the distance that an object has fallen was widely propagated during Galileo's time. Galileo, however, argued that such proportionality was logically contradictory. He recognized that naturally falling objects gained speed continuously as they fell and that in the air, the speed of a falling object increases in proportion to the weight of the object.

Aristotle had claimed that the speed of a falling object is proportional to the object's weight. Through thought experiment, Galileo noted the inherent contradiction in Aristotle's claim. He then hypothesized that all objects fall at a same speed regardless of their weight and attempted to validate his theory with empirical experiments (see Brown 1991; Norton 1991, 1996; McAllister 1996; Gendler 1998; Brown 2000).

It is generally accepted that the process of abstraction is a way to build theory (Morgeson and Hofmann 1999; Ostroff and Bowen 2000). It is also interesting to note that theories may be developed through the use of data derived from different levels of abstraction. For example, Newton used observation to gain empirical data to build his theories of motion. Einstein, in contrast, used data in the form of existing theories to create a more effective theory (Dubin 1978).

The empirical observations of Newton led to a useful abstract theory. In contrast, the integration of theories led to Einstein's theory, which proved more useful than Newton's. This is not to say that either worked exclusively by empirical observation or theoretical integration, only that one emphasized theory and the other emphasized data. As a side note, one can, of course, see theory as data. However, the difference between them (even a difference of scale) suggests an important opportunity to use existing abstract theories in the process of rigorous integration to create theories that are more effective than we ever imagined possible (Wallis 2015).

> Modern science has an historical myth about Galileo. This myth asserts that in the dark ages the speculations of Aristotle, unfounded on observation, were held in high esteem, but Galileo broke the path for science by describing the world as we really experience it. But, it completely distorts the nature of Galileo's achievement. … Aristotle's main weakness was his empiricism, that is, too much use of common sense. In contrast, Galileo took a big step forward by attempting to describe the world in ways we do not experience. Galileo's theory did not depend on empirical observation, but proposed a simple law. Scientific experimentation differs from everyday experience because one can pose a question and formulate a mathematical theory as an answer. (von Weizsäcker 1964, p. 104)

In this context, it is apparent that Galileo's experiment with an inclined plane was conceived in order to demonstrate empirically the principles he had derived through abstraction and mathematics. It is hard to deny that Galileo's law of falling motion based on a series of experiments or observations is a theoretical law derived from well-known axioms, such as the relationship between the simplicity of nature and the relations of integers (Cohen 1985, p. 99). Therefore, we can conclude that Galileo's law of free falling objects resembles the ideas of Einstein more than those of Newton.

A strategy to formulate a more specific law starting from existing theories or principles is a type of rule-forming abduction (Oh 2014; Thagard 1988). Let us consider the following example. Much to everyone's astonishment, Neptune departed slightly from its predicted orbit. Assuming that all celestial objects are under gravitational law (suggesting an explanatory hypothesis), if planet x is near planet y, planet x is perturbed, and it must be planet y that causes the perturbation. Therefore, if Neptune is perturbed, there must be a certain planet y nearby, so gravitational law is formulated to explain this perturbation and is applied to all celestial bodies. Hence, new laws are formulated with an expanded range of application. When Neptune deviated from its expected orbit, explanatory hypotheses were suggested. These explanatory hypotheses not only implied the existence of undiscovered planets but also expanded the new rule that "all objects in cosmic space are subject to the law of gravitation."

According to this *rule-forming abduction* (Oh 2014), the following process is obtained. Galileo concluded that, in free fall, light and heavy objects fall together, but he also wanted to know the details of what was going on while they fell. Through thought experiment, Galileo concluded that the velocity of an object in free fall was not proportional to the weight of the object. He already knew that the speed of an object in free fall increased as the object fell. Surprisingly, Galileo's thought experiment contradicted Aristotle's claim that the speeds of free falling objects *increase in proportion to their weight*.

