Empirical Thought Experiments:
A Transcendental-Operational View

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Abstract. The operational perspective here defended permits a reflexive-transcendental point of view that sharply distinguishes the two concepts, while, at the same time, maintaining the connection between them. On the one hand, simply imagining that the experimental apparatus, counterfactually anticipated in a thought experiment, has really been constructed is sufficient to erase any difference between thought and real experiments. On the other hand, this very 'imagining', this capacity of the mind to assume every real entity as a possible entity, underpins the difference in principle – a properly transcendental difference – between thought and real experiments. This difference, however, implies the intimate association between experiment and thought experiment: *All thought experiments must be thought of as translatable into real ones, and all real experiments as realisations of thought ones*. What thought experiments have over and above real experiments is the mere fact that they exist in a purely hypothetical sphere; what real have over and above thought experiments is the mere fact that they overstep the sphere of the possible, in the experiment's real execution.

It was noted some time ago by James Brown that a Kantian point of view is lacking in the critical literature on thought experiments (cf. Brown 1991a, p. 156). We now know that this, taken literally, is false. Contrary to what was commonly believed until a few decades ago, it was not Mach who introduced the term 'thought experiment', but Hans Christian Örsted; and he did so with the purpose of clarifying an aspect of mathematics and its relation to physical knowledge in Kant. However, this interpretation of the nature of thought experiments and of their relation with real ones has had virtually no impact on the historical development of the concept. This is largely because philosophy of science has mostly taken a course that led to the rejection or dissolution of the Kantian a priori, either in the empiricist direction of Mach, of Neopositivism and of Popper, or in the conventionalist direction of French philosophy, of the relativistic philosophy of science of the 1960s and of the 'sociological turn' (that construed the a priori as changeable in function of historically shifting pragmatic interests). It is certainly possible – even though isolated similarities do not quite prove it – that Mach took the term 'Gedankenexperiment' from Örsted (cf. Kühne 2005, pp. 186-187). In any case, it is important to keep in mind the differences in principle between their conceptions of thought experiment, in particular as to the acceptance or rejection of the transcendental nature of the a priori. For this reason, the claim that a Kantian point of view is lacking in the critical literature on thought experiments was and is fundamentally correct in its spirit; and it has been my intention to fill this gap.

Here, briefly presented, is an account of real and thought experiments in the natural sciences, as it examines their distinction and connection in principle within an operational perspective which brings together the empirical or formal point of view of naturalised epistemologies and the reflexive-transcendental point of view of the Kantian tradition. The account is, in short, *at once reflexive-transcendental and operational*.

Fundamental agreement exists[1] as to the essence of the basic problem faced by any investigation into the epistemological status of thought experiments: How can thought experiments, which, unlike real ones, do not rely on new material drawn from experience, lead to unexpected conclusions sometimes capable of casting doubt on well-confirmed empirical theories?
From a methodological point of view, this explanation presupposes that the relation between thought experiments and real experiments be explained. The latter is possible only if both terms are explicitly and rightly understood. What real experiments are and how they function can not be taken for granted. As will be seen, the two concepts are closely connected, to such a point that it is impossible to overlook this connection without distorting the nature of both concepts.

1. Experiment and Theory: The Dialectic of Question and Answer

The technical, or practical operationalist perspective of the present investigation takes as its basic assumption and methodical starting point concrete human beings pursuing specific goals within shifting horizons of meaning. Through their bodies, such agents find themselves always and already in operational or technical interaction with the surrounding world. Access to the real aspects of the natural world is never given passively. Rather, it is made possible by the connection between, on the one hand, our doing (the experimental practices that constitute our operational relation with the world) and, on the other hand, our theoretical awareness of that doing. To use Wittgenstein's famous image, here is where '[we] have reached bedrock, and [our] spade is upturned'.[2]
When we say that we take concrete human beings as our methodical starting point, this does not mean that we take as primary their interaction with reality with no further qualifications. Strictly speaking, the fact that access to the real aspects of the natural world is never a given means that what is primary is not merely the physical (mechanical, chemical, biological) interaction between people and the surrounding world, but also human beings' capacity to *conceptualise and evaluate* this interaction, since *only both components together make it possible to consider reality from a partial, i.e. theoretical point of view*.
In the thesis of theory ladenness there is both an important element of truth and a fundamental prejudice.
Here is the element of truth: for an observation or an experimental result to have an intelligible meaning, it must be the answer to more or less explicit questions, the formulation of which depends on determinate concepts and hypotheses. Human beings live, already and always, in a dialectic of question and answer. This theoretical-dialogical (or problematic-dialogical) aspect is not limited to scientific knowledge but it concerns all human reasoning, be it scientific, philosophical or ethical. All reasoning involves a dialectic of a non-Hegelian type, but close to the personalistic tradition, characterised by the dialogues which the mind carries on with itself while at the same time referring to a superior authority as the benchmark for the truth or falsity of its judgements. Scientific experiments must be understood as a specific, technical-operational aspect of this general dialectic of question and answer. In short, on Kant's suggestion, experimentation is a 'question put to nature' (*Frage an die Natur*), in a

