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SEMANTICS OF GALILEO'S GRAVITY (THOUGHT) EXPERIMENTS

SEMÁNTICA DE LOS EXPERIMENTOS (MENTALES) DE GRAVEDAD DE GALILEO

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INFORMACIÓN DEL ARTÍCULO	ABSTRACT/RESUMEN
Recibido el: 5/08/2023 Aceptado el: 1/09/203 ***Keywords*:** Semantics, thought experiment (TE), gravity, falling bodies, compound bodies, surface structure (multiple TE), (logical) deep structure ***Palabras clave*:** Semántica, experimento mental (TE), gravedad, cuerpos en caída, cuerpos compuestos, estructura superficial (múltiples TE), estructura profunda (lógica) :	**Abstract:** Galileo Galilei's *Gravity* TE *Falling Bodies* may be analyzed as a (series of) elementary ideal *Trial and Error TE* (thought experiments) analogous to experiments (E) in science. We consider these TE from classical induction the basic TE of natural sciences. As to bridge the (hermeneutical) gap between E and TE in Galileo and its comments of Aristotle, we introduce two types of TE, *Experience TE,* and *Experiment TE.* The *Falling Bodies* TE appear in 1638 *Dialogues concerning Two New Sciences*, and they have recently been updated by Apollo 15's *The Hammer and The Feather,* a falling experiment conducted onthe surface of the moon (Scott, 1971). In recent TE literature it is remarked that they have long been mistaken for a real experiment (Galileo throwing two objects from Tower of Pisa), and it is currently analyzed as a counter-Aristotelian TE of *Compound* or *Strapped Bodies* (Gendler, 1996/2000; Brown 1991a, 1991b; Sorensen, 1992; Brown & Fehige, 2019). In the logical deep analyses we show with help of mathematical predicate logic (1) that the transitive Aristotelian falling theory is replaced by the simpler for symmetrical Galilean gravity theory (as in the second case all objects fall independent of their masses with the same speed relative to gravitation constant of the heavenly body under investigation) and (2) that in accordance with, e.g., Carnapian assumptions inductive and deductive protocols may be considered complementary, that is, translatable into each other,

which may explain how *Trial and Error TE* may be interpreted as *Ideal(ized) Experiments*.

Resumen:
Los TE de los cuerpos en caída aparecen en el *Diálogo sobre los Dos Nuevos Principios* de 1638, y recientemente han sido actualizados por el *experimento del martillo y la pluma* de la misión Apollo 15, una prueba de caída realizada en la superficie de la luna (Scott, 1971). En la literatura reciente sobre TE se destaca que durante mucho tiempo se les ha considerado erróneamente como un experimento real (Galileo lanzando dos objetos desde la Torre de Pisa), y que actualmente se analizan como un TE antagónico a Aristóteles, de cuerpos compuestos o atados (Gendler, 1996/2000; Brown, 1991a, 1991b; Sorensen, 1992; Brown & Fehige, 2019).

En los análisis lógicos profundos mostramos, con la ayuda de la lógica matemática de predicados, que (1) la teoría transitiva aristotélica de la caída es reemplazada por la teoría galileana, más simple, de la gravedad simétrica (ya que en el segundo caso, todos los objetos caen independientemente de sus masas con la misma velocidad relativa a la constante de gravedad del cuerpo celeste bajo investigación) y (2) que, de acuerdo con, por ejemplo, las suposiciones carnapianas, los protocolos inductivos y deductivos pueden considerarse complementarios, es decir, traducibles entre sí, lo que puede explicar cómo los TE de ensayo y error pueden interpretarse como experimentos Ideales.

Introduction

Galileo Galilei's *Falling Bodies* experiment as from top of Leanng Tower of Pisa has recently got renewed attention as a TE instead of an E (e.g. Brown, 1991a, 1991b; Sorensen, 1992; Gendler, 1996/2000; Brown & Fehige, 2019). Close reading of the original Galilean TE text may yield the same conclusion. But it may lead to another formalization of the TE as after the many more (T)E in this Galilean text. Difference between TE and E is not always completely sure from the original phrasings of e.g. Aristotleand Galileo (especially not if we may read some phrases metaphorically), and we may suppose that Aristotle, among more ancient Greeks, such as Archimedes and Pythagoras, just like e.g. Chinese scientists and philosophers, such as Mozi, already conducted real E, which may breach the traditional historical dichotomy between the Ancient and Medieval Period and the herald of the New Period in western science and philosophy, of which Galileo is one of the best known representatives. Moreover, on close reading it may appear that Galileo, like Aristotle, may have conducted many more

experiments and thought experiments, an amazing variety of series of multiple fall (thought) experiments of objects of different materials, from different distances, in different media as air, (hypothetical) void, water, wine, mercury etc.

However, there is a significant breach in gravity theories between the Ancient/Medieval Period and the New Period, which could indeed be considered as a paradigm shift (see e.g. Kuhn, 1962/1996), and which may be understood more fully by hindsight as from Albert Einstein's work and definition of idealized experiments, which per definition can't be real E, and so are necessarily TE, and necessarily ideal concepts as (movement in) vacuum (which can't be realized on Planet Earth).