Let us suppose the speed of a heavy object falling in natural motion *increases at uniform rate regardless of weight* according to the principle of simplicity and economy. If, (1) the surrounding environment of the heavy object is one that allows it to fall in a natural motion, including down an inclined plane and (2) there is no air or friction in that environment, then *the speed of all objects does not increase in proportion to their weight, but increases at a same rate regardless of weight*. In order for this motion to occur, air and friction must be ignored because they prevent natural motion.

Therefore, in instances of natural free fall, including natural motion on an inclined plane, where *the speed of all objects increases at a same rate*, the space through which the object moves must contain no air and provide no friction. Thus, if we assume such an environment, all objects (*theoretical entities*) move in the most simplistic and economical way, and the law that *the speed of natural free fall is proportional to the duration and distance of motion* holds, formulating more new specific laws.

Galileo realized the abstract and mathematical principle of falling motion. The speed of a falling object is proportional to the times or distances of its motion, regardless of its weight, when air resistance and other sources of friction are ignored The idea that the speed of a falling object is proportional to the distance it falls was ignored because falling objects were not observed displaying the behavior Galileo claimed they did. Eventually, the abstract idea that the speed of a falling object is proportional to the time that the object falls was proposed. In addition, motion defined in these terms was verified in experiments on an inclined plane.

It is necessary that processes of elimination and verification should occur before validating a hypothesis by practical experiments. These processes are called *retroduction*.

In Galileo's fall experiments, a new notion of time as *physical time* emerged. The abstract unit t stands for a continuous, linear and measurable scale of temporal units. Galileo was not concerned with the equation of *why* bodies moved but *how* they moved, and whether this movement could be described mathematically.

3.1.2 Second Stage: Idealization Based on Thought Experiment

In free fall, objects have a motion that is totally unimpeded save for the small effect of air resistance. However, the object's motion is far from free because the object is constrained to the surface of the plane. In both cases, however, acceleration is produced by gravity. In the experiments on the inclined plane, the falling effect of gravity is "diluted," only a part of gravity acting in the direction of the inclined plane. In these experiments, one finds that distance is proportional to the square of the time at any inclination. Galileo's experiments are related to free fall because it may be assumed that even in the limited case in which the plane is vertical one can still expect the law to hold (Cohen 1985, p. 96).

1. To justify the hypothesis that *all* objects, regardless of their weight, fall with the *same* speed, at least in the absence of air according to Democritus' atomic theory, the following thought process is required.

If I am correct that atomism, devised by Leucippus and his student Democritus, states that "everything else is uniformly composed of, and smallest indivisible bodies, then there should be an infinite void space in which independent atoms move freely, a vacuum." In addition, if the weight of an object increases, and the number of atoms composing it increases too, then the force acting on an object increases in proportion to its weight and has difficulty moving it. What will each atom composed of those objects follow?

Therefore when objects of different weight begin to free fall, each atom composing those objects will fall at the same speed.

2. To justify the hypothesis that motion on an inclined plane is similar to that of free fall, a thought experiment is required.

According to Cohen (1985), Galileo was not concerned with examining the correlation between the distance covered by a vertically falling object and the duration of the fall. He hypothesized that he could calculate the acceleration of falling objects from observations of motion made on an inclined plane tilted at a shallow angle. In his letter to Baliani, he explained how to calculate the speed of free falling objects from observations of motion on an inclined plane (p. 97). That is how he investigated patterns of speed change under constant acceleration using a ramp apparatus (Drake 1975), and he claimed that free fall was an extreme case of ramp motion (with the ramp surface vertical) (Ford 2003).

Additionally, Galileo's *Two New Sciences* presents a mathematical theory of freely falling bodies, as follows:

> If a body falls in air (or any other resisting medium), the resistance will increase as some function of the speed; when the resistance becomes equal to the body's weight, the acceleration will cease and the body will continue to move with uniform speed downward. (Cohen 1985, p. 214)

Rather than reducing the speeds of falling objects due to the greater density of the medium through which they passed, Galileo sought to slow objects down by rolling balls down inclined planes. He thought that rolling balls down inclined planes might approximate the free fall of objects. If the incline of the plane is reduced, the ball moves slowly. If the incline is steep, the ball moves faster. The steeper the incline is, the more the ball's path approaches free fall. By measuring the rate at which objects rolled down an inclined plane, and how this rate changed as the inclined steepened, Galileo hoped to resolve the motion of freely falling objects.

