Thought Experiments and the Belief in Phenomena

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Thought experiment acquires evidential significance only on particular metaphysical assumptions. These include the thesis that science aims at uncovering "phenomena"—universal and stable modes in which the world is articulated—and the thesis that phenomena are revealed imperfectly in actual occurrences. Only on these Platonically inspired assumptions does it make sense to bypass experience of actual occurrences and perform thought experiments. These assumptions are taken to hold in classical physics and other disciplines, but not in sciences that emphasize variety and contingency, such as Aristotelian natural philosophy and some forms of historiography. This explains why thought experiments carry weight in the former but not the latter disciplines.

1. Introduction. There are several competing views about the nature of thought experiments in science. Some philosophers regard them as acts of introspection into the laws of nature, others as arguments, and yet others as the manipulation of mental images (Brown 1991, 2004; Norton 1996, 2004; Gendler 2000, 2004). Most writers on this topic, however, assume that thought experiments in science possess evidential significance intrinsically. In this paper, I question this view by appeal to the history of science.

To count as a source of evidence in a science, a procedure must satisfy both particular and generic requirements of legitimacy. Let us take concrete experiment as an example. If a particular concrete experiment is to be accepted in a science as a source of evidence, practitioners must be

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‡I thank the other speakers, James Robert Brown, Tamar Szabó Gendler, and John D. Norton, the chair, Nancy J. Nersessian, and the audience for a very enjoyable symposium on "The Epistemology of Thought Experiments" at the 2002 Biennial Meeting of the Philosophy of Science Association, Milwaukee. I benefited from their stimulating comments on the draft of this paper that I presented there.

Philosophy of Science, 71 (December 2004) pp. 1164–1175. 0031-8248/2004/7105-0045$10.00
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persuaded that it meets the standards of competence in experimental practice holding in that science. These standards may prescribe that an experiment be suitably controlled for extraneous factors, that any instruments used be properly calibrated, and so on. More fundamentally, however, the practitioners must be persuaded that experiment in principle yields evidence relevant to resolving controversies in the science. Otherwise, there will be no point for them to debate whether a particular experiment has been conducted competently. I say that a procedure, such as experiment, has evidential significance in a given science if it counts as a source of evidence relevant to establishing and discrediting claims in that science.

In this paper, I argue that thought experiment, like concrete experiment, acquires evidential significance only on particular metaphysical assumptions. These assumptions state that reality is articulated in universal and stable modes, which I shall call "phenomena," underlying occurrences; that phenomena are revealed only imperfectly in actual occurrences; and that science aims at uncovering phenomena. (The term "phenomenon" is used in similar senses in Hacking 1983 and Bogen and Woodward 1988.) In domains and styles of science in which these assumptions are taken to hold, thought experiment acquires evidential significance: it makes sense to attempt to model the world by pure thought and to seek to establish and undermine claims by thought experiment. Where these assumptions are not endorsed, in contrast, thought experiment is evidentially inert: in these domains and styles of science, the suggestion that knowledge can be gained by thought experiment has no force (McAllister 1996).

As we shall see, these metaphysical assumptions were first formulated explicitly by Galileo Galilei in mechanics; they are endorsed in science in the Galilean style, which includes most work in physics since Galileo. The assumptions were rejected in Aristotelian natural philosophy: this explains the bafflement of Aristotelians at Galileo's thought experiments. The assumptions are rejected also in some present-day disciplines, such as botany. Other disciplines, such as historiography, exhibit a variety of styles: the Galilean metaphysical assumptions are endorsed by some practitioners and rejected by others. In these disciplines, in consequence, the evidential weight of thought experiments is disputed.

2. Galileo's Doctrine of Phenomena. Aristotelian natural philosophy was conceived primarily as a project to account for occurrences in natural circumstances. Aristotle and his followers aimed to describe natural occurrences with the greatest accuracy possible. They held detail in high regard and mistrusted abstraction and idealization, which divert attention from the description of actual occurrences. These epistemological values are embodied in Aristotelian botany, for instance. Similarly, the Aristotelian theory of motion aims to account for the particularities of motions in natural circumstances, avoiding abstraction and idealization. For example, the Aristotelian theory of free fall attempts to explain the variety of the attributes of natural falls by appeal to variables such as the substance, shape, and weight of falling bodies.

This approach was not without alternatives in ancient natural philosophy. One was provided by Aristotle himself, who in *Posterior Analytics* outlined a systematization of demonstrative science in a categorical and deductive structure intended for use in teaching. Pythagoras, Plato, and their followers advocated a more radical alternative. In their approach, science is a study of invariant mathematical forms underlying, and often not immediately apparent in, natural occurrences.