We will first show that the text of Aristotle and Galileo discuss many more experiments and thought experiments (surface analyses show a series of multiple TE) and, next, that we may formalize the TE in the same way as the E, namely as classical induction (T)E, applying traditional inductive logical formulas, inferring, first, inductive universal instantiation, which appears translatable in second deductive universal instantiation.

We conclude by returning to the notion of ideal experiment and understand classical physics as an exemplification of mathematics just because physics is expressed in mathematical formulas, and notice that the theoretical distance to understanding by intuition--traditional explanans of dynamics of thought experiments--has got wider and wider throughout the history of physics, since Aristotle's theory may still seem most intuitively plausible (as after conducting of real E), and Einstein's relativity theory can hardly be demonstrated anymore by Es on Planet Earth.

Thought Experiments (TE) and Experiments (E). Experience and Experiment TE (TE_{EI}, TE_{EX})

> SIMP. His [Aristotle's] language would seem to indicate that he [Aristotle] had tried the experiment, because he [Aristotle] says: *We see the heavier;* now the word *see* shows that he [Aristotle] had made the experiment. (Galileo, 1638/1914, p. 106, italics in original, bracketed explanation added)

Both the fall experiments and discussion on Aristotelian gravity theory are in the dialogue of the first day between Salviati, Sagredo and Simplicio (resp. usually Galilean, neutral, and Aristotelian view) in Galileo/Crew (1638/1914) *Mathematical Discourses and Demonstrations, relating to Two New Sciences*, treatise on the behavior of bodies in motion, the nature of acceleration, etc. (which book title is often abbreviated to *Dialogues concerning Two New Sciences* or *The Two New Sciences*). As we will see later, it is about examples of singular, elementary, or basic TE, *Ideal Experiments* that chain a series of *Trial and Error TE*.

As clarified by the bracketed explanation the motto quote does not refer to Galileo but to Aristotle and it is Simplicio's reply to Salviati's doubt if Aristotle may ever have tested by experiment whether two stones of unequal weight may fall at the same speed.

It may seem obvious that the ancients already performed experiments as according to some experimental methodology of *ceteris paribus* and it can even be inferred from Salviati's statement about Aristotle:

> … Aristotle declares that bodies of different weights, in the same medium, travel (in so far as their motion depends upon gravity) with speeds which are proportional to their weights; *this he illustrates by use of bodies* in which it is possible to perceive the pure and unadulterated effect of gravity, *eliminating other considerations*, for example, figure as being of small importance [minimi momenti], influences which are greatly dependent upon the medium which modifies the single effect of gravity alone. … (Galileo, 1638/1914, p.109, brackets in original text, italics added)

Some of Galileo's (T)E are clearly stated as an experiment e.g., Sagredo emphasizing

> But *I*, Simplicio, *who have made the test can assure you* that a cannon ball weighing one or two hundred pounds, or even more, will not reach the ground by as much as a span ahead of a musket ball weighing only half a pound, provided both are dropped from a height of 200 cubits. (Galileo 1638/1914, p. 106-107, italics added)

Some passages, however, have the form of a TE including TE indicators as 'Consider...', 'Imagine...' e.g.

Salviati

> Let us, in view of this, *consider* what takes place in air, where for the sake of a definite figure and light material *imagine* an inflated bladder. The air in this bladder when surrounded by air will weigh little or nothing, since it can be only slightly compressed; its weight then is small being merely that of the skin which does not amount to the thousandth part of a mass of lead having the same size as the inflated bladder. Now, Simplicio, if we allow these two bodies to fall from a height of four or six cubits, by what distance *do you imagine* the lead will anticipatethe bladder? You may be sure that the lead will not travel three times, or even twice, as swiftlyas the bladder, although you would have made it move a thousand times as rapidly. (Galileo 1638/1914, p. 117, italics added)

We would need more proof to falsify such an established paradigm as the rise of the experimental method in western science, but there are surely indications that experiments have been performed many ages before the Renaissance, including ancient Greece of Aristotle's days, and that both the ancients and representatives of the New Period used thought experiments.

Quite a few TE philosophers, such as Rescher (1991) and Lakatos (1976), detect TE in texts of Greek ancients as pre-Socratic philosophers and pre-Euclidean mathematicians.

In favor of the established view of Galileo's new experimental method we quote Salviati where he tells about some sort of a crucial experiment defeating the results of Aristotle's (supposed) mere reasoning

> Aristotle says that 'an iron ball of one hundred pounds falling from a height of one hundred cubits reaches the ground before a one-pound ball has fallen a single cubit.' I say that they arrive at the same time. *You find, on making the experiment*, that the larger outstrips the smaller by two finger-breadths, that is, when the larger has reached the ground, the other is short of it by two finger-breadths; …. (Galileo, 1638/1914, 109, italics added)

However, it does not contradict the importance of the manifold of additional (T)E to both Aristotle'sand Galileo's scientific methodology for--as our surface analyses may show--just one TE or E is notsufficient to develop a new theory.