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1 With only one exception of which I am aware (cf. Reiss 2002: 19).
2 Wittgenstein 1953: § 217, p. 85.

way that enables the researcher to investigate and grasp natural processes, not as a pupil listening passively but as a judge who compels the witnesses to answer his questions.[3]

However, only the *meaning* but not the determinate *truth* (or falsity) of the theories applied to the real world can be legitimately presupposed. If there were a path leading from the experimental question not only to a certain *type* or *genus* of answer but also to an experimental answer that is *specific or determinate in its contents*, then the answer would already be implicit in the formulation of the question. In other words, if the theoretical presuppositions of a a question determined the answer right down to its particular determinacy, then nothing really new, which was not contained (albeit implicitly) in the question, could emerge from the answer. The subject determines the *genus* or *type* of the operations to be performed; but the determinate interaction between our instruments (and, more fundamentally, the organic body) and reality has qualities of its own, independent of the goals or values that led to the choice of the operations.

From this standpoint, the limits and strengths of both new experimentalism and the relativistic turn regarding scientific experimentation can readily be understood. By striving to prevent experiments' being swallowed up by the theoretical aspect, the leading exponents of the new experimentalism have seen experimental practices as independent of linguistic-theoretical practices: unlike theories, experimentation 'has a life of its own'.[4]

Making such a claim, Hacking ended up endorsing the same dichotomy of theory and experiment that he criticised in Popper and in relativistic philosophies of science. Only from a theoretically specific point of view can we say that different scientists have performed or reproduced the same experiment, or that they have tried to measure the same quantity with different instruments. This solves one of the best-known open problems of Bridgman's operationalism – one which *mutatis mutandis* has an obvious bearing on the problem of the identity, or identification, of an experiment. By changing the theoretical framework two instances of one 'same' experiment can become two different experiments. Two experiments, identical *as to the experimenter's actions and the experimental apparatus*, can stand for two distinct experiments, or even two experiments in distinct scientific disciplines, if performed to answer distinct theoretical questions. By ringing a bell before he fed fish in a pond, Otto von Guericke showed that sound travels through water; given that the hungry fish arrived at the ringing of the bell, this experiment in physics could pass perfectly as a psychological experiment in animal conditioning.[5]

Since it would be impossible to identify a scientific experiment without theoretical mediation, it would be equally impossible, both in fact and in principle, to conceive its reproducibility without theoretical mediation. Galileo's original experiment of a free falling body and the repetition of the same, performed by first year physics students using sophisticated devices (such as photoelectric cells, electromagnets, digital clocks), are, for all the various devices, the same experiment because *each brings to*

3 See Kant, *CPR*: B xiii-xiv.

4 Hacking 1983: xiii.

5 For this example, cf. Sorensen (1992: 133), who uses it with a very different purpose, i.e. to show that no experiment is 'completely public'. For another example, cf. Franklin 1989: 438-439. For another example, cf. Franklin 1989: 438-439. Before 1905, experiments on the composition of velocities were considered the 'same' whether the velocities they involved were far from or close to the velocity of light, since Newtonian mechanics does not distinguish on this basis. After that date, in the light of the special theory of relativity, these experiments take on entirely different meanings and therefore should be considered different experiments.

light the same real causal connection that constitutes a specific answer to the same theoretical question.

2. Unity and distinction of real and thought experiments

It makes intuitive sense to connect real and thought experiments in a way which might account both for their unity and their distinction. They are thought of as united because *empirical* thought experiments and real experiments tell us about the same reality, and it would be difficult to deny that they may either collaborate or clash. However, they are considered as distinct since it would be just as difficult to claim that their function is identical, either by declaring that real execution is superfluous or by reducing thought experiments to the formulation of questions that can be answered, even provisionally, exclusively by real experiments.

However, in order to give a non-contradictory account of the connection, made up of both unity and distinction, between experiments and thought experiments, we need to distinguish between an empirical or formal level of reasoning (empirical or formal in the sense of empirical or logical-mathematical disciplines) and a reflexive-transcendental point of view.

Two different ways of understanding the relationship between the two types of experiments correspond to these different points of view. In this way the mutual autonomy and the complementarity of real and thought experiments may be grasped, avoiding the antinomy of making one of them an accessory of the other.

From an empirical and/or logical point of view of, experiments and thought experiments are perfectly identical:

(1) Thought experiments too have a *theoretical-dialogical* nature: they have a determinate meaning only if they are (implicitly or explicitly) understood as answers to theoretical questions put to nature and its laws. Thought experiments, even concretely realised ones, would remain ambiguous if their underlying theoretical hypotheses were not specified.