Pythagoras and Plato influenced the sixteenth-century practitioners of astronomy and mechanics, such as Nicholas Copernicus and Simon Stevin, who conceived of the world as embodying harmonies, symmetries, proportions, and ratios. This approach was formalized by Galileo in the seventeenth century. Partly inspired by Neoplatonism, Galileo came to believe that natural occurrences are an only imperfect reflection of an underlying reality, and that fundamental knowledge of the world is knowledge of this underlying reality rather than of occurrences (Koyré 1968, 16–43).

The details of Galileo's account are highly innovative. The world contains causal factors of two kinds: phenomena and accidents. Phenomena are universal and stable modes in which physical reality is articulated. Accidents, by contrast, are local, variable, and irreproducible. Whereas phenomena account for the underlying uniformities and invariances of the world, accidents are responsible for the great variability of natural occurrences. Every natural occurrence is the resultant of one or more phenomena and a great number of accidents. Mechanics, for Galileo, aims solely to identify and describe phenomena: no scientific knowledge of accidents is possible in his view (Koertge 1977).

An example of a phenomenon, according to Galileo, is free fall. Two natural occurrences determined in part by this phenomenon—that is, two instances of free fall—share qualitative and quantitative features owed to the underlying phenomenon. However, each instance of free fall is also partly determined by accidents, such as the shape of the falling body, air resistance, air currents, and so on. These differ from one occurrence to another. Thus, each instance of free fall shows erratic features that cannot be reduced to any pattern. Only the phenomenon of free fall can be investigated and described scientifically: the accidents that affect individual falls of bodies lie outside the scope of mechanics.

Since phenomena are presumed to be universal, simple, and few, accounts of them will be general, concise, and often mathematical, and there will be a relatively small number of them. These accounts became known as "laws of nature," such as Galileo's own law of free fall.

Galileo faced a problem, however. Evidential significance in Aristotelian natural philosophy was vested in reports of natural occurrences, intended to record happenings with as little idealization and loss of detail as possible. For example, evidence about free fall was constituted by reports of natural falls that strove to record the particular attributes of each. Galileo's laws of nature, it soon emerged, constitute relatively inaccurate descriptions of occurrences under natural circumstances. Galileo could explain this fact by pointing out that laws neglect the influence of accidents, which play a large part in determining natural occurrences (Galilei [1638] 1974, 223–227). By the same token, however, it was difficult for him to portray natural occurrences as corroborating laws of nature. Natural occurrences are in closer agreement with the output of Aristotelian natural philosophy than with the laws of Galilean mechanics. For instance, the free fall of bodies under everyday conditions near the surface of the earth is described more accurately by the Aristotelian account, which is alert to the differential effects of the shapes and materials of bodies, than by Galileo's law (Feinberg 1965; Adler and Coulter 1975).

In response to this problem, Galileo proposed that evidential significance in mechanics be withdrawn from observations of natural occurrences, and vested in new sources of evidence that, he believed, were better indicators of phenomena. These sources of evidence were occurrences determined to as small a degree as possible by accidents: such occurrences would then be determined to a greater degree by the underlying phenomenon. In the limiting case, if the influence of accidents could be reduced to zero, it would be possible to read off the properties of the phenomenon from an occurrence. Any such occurrence, of course, would have to be produced artificially. Galileo called such a contrived occurrence "experiment," redefining a term that, in the scholastic tradition, meant merely an everyday experience of something. Whereas experiment arose from empiricist concerns, it embodies a mistrust of experience (Naylor 1989).

The aim that Galileo assigned to experiment, to produce an occurrence determined entirely by a phenomenon and to no extent by accidents, is evident in his descriptions of his own experiments. Galileo invariably takes care to reduce the magnitude of irregularities and perturbations in his apparatus. His experiments on the fall of bodies along an inclined plane, for example, involve much polishing of bronze balls and smoothing of the parchment lining the groove down which the balls roll (Galilei [1638] 1974, 169–170). This polishing and smoothing is undertaken in the attempt to reduce the influence of accidents on the resulting occurrence, allowing the underlying phenomenon of deflected fall to show through more clearly.

3. Thought Experiments in Classical Physics. In some cases, Galileo's polishing and smoothing of his experimental apparatus yielded the desired result. As he would express it, his experiments produced occurrences that were determined to only a small degree by accidents, and which therefore allowed the experimenter to perceive the properties of a phenomenon clearly. In other cases, however, the polishing and smoothing did not suffice: it proved impossible to reduce the influence of accidents sufficiently to exhibit a phenomenon. Distinct performances of an experiment in these cases yielded different outcomes, indicating that the occurrence had been determined partly by accidents. Galileo was aware that, in these cases, no concrete experiment that he could perform would convincingly establish a law of nature.