We guess that at least some of Aristotle's and Galileo's TE can be categorized as *Experience*-like *TE* instead of *Experiment*-like *TE*, or possibly as a blend of these two

taxonomies, as they often refer not to a supposed experimental setting, but to daily experiences, that is, they call to memory what we are supposed to know from daily life. The call to imagination is partly a call to memory from past experiences. The Experience feature of Galileo's TE is obvious in Galileo's *Ship*, where the thought experimenter recalls common experiences from water travel by ship.

Experiment TE may resemble the description of a real experiment, but in Aristotle and Galileo we can't be sure if the experiment has actually been conducted in reality. The constraints of what an experimentor experimental setting may amount to, have got stricter and more elaborate last centuries, and may include repetition of E, control E, use of laboratorium and special equipment, from telescope in classical physics to cyclotron in modern physics.

Surface Analyses

Galileo's *Gravity* TE of *Falling Bodies*, one of the most famous TE in the history of science was sometimes mistakenly thought to be a real experiment (see e.g. Lodge, 1960, p. 90, recounted in Sorensen,1992, pp. 224-225, who discusses it as an example of a 'mythical experiment'), and even today it is misleadingly accompanied by illustrations of a tower representing the famous Leaning Tower of Pisa, and two objects falling down from it as the *I don't even have to look* Galileo cartoon in *Stanford Encyclopediaof Philosophy* (Brown & Fehige, 2019, fig. 6). In *The Two New Sciences* there are no illustrations in this section, none of all 126 figures in the book shows a tower with falling bodies, and while (T)E of bodies falling from a tower are described some two or three times, there is no reference to Pisa's Leaning Tower. We must add that part of mystery, magic and fame of the TE may have been brought about because of association with Leaning Tower and Renaissance Italian culture and art in general and Galileo in particular. Galileo (1564 – 1642) is considered one of the great creators of the Renaissance as well as the founder of western (experimental) science as prefaces and introductions don't forget to tell.

However, study of Galileo's authentic *Gravity* TE text shows that these eurocentric connotations aren't, in fact, in the TE text. Theoretically speaking, one of its precursors was Mozi (墨子Mo Tzu or Mo Ching, ca. 470 – ca. 391 BCE), founder of Mohism in the Chinese Hundred Schools of Thought Period,who already wrote on, e.g., forces and motion, e.g., reminding Galileo's law of inertia, Isaac Newton's first law of motion “The cessation of motion is due to the opposing force ... If there is no opposing force ... themotion will never stop …”. (e.g., Needham, 1962, p. 56)[1]

The Hammer and The Feather

Galileo's *Gravity* TE has a brilliant update in Galileo's Gravity Experiment *The Hammer and The Feather*, asci story that could look quite sci-fi. It is a video of an experiment by an astronaut on the moon (name of astronaut and date of video go alas unmentioned). The astronaut is shown to drop both a hammer and a falcon feather from chest height and one can witness clearly how they fall at the same speed and hit the surface of the

[1] From Needham (1962) on physics. After Joseph Needham's decease his work on science and civilization in China continues under name of Needham Research Institute. Cf. Smith (2016)

> .... Few histories of physics consider developments outside Europe; and of those that do, non-Western physics is often presented as ‘derivative’ of European work. However, recent scholarship has made it clear that this European view is incomplete, and that numerous non-Western cultures, including those of China, India, the Islamic world, and others, developed sophisticated physical theories independently of Europe. In this expanded view, physics began in prehistoric times”.

Contrarily, western science is often derivative of eastern science, e.g., West and East now acknowledge China was the first to invent or discover (woodblock, movable type) printing press, gunpowder, fireworks, paper, paper money, compass, smallpox inoculation, mechanical clock, suspension bridge, alcohol, tea, soy sauce, tofu, toothbrush, silk, umbrella, kite, acupuncture, chopsticks, go (board game), playing cards, (hand, hanging) scroll, ink, porcelain, bronze, iron smelting, seed drill, row crop farming, earthquake detector, rocket, etc. (see e.g. Wikipedia on (list of) Chinese inventions). Wrt ancient Chinese logic. Liu and Zhang (2010) show e.g.

> First, the Moist theory of classifying names had the same spirit as Aristotle’s account of “genus and differentia.” Indeed, their view on the relationship between names and objects suggests that they already realized the distinction between syntax and semantics, as found in modern authors like Frege. (Liu & Zhang, 2010, p. 619)

We will discuss Galilean gravity theory and (T)E etc. as global cross-cultural, i.e., like they may have been invented, discovered, and applied in non-western cultures, too.

moon at the same time. The astronaut concludes “So, Mr. Galileo was correct in his findings.”[2]

Although one might say it is not a TE but a real experiment (E), one may, firstly, question what is real. Is living on the moon as real as living on Planet Earth? Do the same background assumptions apply as oxygen air, gravity etc.? Clearly not (on the moon there is hardly any atmosphere and only a sixth part of Earth's gravitation)! Secondly, as it is a modern-day registration of an experiment that can't be easily reperformed (when scientists would like to do so, they would have to travel to the moon first), it may fit in with classical TE feature of being essentially unperformable (as on Planet Earth). Thirdly, it could easily be considered a crucial TE showing a paradigm shift--from paradigm of experiments solely performed on Planet Earth to paradigm of experiments performed in space, on the moon, on Mars etc. And, lastly, as it is a visual, video description of an experiment it fits in with one more—but rather weak— feature of *T*E i.e., that is a description of an experiment instead of an experiment itself.