This aspect of thought experiments is particularly significant in the case of Galileo's famous refutation of Aristotle's theory of the free fall of bodies:

> "If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. […] But if this is true, and if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight; but the two stones when tied together make a stone larger than that which before moved with a speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition." (Galilei 1638: 65, Engl. transl. p. 63)

With this thought experiment, Galileo asked what was the precise meaning of the experimental question put to nature by Aristotelian physics about the free fall of bodies: he showed that to formulate that question a distinction was needed, the lack of which made Aristotle's answer ambiguous, and thus potentially contradictory. Strictly speaking, however, Galileo's thought experiment does not show Aristotle's theory to be necessarily contradictory. Rather, contradictions emerge only because of the lack of distinction between two different types of real cases. Galileo does not show that Aristotle's question, and consequently also his answer, are contradictory; what he does show is that they are ambiguous and therefore *possibly* contradictory. Aristotle's theory can be interpreted in two different ways leading to two mutually contradictory hypotheses. In the first interpretation, connected bodies behave, with respect to the system's natural velocity, like separate realities affecting one another so that 'the system will move with a speed less than eight' – that is, at a velocity which is intermediate between the velocities at which each would have fallen had they been completely isolated from one another. In the second interpretation, connected bodies behave like one new reality, so that connected bodies will fall at a higher velocity than each in separation. Aristotle fails to specify a criterion on the basis of which to choose between these two possibilities; consequently, he is unable to distinguish the circumstances when freely falling bodies behave like mutually independent realities affecting one another, from the circumstances when they behave like a new, unique reality (we now know that this happens in some cases of fall within fluids). Since this contradiction arises from the conflation of two possible types of real cases, it can easily be eliminated by introducing the relevant distinction and then choosing in which of the two possible senses we want to interpret physically the 'sum' of the weight of the bodies.[6]

(2) Thought experiments too have a *technical-operational* nature. On the one hand, both experiments and thought experiments are methodical procedures guided by certain hypotheses. At the same time, however, the aim of such hypotheses is to understand, by applying the method of systematic variation, how a certain experimental apparatus varies in response to our specific interventions on it. Put another way, the aim of experiments and thought experiments is to attain assertions about the functioning of an experimental apparatus that are intersubjectively and technically testable. Empirical thought experiments too can determine the *generic* meaning of theoretical questions, through use of experimental apparatuses, from simple surfaces and spheres to very complex mechanisms; these very apparatuses make it possible to apply the method of systematic variation. This is why thought experiments (spanning from Galileo's simple ones about falling bodies to the more complex one involving Schrödinger's unhappy cat[7]) have the same constitutive elements as real experiments – namely, a theory and a particular, well specified, experimental apparatus. We modify some aspects of the apparatus intentionally, in order to see the effects of these modifications in the light of (1) the hypothesis that has to be tested, and (2) assumptions, knowledge or skills accepted as obvious because

6 Norton 1996 and Gendler 1998 (taken up in Gendler 2000), believe, for different reasons, that Galileo's argument is on the whole correct. On the other hand, the arguments of Stäudner 1998, Atkinson 2003, Atkinson and Peijnenburg 2004 seem to converge, albeit indirectly, with my interpretation. Stäudner rightly notes that to remove a contradiction it is sufficient to abandon one of two mutually contradictory premises (cf. Stäudner 1998: 44). Atkinson and Peijnenburg just as rightly point out that it is impossible to prove that Aristotle's theory is formally contradictory, since it is correct at least in one possible interpretation, namely in the case of bodies moving in a fluid, such as air or water: two twin sisters hanging from the same parachute fall twice as fast as only one sister hanging from that parachute (cf. Atkinson and Peijnenburg 2004: 118 and 128-129, who also explain this fact in terms of Newton's theory). Kühne's 2005 analysis is different, since it questions the Aristotelian character of the law of free fall that Galileo refutes; Kühne believes that Aristotle's law is, strictly speaking, analytic and does not make quantitative predictions (see Kühne 2005: 40-41). The philological reconstruction of Aristotle's theory does not fall within the scope of this psper. I limit myself to noting that Kühne stresses the lack in Aristotle's theory of the distinction between a weight at rest (weighed by means of a beam scale and responsible for our feeling of heaviness when carrying something heavy) and a weight in free fall (which we would not perceive if we were falling together with it, since we would be moving at the same speed) (cf. Kühne 2005: 49). On thought experiments in Galileo, cf. also Koyré 1939; Geymonat and Carugo1960; Drake 1973, 1974 and 1978; Settle 1961 and 1975; Koertge 1977; Segre M. 1980; McMullin 1985; Naylor 1974, 1976 and 1989; Prudovsky 1989; Arthur 1999; Palmieri 2003 and 2005; Atkinson and Peijnenburg 2004; McAllister 2004, especially pp. 1168-1171.

7 See Schrödinger 1935; on which see, e.g., Audretsch 1990.

they are underpinned by independently confirmed empirical observations. In both real and thought experiments, technically and operationally testable statements about an 'experimental machine' are sought.