If the hypothesis that objects with mass follow only natural motion is correct, and if the steeper the incline the closer to free fall, what motion will the object follow? Eventually, the ball's path (*quasi-idealized entities*) will approach free fall (that is, it will fall at a speed that is proportional to time it has fallen).

Therefore, an object in motion on an inclined plane with minimum friction will follow the same principle of motion as a freely falling object (*idealized entities*), regardless of its weight. In addition, if an object is in natural motion in an environment devoid of all obstacles including air resistance, ignoring size, color, and odor, an object in motion on a inclined plane will follow the same principle of motion regardless of its weight as a vertically falling object (*theoretical entities*). In the case of the law of falling bodies (*theoretical entities*), ideal conditions are obtained when the body feels no forces other than Earth's gravitational pull, (Aristotelian natural motion at that time, which, for instance, requires its falling in a vacuum).

3.2 Justified Processes and Problems

The aim of experimenting on an inclined plane was not to formulate an original law but, rather, to make certain that the accelerations Galileo had already postulated may actually occur in nature (Cohen 1985, p. 95).

In natural acceleration, or in uniformly accelerated motion, the speed increases as the integers 1, 2, 3…. (We write this law algebraically as, starting from rest, $v \propto t$ [or $v = At$]). It follows that the distance increases as the square of the time (or $d \propto t^2$ [actually $d = 1/2\ At^2$]). Galileo showed by experiment that $d \propto t^2$ is valid for the motion of a ball rolling down any inclined plane. In such motion, the distance traversed in successive equal intervals of time are as the odd numbers 1, 3, 5, 7, 9 … because the total distances traversed are as the squares (1, 4, 9, 16, …) and $4 - 1$, $9 - 4 = 5$, $16 - 9 = 7$ … (Cohen 1985, p. 215).

In Galileo's *Dialogues Concerning Two New Sciences* (1954; written in 1638), he said the following with regard to acceleration in free fall:

> Salv. The present does not seem to be the proper time to investigate the cause of the acceleration of natural motion concerning which various opinions have been expressed by various philosophers, … but it is not really worthwhile. At present it is the purpose of our Author merely to investigate and to demonstrate some of the properties of accelerated motion (whatever the cause of this acceleration may be) – meaning thereby a motion, such that the momentum of its velocity goes on increasing after departure from rest, in simple proportionality to the time, which is the same as saying that in equal time – intervals the body receives equal increments of velocity; and if we find the properties [of accelerated motion] which will be demonstrated later are realized in freely falling and accelerated bodies, we may conclude that the assumed definition includes such a motion of falling bodies and that their speed … goes on increasing as the time and the duration of the motion. (pp. 166–167)

Rather than explaining *why* a body speeds up, Galileo describes *how* it speeds up. It sounds as though he is proposing a law of nature, but he is explaining nothing. He always refers to accretion due to gravity as simply "natural acceleration," Which takes place as the natural motion of Aristotle.

3.2.1 Third Stage: Deduction–Induction Cycle

The resulting inferred explanation is described in Magnani's epistemological model as part of the complete abduction–deduction–induction cycle (see Maganani 1999, 2009; Oh 2012, 2014):

> **Deduction** If the hypothesis that "the speed of a falling object increases in proportion to time the object has fallen for when an object follows simple path in natural motion" is correct (*theoretical entities*), and if free fall and motion on an inclined plane are the same type of uniformly accelerating motion and natural motion, reducing friction and increasing density will result in the same phenomenon. To demonstrate this, parchment paper was put on the slanted surface to reduce friction, and a large lead ball with a high density was used to reduce the effect of air friction. If air resistance is decreased by slowing the object down and the rate of acceleration is reduced by creating a minimum gradient, the distances traversed in successive equal intervals of time are the odd numbers 1, 3, 5, 7, …

Induction As a result of repeating the inclined surface experiments, Galileo obtained results similar to those predicted by the hypothesis (*quasi-idealized entities*). This supports the hypothesis that "an object's speed is proportional to the time it has been accelerating for when it accelerates uniformly on a certain angle."