Two New Sciences (Galileo/Crew 1638/1914)–Series of TE

Returning to 17th century text by Galileo--The famous TE is introduced by Salviati to Simplicio on the First Day of the Dialogues between Salviati, Sagredo and Simplicio (Galileo, 1638/1914, p. 117) “Our problem is to find out what happens to bodies of different weight moving in a medium devoid of resistance, so that the only difference in speed is that which arises from inequality ofweight”.

Not just falling bodies in air -fall experiment as we imagine it could have taken place from Leaning Tower of Pisa- are discussed, but many more as relating to density of medium -among more factors- and Sagredo and Salviati bring up for discussion many alternate (T)E that not only vary mass (e.g. cannon ball of 200 pounds, musket ball of only half a pound, stones of 20 pounds, 2 pounds, bird- shots), but also falling distance (height – e.g. 1, 4-6, 12, 20, 50, 100, 200, 1,000, 'some thousands of cubits', 'from the distance of the moon or from the upper regions of the atmosphere'), force, momentum,

[2] See references, Top 10 Most Famous TE (on the net). It is about astronaut David Scott of Apollo 15 project in 1971.

figure (e.g. gold leaf, inflated bladder, stone), material of bodies (e.g. gold, lead, copper, porphyry, ivory, ebony balls, bladder, wood, knots, roots), resistance of medium (e.g. vacuum, air, water, wine, quicksilver). This array of (T)E is not only about falling (e.g., stones through air), but also about sinking (e.g., ball oflead through water, gold through quicksilver) or drifting (e.g., knots and roots resting on water). The (T)E touch on seemingly unrelated matters as cohesion of fluids (water, wine) and fish maws.

The (T)E are set to counter persistent doubts and critical questions by Simplicio “Perhaps the result would be different if the fall took place not from a few cubits but from some thousands of cubits” (Galileo 1638/1914, p. 110) or “Your discussion is really admirable; yet I do not find it easy to believe that a bird-shot falls asswiftly as a cannon ball” (Galileo, 1638/1914, p. 109) which are indeed justified as Aristotle's theory is more in accordance with daily experience thanGalileo's theory which seems counter-intuitive, unnecessarily abstract etc.

Instead of just one E or TE we find in Galileo's text a multitude of a variety of series of multiple TE, either mentioned by Galileo's interlocutors, or in Aristotle—as paraphrased by Galileo. Some TE seem necessarily TE as they can't be performed in reality, certainly in those days they could not, as fallingbodies in vacuum, from 'some thousands of cubits', 'from the distance of the moon or from the upperregions of the atmosphere' etc.

The Hammer and the Feather (T)E fits in perfectly with this discussion as a whole, as it is not just aboutfalling in air – “this vapor-laden atmosphere of ours” (Galileo, 1638/1914, p. 122)-but about many more media, and changing the medium to the atmosphere of the moon fits in with Galileo's line of argument. We may conclude that neither Aristotle nor Galileo based their theories on just one E or TE, but that both have performed many more (T)E, and, so, the authentic TE text in *Two New Sciences* suggests ananalysis of a series of basic or elementary (T)E instead of only one conclusive TE as suggested in secondary TE literature as (Brown, 1991a, 1991b; Brown & Fehige, 2019).

The (T)E as mentioned in e.g. (Brown,1991a, 1991b; Brown & Fehige, 2019; Sorensen, 1992 and Gendler, 1996/2000) is not a report of one of the many elementary (T)E, but an argumentative reply by Galileo to a passage in Aristotle's text.

We can reconstruct this complex (T)E—one or two bodies and a compound body falling through PlanetEarth's atmosphere from considerable height as 200 cubits (i.e., 200 x 46 cm, 92 m)[3]—as both inductive and deductive universal instantiation (UI) of Galileo's general physical law that objects (of same material, in same medium etc.) fall at the same speed.

But, again, James Brown (and more philosophers) have not firstly reconstructed a (T)E proving Galileo's law of gravity, but foremost Galileo's argument of refutation of Aristotle's view that falling speed of objects depends on mass of the objects as illustrated by an argument why a compound body falls with the same speed as its components.[4] That is, their analyses don't represent the structureof the classical induction TE or *Trial and Error TE*, that abound in Galileo's text, and many of which may have been real

[3] A cubit is an ancient unit of length. 1 Cubit is 46 cm, 'based on the length of the forearm ...' (according to Webster's 11th). The Leaning Tower of Pisa is about 56 m, so also proposed falling distance of 92 m does not match Tower of Pisa.