(3) A third general feature of both real and thought experiments emerges from the first two common traits: *experiments and thought experiments must both obey the same technical-operational criterion, and they can both be evaluated only on the basis of that criterion.* Practical-technical feasibility is thus the decisive criterion, even for empirical thought experiments. A thought experiment may be criticised if its experimental realisation is believed to be impossible, either because it contradicts scientific statements or laws about which there is reasonably certainty, or because it contains contradictions that make any realisation a priori impossible.

To be sure, there are a lot of thought experiments where the requirements of empirical realisability and technical-operational testability seem, at first sight, to be in principle unsatisfiable. A well-known example is the thought experiment where Galileo asked what would happen to the weight of a stone that was dropped into a tunnel that cut through the earth and went beyond its centre.[8] Another well-known *exemple* is Einstein's lift thought experiment, which shows that there is no reason to accept certain empirical differences (in particular, between acceleration and gravity) in the absence of experimentally observable differences.[9]

The crucial point, however, is that no hypothesis suggested by an empirical thought experiment can ever be absolutely unrealisable. Empirical thought experiments are held to be scientifically useful and reliable because it is presupposed that, if they were realised, the sequence of events *that they describe according to causal connections, which we assume to be operative in the real world*, would occur in the way they anticipate, and would lead to the consequences that they predict: this holds in principle, no matter how remote the realisability of certain thought experiments may be. Of course, with the use of current technology we are unable to dig a hole through the centre of the earth; nonetheless, here too there is testability in principle. As for Einstein's lift thought experiment, the possibility of satellite laboratories rotating around the earth seems to suggest that it might one day be realised.[10]

(4) As in the case of real experiments, a thought experiment's mental anticipation of nature's particular answer to the experimental question must include at least an inductive inference which exemplifies a nomic or law-like connection in a particular concrete situation – that is, a connection which can be reproduced according to a certain rule, or, in other words, a law immanent to that situation.[11]

(5) As stated above, the meaning of the question put to nature is clarified in view of an experimental test which must be in principle reproducible, but this reproducibility can be only displayed *in a concrete case*. The importance of intuitive appeal and perspicuity in thought experiments depends on the fact that, like real, thought experiments explore the links which, *in concrete cases*, connect theoretical hypotheses to empirical reality. In both real experiments and empirical thought experiments, a theoretical hypothesis is applied to a particular case or example in order to argue for or against that hypothesis. This is why visualisation is so important, even in quantum physics.[12]

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8 Cf. Galilei 1632, 162, Engl. transl. pp. 135-136.

9 Cf. Poser 1984: 185; Buschlinger 1993: 42 and 65-67; Schlesinger 1996: 478; Genz 1999: 101-104.

10 Cf. Sexl and Urbantke 1975: 22. It is hard to see why Buschlinger – who, as we have just noted, considers this experiment in principle unrealisable – cites this work: cf. Buschlinger 1993: 63.

11 Cf., for more details, especially Buzzoni 2008, ch. 2, §§ 2 and 6.

12 Cf., for more details, Buzzoni 2008, ch. 2, § 2.

These resemblances are not accidental. In the positive (empirical and logical-formal) sense, experiments and thought experiments must be identical. They coincide completely, as do the hundred real dollars and the hundred merely thought ones in Kant. My conception of a hundred dollars remains the same whether I am in possession of that sum or not: *thought experiments anticipate a connection between objects which, when thought of as realised, makes the concepts of experiment and thought experiment coincide completely*. In a positive sense, every (empirical) thought experiment corresponds to a real one that satisfies the same conceptual characteristics, and vice versa: *simply to imagine that the experimental apparatus, counterfactually anticipated in a thought experiment, has really been constructed is sufficient to erase any difference between thought and real experiments*.

However, despite the perfect correspondence on a positive level between the intensions of the terms ‘experiment’ and ‘thought experiment’, there is also an obvious, if elusive, difference between them. While both types of experiments raise questions about nature and its laws, real experiments fix only the type, or *genus*, of the answer that will depend on a particular functioning of the experimental apparatus. Thought experiments, on the other hand, relying on previously accepted knowledge, also anticipate in thought what nature’s specific answer will be. *A thought experiment is both the project in thought of a real experiment that is in principle realisable, and the linguistic-discursive anticipation of nature’s specific answer to the question implicit in that real experiment*.

As earlier stated: simply imagining that the experimental apparatus, counterfactually anticipated in a thought experiment, has really been constructed is sufficient to erase any difference between thought and real experiments. This very ‘imagining’, this capacity of the mind to assume every real entity as a possible entity, underpins the difference in principle – a properly transcendental difference – between thought and real experiments. On a transcendental level, experiments and thought experiments are distinct in principle. This distinction cannot be suppressed, since it is the same distinction between the hypothetical-reflexive domain of the mind and reality (which can always only occur and develop in only one way).

If we neglect the transcendental distinction between our capacity to put questions to nature on the one hand, and the determinate empirical knowledge obtained by means of our body’s interaction with the surrounding empirical reality on the other, we end up by either mixing up or, on the contrary, juxtaposing the mental and the real dimensions of experiment.