I suggest that Galileo devised thought experiment as a source of evidence about phenomena for use where all feasible concrete experiments exhibited this shortcoming. Thought experiments represent a continuation of the process of polishing and smoothing, until—to speak figuratively—the entire, imperfect physical apparatus of the experiment has been polished and smoothed out of existence. With the abstract experimental apparatus that remains, we can at last be certain that accidents will no longer obstruct our view of the phenomenon. If a phenomenon is so subtle that no concrete occurrence can be produced in which the phenomenon is displayed in accident-free form, the phenomenon may be displayed only in an abstract occurrence: that produced in a thought experiment. This view explains why Galileo, in the case of some phenomena, withdrew from the sphere of sense data and sought knowledge about the world in thought experiment rather than in concrete experiment.

As an example, consider the most famous of Galileo's thought experiments—the one involving bodies of different weights dropped from a tower, by which he claimed simultaneously to discredit the Aristotelian account of free fall and establish his own law that the rate of fall of a body is independent of the body's mass (Galilei [1638] 1974, 66–72). Why did Galileo resort to thought experiment in the study of free fall? Distinct performances of any concrete experiment with falling bodies that was technically feasible in Galileo's time would not have accorded on any clear-cut phenomenon of free fall. In Galileo's terms, such concrete experiments fail to display the phenomenon "free fall" in accident-free form. Thus, to display this phenomenon, Galileo was compelled to turn to an immaterial occurrence—the one that his thought experiment presents. Only this immaterial occurrence allowed Galileo to establish the claim that, in the phenomenon "free fall," the speed of falling bodies is independent of their weight.

The same holds for all other appeals by Galileo to thought experiment. For example, Galileo claimed that, under ideal conditions, the period of a simple pendulum is independent of the amplitude of the swing. In reality, the period of a pendulum depends to some extent on the amplitude of the swing; moreover, this dependence is different in different pendulums. Because of this fact, no feasible concrete experiment would have corroborated Galileo's claim. Galileo was thus wise to present his readers with a thought experiment that supports his claim, rather than assemble empirical evidence in concrete experiments (Galilei [1638] 1974, 97–99). In his advocacy of Copernicanism, similarly, Galileo wished to establish that we should not expect the earth's motion to have a detectable effect on the motion of objects around us. He may originally have considered arranging a series of concrete experiments aboard a moving ship in which objects dropped from the crow's nest landed precisely at the foot of the mast, and in which insects flew and water dripped in the ship's cabin precisely as if the ship were at rest. If so, he must have realized that distinct performances of such experiments on a rolling and pitching ship would have given a confused picture. Instead, Galileo appealed to thought experiments, in which the accidents of the ship's motion were removed and the underlying phenomenon of the relativity of motion was convincingly displayed (Galilei [1632] 1953, 141–145 and 186–188).

The Galilean distinction between phenomena and accidents was taken over, in slightly different terms, by classical physics. Newtonian mechanics regards natural occurrences as determined jointly by two causal factors: universal regularities, which resemble Galileo's phenomena and are described by laws of nature, and initial or boundary conditions, which are considered as non-law-like and as lying outside the scope of physical theorizing, like Galileo's accidents (McAllister 1999). This analysis leads Newtonian mechanics to envisage that, while a regularity may not always be apparent in natural occurrences, it may be displayed in an imaginary occurrence that abstracts from the peculiarities of initial conditions. Consequently, Newtonian mechanics attributes evidential significance to thought experiment as a means to display phenomena. An example is the phenomenon of absolute rotation. Concrete experiment is not suited to display this phenomenon, since the objects surrounding any actual rotating body make it impossible to distinguish absolute motion from relative motion. However, Newtonian mechanics allows absolute rotation to be displayed in a thought experiment: indeed, Isaac Newton believed that this phenomenon was displayed by a thought experiment that he presented, in which a bucket partly filled with water rotates in an otherwise empty universe (Laymon 1978). According to Newton, this thought experiment allows us to establish the existence of absolute rotation—and thereby the existence of absolute space—whereas no concrete experiment is able to do this.