[4] This is indeed noticed by Tamar Gendler who unfolds something like a surface analysis in her 1996 dissertation. Although Gendler's discussion focuses on the famous TE of two bodies strapped together, her introduction acknowledges that this TE only poses a weaker conclusion than the main one discussed in Galileo's section aimed at challenging and falsifying the preeminent Aristotelian gravity view of linear proportionality 'a moveable ten times as heavy as another is moved ten times as fast' as the other. Our discussion does not neglect the many more E or TE (it is not always sure if they are E or TE) that are mentioned in the text, in which, e.g., material of falling bodies, falling distance and (density of) medium is changed. Gendler (1996, pp. 55-56):

> Perhaps the most famous thought experiment in the history of western science is the thought experiment with which Galileo is credited with having refuted the Aristotelian view that the speed with which a body falls is directly proportional to its weight [...]. The thought experiment appears in his last and most mature work, the Discourse Concerning Two New Sciences [...], in the context of a more general discussion of the possibility and nature of motion in a void. Galileo's goal in the section as a whole is to establish that 'if one were to remove entirely the resistance of the medium, all materials would descend with equal speed' (Galileo 1638/1914, 116); the thought experiment in question leads to the weaker conclusion that “both great and small bodies, of the same [material], are moved with like speeds”. (Galileo, 1638/1914, p. 109, italics added).
>
> The view that Galileo is challenging is that 'movables differing in heaviness are moved in the same medium with unequal speeds, which maintain to one another the same ratio as their weights [gravità]' (Galileo 1638/1914, p. 106). That is, he is challenging the view that heavier bodies fall faster than lighter ones, and that they do so in direct proportion to their heaviness. On the version Galileo takes himself to be opposing, the proportionality is linear; 'a moveable ten times as heavy as another is moved ten times as fast' as the other. (Galileo, 1638/1914, p. 106)

Sorensen describes 'the Pisa experiment' as an example of a “mythical experiment” that “probably never occurred” (Sorensen, 1992, pp. 224-225), and calls the argumentative refutation of Aristotle's theory of motion by “having us suppose that a heavy falling object is joined to a lighter one”, (p. 126) what Brown and Fehige calls Compound Bodies and Gendler Strapped Bodies, “fused-descent” TE. (p. 316)

experiments, either already performed by Aristotle, or by Galileo.

We call these TE classical induction TE or *Trial and Error TE* after their real analogues of classical physics which are called *Trial and Error E* as part of the methodology of classical induction. We are aware that our analyses could be considered overcomplex, but they are not. Only a close reading of the authentic TE text and its manifold of (T)E can reveal it is about a chain of basic or elementary TE of (classical) physics, which are often performed in series of *Trial and Error TE*, trying, checking, and balancing out a multitude of possible variables and constants, which is a procedure typical for classical induction. These procedures are fallible, and one may need many heuristic guesses to arrive at a subsequent *Ideal TE*, which we will discuss under a separate heading later on.

Because it is foremost about series of many classical induction (T)E, the procedure of *Trial and Error (T)E* is empiricist, and we don't need recourse to mysterianism of *Platonist TE*, through which we may'see' the laws of nature in a Platonist sense (see e.g., Brown 1991a, b). Instead, we rebaptize this type ofTE that destruct, falsify an old (e.g., Aristotelian) paradigm and construct, verify a new (e.g., Galilean) paradigm, *Deconstructive TE,* and we hold on to an empiricist and argumentative view of TE, which isdefended in e.g., Norton (1996, 2004a, 2004b).

Deep Analyses - Inductive and Deductive UI

Galileo's argument as retold in e.g., Brown (1991a, 1991b), is not a mere TE but rather like a calculation. It is also considered an argument as based on a supposed experiment of *Compound* or *Strapped Bodies*, of which it is not clear if it has indeed been performed by Aristotle or Galileo, but the argument seems to make execution of the (T)E superfluous:

> But, even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that a heavier body does not move more rapidly than alighter one provided both bodies are of the same material and in short such as those mentioned by Aristotle. (Galileo, 1638/1914, p. 107, see Section 3.3)

In our analyses of the many *Falling Bodies (T)E*, we have concluded to a sequence

of *Trial and Error(T)E* from classical induction, which we may formalize with help of inductive logic and generalize to inductive universal instantiation. Since induction and deduction may be considered logically complementary (see e.g., Carnap, 1966), we may next translate inductive universal instantiation into deductive UI.

Inductive Universal Instantiation

for all x it holds that x falls at speed y (given a certain material and medium) (1)
a falls at speed s
b falls at speed s
c falls at speed s
…
- -
all objects fall at speed s (2)

Suppose

Fx	x Falls
xF'y	x Falls at speed y
a, b, c …	objects with different masses (constants for variable x)
s	(a certain) speed (constant for variable y)
∀x	universal quantifier
∧	conjunction

∀x (Fx ∧ xF'y)Fa ∧ aF's
Fb ∧ bF's
Fc ∧ cF's
….
- - - - - - - - - - - - induction
∀x (Fx ∧ xF's)

Suppose (3)

Fx x Falls

Sx x has Speed s

Fa ∧ Sa

Fb ∧ Sb

Fc ∧ Sc

…

- - - - - - - - - - - - induction
∀x (Fx ∧ Sx)

In these formulas, constants a, b and c represent objects with different masses. In formula (2) supposed relation F' turns out to be property S in formula (3) as all objects fall at the same speed.[5]

It is counter-intuitive to many people, that is why it makes sense to pay some attention to it as by (thought) experiments. And foremost it is contradicting Aristotle's theory saying that heavier bodies fallfaster than lighter bodies, which is in accordance with intuition of many people.