From a comprehensively naturalistic point of view, real and thought experiments do wholly coincide. If there were no other point of view from which to understand them, experiments and thought experiments would coincide completely.

It may, indeed, be objected that no one has ever reached such a conclusion. Certainly, no one can deny the difference between the mental and the real, between the idea, as such, of a chair and an individual, real chair: we all know that we can sit on the latter but not on the former. Oblivious of its transcendental basis, however, comprehensive naturalists treat this distinction as one between different, fixed logical entities – for example, as a distinction between analytic and synthetic judgements, with which thought experiments and real ones are respectively linked. In other words, naturalism can conceive of thinking and acting as complementary only as parts or entities that exist in the way in which sensible reality does. This is why naturalistic accounts of the distinction between real and thought experiments oscillates between the Scylla of the latter’s derivation by abstraction from the former, and the Charybdis of a supposed autonomy of thought experiments, usually secured by assimilating them to logical-formal procedures. If we neglect the transcendental distinction between our capacity to put questions to nature on the one hand, and the determinate empirical knowledge obtained by means of our body's interaction with the surrounding empirical reality on the other, we end up by either mixing up or, on the contrary, juxtaposing the mental and the real dimensions of experiment.

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Like the intensions of the concepts of a hundred imaginary and a hundred real dollars, experiments and thought experiments are, from different points of view, both identical and different. They are empirically identical, since thought experiments have the same distinctive characteristics as real ones – *apart from the fact that they anticipate an answer on the basis of knowledge or skills widely accepted or easily available within a certain scientific community*. However, just herein lies the irreducible difference between the two types of experiments: it is impossible to deny, without performative contradiction, the mind's ability to detach itself critically from any reality, and to picture it as a mere future possibility or (which is the same thing) as a mere future meaning.

This irriducibility of the transcendental-reflexive distinction between real and thought experiments, however, is the most profound root of their indissoluble connection from the technical-operationalist perspective here defended. First of all, consider the connection between experiments and thought experiments on the transcendental level. In this case, we need to hold fast both to their mutual irreducibility, and to their in principle necessary connection. They are irreducible to one another because the activity of using hypotheses and anticipations (to which also the empirical use of our intellect is connected) is, *as such*, irreducible to physical reality. However, the two types of experiments are also connected, not because there is no distinction between them, but because the transcendental and the empirical aspects necessarily presuppose each other: a thought experiment would be devoid of *empirical meaning* (that is, it would not be a thought experiment proper to empirical science) if, in formulating and evaluating it, in principle an at least implicit reference to a real experiment were not assumed. Kant's example makes the point: thought dollars, like thought experiments, exist only in the sphere of the possible, while real dollars, like real experiments, occupy a specific place among the interactions between our bodies and the surrounding reality; neither the thought nor the real entities, however, could exist outside their mutual relationship.

The so-called 'given' of experience remains outside our cognitive horizon unless we put questions to nature – unless, that is, we subject the empirical data to the mediation of theory and hypothesis, and consider the possibility of the data being given or not. Each new word learnt by a child is an empirical example of this transcendental connection between, on the one hand, the purely hypothetical character of the mind and, on the other hand, the individual hypotheses that the mind develops and tests on the basis of experience. A child's utterance of the word 'dog' in front of the appropriate animal is the answer to a previous question about a certain object of experience, and presupposes the ability in general to problematise – that is, the ability to consider any datum as merely hypothetical. This is the only sense in which a child's behaviour is irreducible to the performance of a machine which we can programme to say 'dog' whenever it encounters one.

The reflexive-transcendental unity and distinction of real and thought experiments also excludes any positive difference (any difference, that is, other than the transcendental one just referred to) between the intensions of the concepts in question. Experience 'accompanies' (in the Kantian sense of the word) thought experiments from the beginning to the end. This is the ultimate reason why *all thought experiments must be thought of as translatable into real ones, and all real experiments as realisations of thought ones*. *Thought experiments are conceivable as preparing and anticipating real ones: they anticipate a connection between objects which, when thought of as realised, makes the concepts of experiment and thought experiment coincide completely*. What thought experiments have over and above real experiments is the mere (transcendental) fact that they exist in a purely hypothetical sphere; what real have over and above thought experiments is the mere (empirical-operational) fact that they overstep the sphere of the possible, in the experiment's real execution.

3. Idealisation and counterfactuals in real and thought experiments.

The distinction between the transcendental-reflexive, and the empirical or formal level of reasoning is also necessary to correctly evaluate the fact that the premises of thought experiments typically contain counterfactual assumptions.

According to several authors, the presence of counterfactual assumptions, typical of thought experiments, raises two problems: (1) it seems to constitute the main difference between thought experiments and real ones; (2) it seems to exclude empirical testability.