4. The Domain of Thought Experiment. Galileo's account of phenomena and accidents is familiar and attractive to the ears of modern physicists and philosophers. This leads some writers to assume that thought experiments have evidential significance intrinsically, irrespective of context. For example, Brown claims that thought experiments yield a priori knowledge. He holds that Galileo's thought experiment on free fall self-evidently discredits Aristotle's account and establishes that the rate of fall of bodies is independent of their weight (Brown 1991, 77–79; 2004; see also Arthur 1999). Norton (2004) agrees that Aristotelian natural philosophers are bound to share Galileo's belief that thought experiment is a source of evidence about the world, especially since, as he claims, Aristotle himself used many thought experiments.

Brown's and Norton's confidence that thought experiments have evidential significance intrinsically is not well grounded. Most alleged appeals to thought experiment in Aristotle and in scholastic writers are better regarded as instances of reasoning from hypothesis and analogy, familiar to Aristotelian dialectic. Furthermore, these devices are mostly contributions to the systematizing project of *Posterior Analytics* rather than to Aristotelian natural philosophy (King 1991). In any case, even if Aristotle were found to have made occasional use of thought experiments, this finding would not erase the distinction between Aristotelian natural philosophy and Galileo's mechanics. The former is a science of natural occurrences based on ordinary observation, whereas the latter is a science of phenomena in which a consistent practice of experimentation—in the laboratory and in thought—is credited with revealing fundamental truths.

Let us return to Galileo's thought experiment on free fall. Aristotle's account claimed that, in general, heavier bodies fall faster than lighter ones (Casper 1977). Galileo asks us to imagine dropping from a tower a compound body consisting of a cannonball joined to a musketball. How would the Aristotelian theory analyze this occurrence? On one reading, Galileo says, Aristotle's theory implies that the compound body falls more slowly than the cannonball alone would, since the musketball retards the cannonball to some extent. On another reading, Aristotle's theory entails that the compound body falls faster than the cannonball alone would, since the compound body is heavier. Galileo concludes that Aristotle's theory of free fall is inconsistent. To avoid this inconsistency, a theory of free fall must entail that the compound body falls at the same rate as the cannonball alone would; and, in order to entail this, the theory must claim that the rate of fall of bodies is independent of their weight.

In fact, this thought experiment does not prove that the Aristotelian account of free fall is incorrect. It could not have done so, for the reason that the Aristotelian account is, in the circumstances of everyday experience, correct: in everyday circumstances, heavier bodies indeed fall faster than lighter bodies. Galileo's thought experiment establishes merely that, if the rate of fall of simple and compound bodies were a function of their total mass alone, then the rate of fall of bodies would necessarily be independent of their mass. The conclusion of this thought experiment holds only in a world in which the premise also holds. Ours is not such a world: the rate of fall of bodies in our world is a function of many variables, including their mass, their volume, their shape, their surface properties, and the density and viscosity of the medium in which they are immersed (Gendler 2000, 33–63).

Concern for the real world is apparent in the Aristotelian reactions to the thought experiments that Galileo used against them. In a few instances, Aristotelian natural philosophers argued that Galileo's thought experiments admitted conclusions different from those that he drew: this response may be regarded as a concession that thought experiments have evidential significance. For the most part, however, Aristotelian natural philosophers countered Galileo's thought experiments with reports of real occurrences. Against his thought experiment on free fall, for example, Aristotelian natural philosophers cited observations of actual falls of bodies of different weights, in which the heavier body reached the ground before the lighter one (Shea 1972, 11 n. 10). Responding to Galileo's thought experiments set on a moving ship, similarly, Aristotelian natural philosophers presented testimony that, in some actual occurrences of stones dropped from ships' masts, the stones had fallen not onto the deck at all, but overboard (Shea 1972, 156; Grant 1984, 36–42). Such natural occurrences are what the Aristotelian form of mechanics takes as evidence.

Contrary to Brown's and Norton's view, the principal dispute between the proponents of the Aristotelian and Galilean theories of motion concerned the forms of evidence that were to be admitted in the discipline. Both sides took legitimate and defensible positions. It is clearly open to the practitioners of mechanics to choose whether it should be a science of natural occurrences, as the Aristotelians intended, or of phenomena, as Galileo advocated. Therefore, neither natural occurrences nor experiments have or lack evidential significance in mechanics intrinsically: evidential significance is attributed to natural occurrences in the Aristotelian theory of motion and to experiments and thought experiments in the Galilean theory.

5. Thought Experiments in Historiography. The distinction between phenomena and accidents is accepted in all areas of modern physics, together with an array of derived concepts and tools: the notions of law of nature and natural kind, counterfactual reasoning, and the procedures of experiment and thought experiment. Physics is atypical of the family of the sciences, however: in many disciplines, these concepts and tools are controversial. An example is offered by historiography.