Please, compare, Ptolemaic-Aristotelian geocentric sun-rotates-around-earth universe, which is in accordance with everyday living experience and language (e.g. 'the sun rises at 7 AM today', see Gadamer, 1960) and Galilean-Copernican heliocentric earth-turns-around-sun theory (please, see Galileo, 1632/1967 *Two Chief World Systems*), which is not easily understood from daily experienceand language, so, it could be considered counter-intuitive, too.

The TE debate is not just about elementary inductive universal instantiation, but

[5] More alternate formalizations and analyses are possible e.g., suppose:
F"x x Falls at speed s (given a certain material and medium)
a, b, c … objects of different weights (constants for variable x)

F" a
F" b
F" c …
- - - - - - - -
∀x F" x

foremost about falsifying Aristotle's theory. This is a more complex part of the argument, possibly requiring higher-order predicate logic involving relations to express relative (falling) speed.

Deductive Universal Instantiation

(4)

As from modus ponens,

If an object x Falls, then it has Speed s

a Falls

- - - - - - - - - - - - deduction

a has Speed s

(5)

Suppose

Fx	x Falls,
Sx	x has Speed s
a	object (constant for variable x)

$\forall x\ (Fx \rightarrow Sx)$

Fa

- - - - - - - - - - - - deduction

Sa

Again, alternate analyses are possible.[6]

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[6] Proposition logic: Modus ponens, p → q, p therefore q. Adding predicate logic:

p	x Falls
q	x has Speed s

Predicate logic is appropriate here for it is about propositions that predicate different properties of object(s) that are related to each other as shown in modus ponens. Furthermore, predicate logical analysis may demonstrate (deductive) universal instantiation.

Formula (5)] resembles Rudolf Carnap's generic scheme of scientific explanation or prediction, which is also modus ponens (instantiation)

(x) (Px → Qx)
Pa
———
Qa

Next, there are some more examples of *Falling Bodies* added, that is the deductive universal law isinductively confirmed by a set of examples or instantiations.

It is about a property that connects mass to speed as according to Aristotle's gravity theory, so, arelation, and we could need a higher-order predicate logic to express it (see formula (2)).

However, Galileo's TE argument shows that the property of mass relative falling/gravity motion is nottransitive as Aristotle may have concluded, but symmetrical, that is to say: speed of falling objectsis independent of mass of the objects (see formula (3)).

If it is an important step in Renaissance development of physical theories that they apply mathematicalformulas, then Galileo's (T)E examples may prove that physical laws of Galileo's classical mechanics hold on to symmetry feature of Euclidean mathematics, not just transitivity like Aristotle's.

The transitive laws of Aristotle appear to be symmetrical as in accordance with results of (T)E, andinstantiation of Galileo's new universal law of gravity.[7]

***Compound* or *Strapped Bodies* TE (e.g., Gendler, Brown)**

SIMP. But what if we should place the larger stone upon the smaller?

SALV. Its weight would be increased if the larger stone moved more rapidly; but

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where (x) (Px → Qx) is a scientific law; Pa is a description of the initial conditions; and Qa is the description of the event we want to explain. The last statement is a logical consequence of the first and the second, which are the premises of the explanation. A scientific explanation is thus a logical derivation of an appropriate statement from a set of premises, which state universal laws and initial conditions. (Carnap 1966, pp. 7, 17)

Carnap’s scheme may read both as explanation and prediction -inductive UI may count as explanation (emergence of a new event subsumes under an existing rule or law), deductive UI as prediction of the same event (from an existing rule or law a new event may be predicted). Popper's falsificationism tries to replace inductivism, which was unreliable according to Popper, by deductivism of critical rationalism (cf. e.g., Popper, 1959), another example of how induction may be translated into deduction.

[7] That is, the new theory is simpler than the old one, a fact that advocates simplicity as an epistemological maxim. Symmetry implies transitivity but transitivity does not (necessarily) imply symmetry i.e., symmetry is stronger and simpler than transitivity. Change from Aristotle's to Galileo's theory is in accordance with epistemological maxims as simplicity. (Cf. e.g., Ockham's razor, “Simplification of theory is a central motive …”. (Quine,1960, p. 158) See also Sorensen (1992, pp. 194-195), in note 9, e.g., “an idealization is supposed to be an effective simplification”.