However, in the limited case of free fall, the ball does not roll as it does on an inclined plane. The case of an inclined plane is not idealized, as is a free fall experiment conducted in a vacuum. A well-equipped laboratory can recreate experiments with an inclined plane; however, it is difficult to approach using only quasi-idealized entities in which an object slides down a steep surface without any friction. From a modern perspective, the production of such a case is plausible on the assumption that an object slides down without friction rather than rolling down. Because there is no rotational acceleration during free fall, all of the object's potential energy transforms into translational kinetic energy. On the other hand, a rolling object on an inclined plane (without air friction), divides its potential energy between translational and rotational kinetic energy (Giancoli 1998, p. 227). Galileo could not take rotation kinetic energy into account because of the limited knowledge of physics at the time.

Galileo's natural philosophy is seriously problematic, such as its use of circular inertial law rather than liner inertial law. However, his thought experiment methods were taken up by his followers and are still applicable in modern science. He pursued explanations for observed phenomena that depend solely on natural causes rather than the occult and attempted to explain things entirely in terms of motion and bodies in motion.

4 Discussion and Conclusion

Galileo can be seen as a Platonic or Pythagorean thinker, thanks to his emphasis of mathematical and geometrical approaches to understanding the world. Plato wanted to exemplify his belief that truth can only be achieved by the use of logic and geometry and that the world, in a mess, can be understood through abstract and mathematical concepts (Henry 2012, p. 19).

First, we need to be aware of the significance of idealization in Galileo's thought experiments in order to fully comprehend the importance of his discoveries, because Galileo used idealization with fine instruments.

Second, Galileo showed how certain laws and principles were formulated by analyzing and abstracting bold hypotheses mathematically. In other words, he ignored properties such as size, color, and odor; instead, he used mathematical abstraction to walk directly into the idealized world of theories, making the bold assumption that there is no air resistance or friction on an inclined surface. Due to the mathematical simplicity of his approach, however, he neglected factors that inhibit movement; thought experiments do not represent such forces. It is necessary to use limited principles to create an idealized theory. Although mathematical abstraction and thought experiments played a huge role in Galileo's process of formulating theories, we cannot conclude that his experiments were conducted only to justify his theories, which were simply the result of mathematical abstraction. In formulating laws and theories, mathematical abstraction and thought experiments work together. Galileo used experiments to justify his ideas to the public. "Seldom today does the design of an experiment, reach its object with the simple elegance of Galileo's inclined plane. Physicists today pose questions about hypothetical particles and forces drawn from labyrinths of mathematical abstraction. They confront them with experience in accelerator experiments that yield results in computer readouts at second and third remove from the event. The Galilean example remains the ideal, if nostalgic, model" (Piel 2001).

Third, Galileo showed how laws and theories are established through the strategy of idealization. When the angle of an inclined surface increases, the friction between the object and the surface will eventually disappear, and the motion of the object becomes that of free fall. This approaches the idealized world. Once it is assumed that the object falls in a vacuum, the idealized world becomes the theoretical world as established by mathematical abstraction.

Fourth, Galileo tried to show how laws and theories could be empirically justified. The motion of objects on possible smooth surfaces was used to justify his theory rather than to formulate it.

Fifth, Galileo was the first to formulate the principle that all objects on earth accelerate at a uniform rate, regardless of weight. Newton, who discovered that bodies in space orbit one another in free fall, built his theory on this idea, which became the theoretical foundation for Einstein's theory of relativity.

Galileo's scientific activities are very useful for the proper understanding of Newton's dynamics and for enhancing scientific literacy. Scientific literacy can affect not only the formation of scientific knowledge and values but can also change attitudes toward science by formulation of those values. Recently Magnani (2012) concluded that "like experiments in science, good thought experiments are not evanescent and fuzzy, but clear, repeatable, and sharable, in so far as it can involve unambiguous constructive representations in various human agents" (p. 30).

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