There are two main styles in modern historiography. In one approach, the discipline of history is regarded as a social science. This approach assumes that historical events are determined by a combination of regularities of human behavior and contingent accidents. The main aim of historiography in this style is to identify and describe the underlying regularities. In the most favorable cases, the regularities will be described by causal laws, which will allow for the partial explanation of historical events, perhaps on the deductive-nomological model (Hempel 1965, 231–243). Practitioners of this style thus assume that phenomena in the Galilean sense exist in the historical domain. In consequence, this style of historiography—which is especially prominent in economic, strategic, and military history—ascribes evidential significance to thought experiment. In historical thought experiments, one appeals to the presumed regularities of human behavior to establish what would have happened under different circumstances, often with the aim of elucidating the causal interrelations or historical significance of actual events. In a thought experiment in military history, for example, one may appeal to the presumed regularities of rational agents to ascertain what decisions military leaders would have taken if they had had access to different information (Tetlock and Belkin 1996; Ferguson 1997; Cowley 1999).

In the second approach, theorized by Wilhelm Dilthey, William Dray, and others, history is practiced as a *Geisteswissenschaft*. This approach views the historical record as a sequence of unique, contingent, and unpredictable actions and events that cannot be reduced to any rule. The aim of this approach is *Verstehen*, or the understanding of unique actions and events in their specificity and context. This approach rejects the assumption that phenomena in the Galilean sense underlie historical events. Since history is a sequence of unique and unpredictable events, there is no basis for counterfactual claims about what would have happened under idealized or altered circumstances. In this approach, therefore, thought experiments lack evidential significance. Almost all work in history of art, for example, belongs to this tradition. Art historians seldom perform thought experiments: they do not regard them as having evidential significance in their discipline.

The diversity of styles in historiography shows that thought experiment acquires evidential significance only on the assumptions that reality is articulated in phenomena, that phenomena are revealed only imperfectly in actual occurrences, and that science aims at uncovering phenomena. Endorsing these assumptions is not a necessary condition for practicing a science; indeed, they are rejected in many sciences. In domains of science inspired by Galilean mechanics, thought experiments constitute a valid approach to uncovering laws of nature or regularities; in other domains, they are assigned no evidential significance.

6. Response to Fellow Symposiasts. To conclude, I trace my further agreements and differences with the other contributors to this symposium.

I agree with Brown (2004) that thought experiment is a Platonist device. This statement accurately reflects, among other things, the metaphysical view from which thought experiment arose. From this, however, I draw a conclusion that Brown would resist: whether thought experiment has evidential significance in a discipline is determined by whether the practitioners of that discipline endorse the Platonist assumptions. Whereas Brown's arguments are capable of converting scientists to Platonism, they are not able directly to establish that thought experiment has evidential significance in a science: for that to be the case, the practitioners of that science themselves must endorse the relevant metaphysical assumptions.

Norton (2004) contends that thought experiments are nothing but picturesque arguments. I grant that many thought experiments can be reconstructed as arguments (for one possible exception, see Bishop 1999). The question is, however, whether this provides sufficient grounds for identifying thought experiments with arguments. Norton's account, I feel, does insufficient justice to the conceptual and historical genealogy of thought experiment. The most valuable taxonomies, as in biological systematics, do more than chart morphological similarities: they reflect evolutionary relationships too. Thought experiment represents a continuation of experimental practice by other means: it evolved from experimental practice as a limiting case of concrete experiment. Even though classifying thought experiments as arguments of a particular sort may be empirically adequate, therefore, it is more informative to classify them as an offshoot of concrete experiments. I thus ally myself with writers who regard thought experiment as a species of experiment (Sorensen 1992, 216–251; Gooding 1993).

Lastly, I have sympathy with the view of Gendler (2004) that thought experiment consists of the mental manipulation of images. This view captures, for example, Galileo's line of reasoning when he resorted to thought experiment after concrete experiment had failed him. For a thought experiment to be valid, of course, the manipulation of images must conform to certain rules, or else it would be an arbitrary rearrangement with no link to reality. What rules are these? I suggest that they must include the Galilean metaphysical assumptions that, on my view, underpin thought experiment. In other words, the rules for the valid manipulation of images must include the assumption that an image presents some invariant aspects that must be preserved in any manipulation, and some mutable aspects that can be changed at will. These correspond to Galileo's phenomena and accidents respectively. In domains of science where Galileo's causal analysis of occurrences into phenomena and accidents is not endorsed, there is no guide to which aspects of mental images may and may not be altered, and thought experiment is evidentially inert.

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