> we have already concluded that when the small stone moves more slowly it retards to some extent the speed of the larger, so that the combination of the two, which is a heavier body than the larger of the two stones, would move less rapidly, a conclusion which is contrary to your hypothesis. We infer therefore that large and small bodies move with the same speed provided they are of the same specific gravity. (Galileo,1638/1914, pp. 108-109)

Introducing relative motion, a relation (higher-order predicate logic)

Suppose (6)

Mxy x Moves faster than y

Mxy = Myx x Moves faster than y, and y Moves faster than x (i.e., x moves as fast as y (and y moves as fast as x)

Fx x Falls

$\forall$xy Fx, Fy $\wedge$ Mxy = Myx

ab Fa, Fb $\wedge$ Mab = Mba[8]

The argument is reconstructed in Brown (1991a,1991b), Brown & Fehige (2019) like this:

(7)

Suppose

H is Heavy body, L is Light body, HL is compound body

Suppose speed of movement of bodies depends on mass of bodies (when made of same material and moving in same medium, etc.).

Compound HL body falls both faster and slower than L and compound HL body falls as fast as both H and L. (Please, see Brown & Fehige (2019)

> But consider Figure 6 [dropping two objects from Tower of Pisa], in which a heavy cannon ball (*H*) and light musket ball (*L*) are attached together to form a compound object (*H*+*L*); the latter must fall faster than the cannon ball alone. Yet the compound object must also fall slower, since the light part will act as a drag on the heavy part. Now we have a contradiction: *H*+*L* > *H* and *H* > *H*+*L*. That's the end of Aristotle's theory. But there is a bonus, since the right account is now

[8] More alternate formalizations, analyses are possible.

obvious: they all fall at the same speed (*H* = *L* = *H*+*L*).

In Gendler (1996/2000, 1998) it is emphasized that it is about the "possibility and nature of motion is avoid", the counter-Aristotelian TE is called *Strapped Bodies* here, and it is considered to prove only aweaker version of the new Galilean gravity theory

> …. Galileo's goal in the section as a whole is to establish that 'if one were to remove entirely theresistance of the medium, all materials would descend with equal speed' (Galileo 1638/1914, 116); the thought experiment in question leads to the weaker conclusion that "both great and small bodies, *of the same* [*material*], are moved with like speeds" (Galileo, 1638/1914, 109, italics added). (Gendler 1996, p. 55-56, see note 4)

Compound or *Strapped Bodies* TE is in accordance with inductive UI analysis on Galilean account of gravity as it is just one more instantiation of general inductive rule, e.g., suppose (e.g.) c to be equal toab, that is a+b (c = ab = a+b).

Suppose (8)

Fx	x Falls
Sx	x has Speed s
a, b, c	objects of different masses (constants for variable x)

Additionally, suppose:

c = ab = a+b	mass of object c equals mass of conjunction of objects a and b
$\forall x$ (Fx $\wedge$ Sx)	
Fa $\wedge$ Sa	
Fb $\wedge$ Sb	
Fc $\wedge$ Sc	

So, a, b and (compound) ab (c) fall at same speed s.

TE as Ideal Experiments

Although there may have been series of experiments that have been claimed by Salviati and Salgredo inthe text to have been performed in reality, the manifold of approaches by varying variables makes one believe that all these endeavors sum up to a sort of ideal

experiment in favor of two competing theories or paradigms, the Aristotelian, and Galilean(-Newtonian).

For Galilean gravity it is essential that the experiments are TE for as with regard to the law Galileowants to formulate, gravity is considered in vacuum, that is, without effects of friction and air resistance. Exactly the latter factors make light bodies fall slower than heavy bodies and his TE shows that these effects are not fundamental to gravity.

Einstein refers to his TE as idealized experiments that are experiments “created by thought” (Einstein & Infeld 1938, p. 226) by which procedure there is abstracted from friction, air resistance, etc., and he often mentions example of c, that is speed of light in vacuum.

In Einstein & Infeld (1938) there are -next to the famous *Elevator* TE- many more TE, from classical mechanics, electrodynamics ('repeating Faraday's experiment with a circuit shrinking to a point', 'smallsphere with an electrical charge') and quantum physics involving electrons or photons.

Einstein & Infeld (1938) classical mechanics TE are about a 'cart on a perfectly smooth road', 'wheels withno friction at all,' 'a perfect sphere rolls uniformly on a smooth table', ' a body moving forever with no friction nor any other external forces acting', and so on.

Einstein considers these TE necessarily unperformable in reality:

> Imagine a road perfectly smooth, and wheels with no friction at all. Then there would be nothing to stop the cart, so that it would run for ever. This conclusion is reached only by thinking of an idealized experiment, which can never be actually performed, since it is impossible to eliminate all external influences. The idealized experiment shows the clue whichreally formed the foundation of the mechanics of motion. (Einstein & Infeld, 1938, p. 8)

> We have seen that this law of inertia cannot be derived directly from experiment, but only by speculative thinking consistent with observation. The idealized experiment can never be actually performed, although it leads to a profound understanding of real experiments. (Einstein & Infeld 1938, pp. 8-9)

> The division leads to an idealized experiment, for a physical process in which

> only themechanical aspect appears can be only imagined but never realized. (Einstein & Infeld 1938, p. 47)

Although in Einstein's days, there were already vacuum pumps and suction pumps (as there already were in ancient days of Pompeii) and philosophical speculation of (e.g.) horror vacui had been replacedby empirical experiments to actually construct a vacuum (like 1643 so-called first laboratory vacuum, Torricellian vacuum), one may say that with the introduction of vacuum technology as vacuum tubes and later construction of experimental ultra-high vacuum chambers and discovery of outer space with only a few atoms per cubic meter, one has succeeded in creating or discovering a near-vacuum as a near- approximation of a realization of what Einstein still considered actually unperformable TE, so that we can relativize necessarily unperformable to a certain stage in the progress of science.