Both claims are to be rejected. First, real experiments too are unable to elude hypothetical or counterfactual assumptions. According to the dialectic of question and answer, it is impossible to conceive of a real experiment, or even to make the simplest observation, without assuming counterfactually a theoretical horizon that defines the meaning of a question put to nature. The simplest observation of the way reality is, presupposes that it might be otherwise; and thus presupposes the ultimate counterfactual assumption which provides the horizon of meaning of all understanding – namely, the transcendentally hypothetical character of the mind. Even a declarative sentence such as 'the sun shines' has a meaning only against the background of the possibility that the sun might not shine. This sentence expresses an empirical observation which is the answer to a cognitive question, to a hypothesis about the state of the sun; without this hypothesis, which normally remains in the background and is not made explicit, the observation that the sun shines would have no determinate meaning. I am able to perceive the redness of the rose that I am looking at right now, only because I can assume hypothetically the possibility that it might be any other colour, and then reject that possibility on the basis of my empirical perceptions, i.e., on the basis of the interaction between my eyes and that determinate aspect of the real thing which is its colour.

Second, counterfactual assumptions do not rule out the empirical testability of thought experiments. It was Weber who first clearly saw the intimate association between the foundation of our knowledge and counterfactual assumptions. Weber famously defied the traditional mistrust of 'what if' questions in history when he argued that, in order to understand the causal-probabilistic importance of an event such as the battle of Marathon for the development of Greek culture and Western civilisation, a historian must start by asking (explicitly or implicitly) what would have happened if the Persians had won rather than the Greeks. The historian must answer this question *by abstracting from what really happened and constructing an ideal, or possible, course of events*.

The decisive point of Weber's analysis of the famous Marathon battle example is the fact that the understanding of causal connections is not hindered, but indeed made possible, by the use of counterfactual conditionals. As Weber aptly puts it, '[i]n order to penetrate to the real causal interrelationships, *we construct unreal ones*.'[13]

Weber, however, defended the 'objectivity' of causal imputation by appealing to a nomological knowledge that we already possess, but gave no clear answer as to the basis for the legitimacy of this type of knowledge. How can we give empirical content to ideal entities that are the product of counterfactual assumptions? This difficulty can be expressed with relation to the model of experimental investigation based on the dialectic of question and answer: how can real experiments specify and determine the generic concept that forms the theoretical horizon of the experimental question, when they contain idealisations and counterfactual assumptions which, by definition, make use of unreal entities such as we could never encounter in real experience (like perfectly flat frictionless surfaces, inextensible pendulums etc.)? The presence of counterfactual assumptions in thought experiments prevents neither their realisation nor the possibility of obtaining concrete empirical information from them which extends our mastery of reality. On the contrary, counterfactual assumptions are the condition that makes it possible in principle for thought experiments to become real ones; they are the condition of the possibility of the production of increasingly good technical-practical realisations of thought experiments.

Counterfactual idealisations form the theoretical background against which we are able to detect empirical imperfections and deviations from the ideal type; the knowledge attained in this way makes it possible to translate the ideal model, technically and operationally, into technical and experimental apparatuses that *increasingly* approximate the ideal type. This binds thought experiments closely to real ones, since in both cases good idealisations, unlike bad ones, allow predictions that fit with what we can ascertain experimentally, and realise technically.

Idealisations that omit certain variables – and so lead to statements that are empirically 'false' from certain points of view – can have empirical meaning, if the technical-experimental, reproducible conditions under which specific omissions take place are clearly spelt out. Once this is done, it becomes clear that, from the epistemological point of view (that is, regardless of the personal abilities of those who apply the theory), idealisation, far from jeopardising the connection between truth and technical applicability, reaffirms it. The legitimacy of counterfactual idealisations depends on the possibility in principle, or on the actual existence, of an experimental apparatus that realises the same result of the thought experiment with a degree of approximation sufficient to attain certain goals.

It is irrelevant whether Galileo's refutation of Aristotle's theory of free fall was a mere thought experiment, or whether it was actually performed. In either case, Galileo ignored certain variables, such as the lack of friction with the medium, and all those qualities that, in Galileo's terminology, reside in the 'sensitive body', such as colour, smell, taste etc. *This serves the purpose both of circumscribing and simplifying the object of investigation (which as a result becomes somewhat idealised), and, especially, of making experiments in principle reproducible in a technical, and not only mental, sense*.

The counterfactual assumption of a perfectly smooth, frictionless surface constitutes a sort of zero coordinate; and with respect to this the fact that a metal block, when subjected to an impulse force, will stop after a certain distance, requires a causal explanation. Even though the surface is perfectly smooth according to the instruments at our disposal, it is perhaps not absolutely smooth: consequently, friction may be at least one of the causes of the end of the motion. The fact that, in the absence of friction, a body would continue to travel for ever is a thought experiment which,

[13] Weber 1906: 287, Engl. transl. pp 185-186.

because it is counterfactually assumed, makes friction a possible real cause: perhaps if we reduced friction, the body might cover a proportionally greater distance, and if we increased friction, the body might slow down and, above a certain value, even come to a halt.

We must now test these hypotheses. First, we must devise technical procedures to make the surface smoother; then, if we find out that the same body, to which the same impulse force is applied, covers a greater distance on a smoother surface, we will have reason to believe that we have discovered at least one of the causes of the phenomenon – that is, one of the conditions that make the phenomenon reproducible and controllable. In other words, one of the reasons for the claim that friction ‘causes’ a moving body to stop is that we can reduce friction, *concretely making* surfaces that increasingly approximate the ideal type of a frictionless surface, and note the corresponding reduction of the effect of friction.

When in a thought experiment it is claimed that a surface is perfectly smooth or that the arms of a balance are perfectly symmetrical, there is imagined an ideal entity which provides a rule, a norm or a criterion. Without this criterion, we would be unable even to *conceive of* the imperfections and empirical deviations that characterise *real* occurrences and situations; we would be unable to measure those empirical deviations, and to search for their causes; finally, we would be unable to realise technically increasingly smooth surfaces and increasingly symmetrical balance arms. In short, we would be unable to satisfy the technical-operational criterion, which is the distinctive feature of empirical sciences.

References

Arthur R. 1999: ‘On thought experiments as a priori science’, *International Studies in the Philosophy of Science*, 13: 215-229.

Atkinson D. 2003: ‘Experiments and Thought Experiments in Natural Science’, in M.C. Galavotti (ed.), *Observation and Experiment in the Natural and Social Sciences*, Kluwer, Dordrecht, pp. 209-225.

Atkinson D. and Peijnenburg J. 2004: ‘Galileo and prior philosophy’, *Studies in History and Philosophy of Science*, 35: 115-136.

Audretsch J. 1990: ‘Eine andere Wirklichkeit: Zur Struktur der Quantenmechanik und ihrer Interpretation’, in J. Audretsch and K. Mainzer (eds), *Wieviele Leben hat Schrödingers Katze?*, Wissenschaftsverlag, Mannheim/Wien/Zürich, pp. 16-61.

Brown J.R. 1991a: *Laboratory of the Mind: Thought Experiments in the Natural Sciences*, Routledge, London and New York.

Brown J.R. 1991b: ‘Thought Experiments: A Platonic Account’, in Horowitz and Massey (eds) 1991: 119-128.

Buschlinger W. 1993: *Denk-Kapriolen? Gedankenexperimente in Naturwissenschaften, Ethik und Philosophy of Mind*, Königshausen+Neumann, Würzburg.

Buzzoni M. 2008: *Thought Experiment in the Natural Sciences. An Operational and Reflexive-Trascendental Conception*, Königshausen+Neumann, Würzburg.

Drake S. 1973: ‘*Galileo’s Experimental Confirmation of Horizontal Inertia: Unpublished Manuscripts*’, *Isis*, 64: 291-305.

Drake S. 1974: ‘Galileo’s work on free fall in 1604’, *Physis*, 16: 309-322.

Drake S. 1978: *Galileo at Work: His Scientific Biography*, University of Chicago Press, Chicago.

Franklin A. 1989: ‘The Epistemology of Experiment’, in Gooding, Pinch and Schaffer (eds.) 1989: 437-460.

Galilei 1632: *Dialogo sopra i due Massimi Sistemi*, Florence, reprinted in *Le opere di Galileo Galilei*, Edizione Nazionale, Florence 1890-1909, vol. VII (quotations are from this edition), *Dialogue Concerning the Two Chief World Systems – Ptolemaic & Copernican*, transl. S. Drake, 2nd ed., University of California Press, Berkeley/Los Angeles/London, 1967.

Galilei G. 1638: *Discorsi e dimostrazioni matematiche intorno a due scienze nuove*, Leiden, reprinted in *Le opere di Galileo Galilei*, Edizione Nazionale, Florence, 1890-1909, vol. VIII (quotations are