Speculative nature of TE can be reduced in these experiments, that can be performed as near-real E aswell e.g., Galileo's TE of *Falling Bodies* executed on the moon like above *Hammer and Feather E*.[9]

[9] If one wants to hold on to emphasizing negligible or only theoretical differences, one may wonder which entities and qualities do really exist in our world--Do numbers really exist? Which horse is a really (perfect) essential, ideal, archetypal (etc.) horse? For us there is no reason to believe in (existence of), let's say, Platonic ideals or Aristotelian essences in mathematics or physics or anywhere and we rather consider mathematical laws and physical laws using mathematical symbols, operators and formulas abstractions, idealizations from empirical regularities. Stating that TE can never be actually performed or realized or only exist in imagination or in an ideal realm is reversing a possibly contrary naturalist process of thinking from concrete to abstract, from empirical to rational, from real to 32 ideal instead of the other way around. Nevertheless, there may be good methodological or conventional reasons to work with ideal or idealized entities as numbers, formulas, physical laws, genera or DNA structures of organisms, concepts of I and God etc. and, so, also with TE. Sorensen’s view accounts for both Galileo's simplification and idealization

> .... Galileo engineered his methodology with the pragmatism of a physician who changes his treatment of a patient.... Galileo found that nuisance variables could be eliminated by creating a highly artificial setup. Some biases could be canceled by others. Small disturbances could be ignored. Hard-to-reach values could be extrapolated by a trend from a series of easier-to-reach values. All of these are empirical lessons learned about experiment, not a priori methodological principles. When things get working, there is often a residue of uncertainty as to how the changes succeeded, what the specific problem was, or whether a particular adjustment even had any real impact at all. Hence, experimental design evolves in the uneven, half-blind manner of medical lore. Theorists can come in later and rationally reconstruct many aspects of laboratory craft. They will dismiss other features as vestigial or as superstitious pieties. Thought experiments are equally dependent on their track records. After all, an idealization is supposed to be an effective simplification—a shortcut that gets you most of the effect by concentrating on just a few variables. (Sorensen, 1992, pp. 194-195)

However, the speculative TE with regard to General Relativity remain what we will call *Theoretical TE* for they refer to micro- and macro-physics and can't be persuasively reenacted on earth, although Einstein's *Elevator* TE was possibly devised with this goal.

Trial and Error TE (Classical Induction)

It is true that if we analyze the TE instead of its use in a scheme as to falsify an old theory and advancea new one, our analysis may as well like an inductive hypothetico-deductive methodology. We also baptize one of our deep analyses as inductive …. Indeed, we hold that in Galileo's text there is reference to many (T)E that are used to inductively prove Galileo's new theory as falling (T)E in different media, trying different materials of objects and different falling distances.

We see no problem in this likeness to induction nor in the fact that our TE are formally indistinguishable from E analyses, particularly as from Galileo's text we can't make sure if it is about TEor E and it is not necessary to employ modal logic in our analyses as it is not about an essentially modalargument (as e.g. logical possibility of *Zombie* TE in consciousness studies , see e.g. Chalmers (1996, 2017).

We will add some more examples wherein use of TE likes inductive use of E to a high extent. Consider someone who wants to get a drifting ball from a pool and who can choose out of three lengthsof available sticks. Now we perform TE in the head as preps to our actions, that is, we may first measure the lengths of the sticks in the head and try in the mind the three sticks—one by one--before actually choosing a stick to try and reach the ball. We are measuring the distance to the ball to the lengths of the sticks before actually choosing a stick. In this case, we inductively perform TE as trial and error in the head, and, after, possibly perform two or three inductive E if we don't pick out a good stick at once.

We hold that these -and many more- sorts of TE are used in daily life very often as by trial and errorin the mind. It is about TE which we can perform in a split second, and in many more rather abstract situations e.g., in algebra where this method is called

guess and check and in decision theory when we want to choose from alternates. We can then perform TE and go through all available alternates and possibilities in the head as (e.g.) A, B and C by inductive trial and error, first trying A to situation S, next B, next C, assessing possible consequences of A, B and C and, finally, make our choice between A, B or C.

As we may see in analyses of Einstein's TE (see e.g., Hertogh, 2015, Pt. III, 2022a) this classicaldefinition of TE can't hold anymore for Relativity TE, that are about micro-physics (quantum mechanics) and macro-physics (astronomy) and engage so-called *Theoretical TE*.

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List of abbreviations

Abbreviations of technical terms used in this paper:

TE: thought experiment(s)

E: experiment(s)

(T)E: (thought) experiment(s) e.g., TEs and Es, or E that looks like TE, or TE looking like E,or event of which it is nor sure if it is a TE or E

UI: universal instantiationTE_{EI}: Experience TE

TE_{EX}: Experiment TE

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