from this edition); *Dialogues Concerning Two New Sciences*, transl. H. Crew and A. de Salvio, Dover Publications, New York, 1954.
Gendler T.S. 1998: 'Galileo and the Indispensability of Scientific Thought Experiment', *The British Journal for the Philosophy of Science*, 49: 397-424.
Gendler T.S. 2000: *Thought Experiment. On the Power and Limits of Imaginary Cases*, Garland, New York and London.
Genz H. 1999: *Gedanken-experimente*, Wiley-VCH, Weinheim.
Geymonat L. and Carugo A. 1960: 'I cosiddetti 'esperimenti mentali' nei *Discorsi* galileiani e i loro legami con la tecnica', in *Actes du II*[ème] *Symposium d'histoire des sciences* (Pisa-Florence, 16-18.6.1958), Paris, reprinted in M. Quaranta (ed.), *Per Galileo. Attualità del razionalismo*, Bertani, Verona, 1981, 79-98 (quotations are from this edition).
Gooding D., Pinch T.J., and Schaffer S. (eds) 1989: *The Uses of Experiment*. *Studies in the Natural Sciences*, Cambridge University Press, Cambridge.
Hacking, I.: 1983, *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*, Cambridge University Press, Cambridge.
Koertge N. 1977: 'Galileo and the Problem of Accidents', *Journal of the History of Ideas*, 38: 389-408.
Koyré A. 1939: *Études galiléennes*, Hermann, Paris.
Kühne U. 2005: *Die Methode des Gedankenexperiments*, Suhrkamp, Frankfurt a.M.
McAllister J. 1996: 'The Evidential Significance of Thought Experiments in Science', *Studies in History and Philosophy of Science*, 27: 233-250.
McAllister J. 2004: 'Thought Experiments and the Belief in Phenomena', *Philosophy of Science*, 71 (Proceedings of the Biennial Meeting of the Philosophy of Science Association, Milwaukee, Wisconsin), pp. 1164-1175.
McMullin E. 1985: 'Galilean Idealization', *Studies in History and Philosophy of Science*, 16: 247-273.
Naylor R. 1974: 'Galileo and the Problem of Free Fall', *British Journal of History of Sciences*, 7: 105-134.
Naylor R. 1976: 'Galileo: Real Experiment and Didactic Demonstration', *Isis*, 67: 398-419.
Naylor R. 1989: 'Galileo's Experimental Discourse', in Gooding, Pinch and Schaffer (eds) 1989: 117-134.
Norton J. 1996: 'Are Thought Experiments Just What You Thought?', *Canadian Journal of Philosophy,* 26: 333-366.
Palmieri P. 2003: 'Mental models in Galileo's early mathematization of nature', *Studies in History and Philosophy of Science*, 34: 229-264.
Palmieri P. 2005: '"Spuntar lo scoglio più duro": did Galileo ever think the most beautiful thought experiment in the history of science?', *Studies in History and Philosophy of Science*, 36: 223-240.
Poser H. 1984: 'Wovon handelt ein Gedankenexperiment?', in H.P. Poser and H.-W. Schütt (eds), *Ontologie und Wissenschaft. Philosophische und Wissenschaftstheoretische Untersuchungen zur Frage der Objektkonstitution*, Technische Universität Berlin, 19, pp. 181-198.
Prudovsky G. 1989: 'The Confirmation of the Superposition Principle: On the Role of a Constructive Thought Experiment in Galileo's *Discorsi*', *Studies in History and Philosophy of Science*, 20: 453-468.
Reiss J. 2002: 'Causal Inference in the Abstract or Seven Myths About Thought Experiment', www.lse.ac.uk/Depts/cpnss/pdf/pdfcaus/CTR%2003-02.pdf.
Schlesinger G.N. 1996: 'The Power of Thought Experiments', *Foundations of Physics*, 26: 467-482.
Schrödinger E. 1935: 'Die gegenwärtige Situation in der Quantenmechanik', *Die Naturwissenschaften*, 23: 807-812, 823-828 and 844-849.
Segre M. 1980: 'The Role of Experiment in Galileo's Physics', *Archive for History of Exact Sciences*, 23: 227-252.
Settle T. 1961: 'An Experiment in the History of Science', *Science*, 133: 19-23.
Settle T. 1975: 'On Normal and Extraordinary Science', *Vistas in Astronomy*, 17: 105-111.
Sexl R.U. and Urbantke H.K. 1975: *Gravitation und Kosmologie. Eine Einführung in die Allgemeine Relativitätstheorie*, Bibliographisches Institut, Zürich.
Sorensen Roy A. 1992: *Thought Experiments*, Oxford University Press, Oxford/New York.
Stäudner F. 1998: *Virtuelle Erfahrung. Eine Untersuchung über den Erkenntniswert von Gedankenexperimenten und Computersimulationen in den Naturwissenschaften*, Diss. Friedrich-Schiller-Universität, Erlangen.
Weber M. 1904: 'Die "Objektivität" sozialwissenschaftlicher und sozialpolitischer Erkenntnis', *Archiv für Sozialwissenschaft und Sozialpolitik*, 19: 22-87, reprinted in *Gesammelte Aufsätze zur Wissenschaftslehre*, Mohr, Tübingen, 1922; 2[nd] ed. 1951; 5[th] ed. 1982 (quotations are from this edition), pp. 146-214, '"Objectivity" in Social Science and Social Policy', in M. Weber, *The*

Methodology of the Social Sciences, transl. E.A. Schils and H.A. Finch, The Free Press, Glencoe, Illinois, 1949, pp. 50-112.

Weber M. 1906: 'Kritische Studien auf dem Gebiet der kulturwissenschaftlichen Logik', *Archiv für Sozialwissenschaft und Sozialpolitik*, 22: 143-207, reprinted in *Gesammelte Aufsätze zur Wissenschaftslehre*, Mohr, Tübingen, 1922; 2nd ed.., 1951; 5th ed. 1982 (quotations are from this edition), pp. 215-290, 'Critical Studies in the Logic of the Cultural Sciences', in M. Weber, *The Methodology of the Social Sciences*, transl. E.A. Schils and H.A. Finch, The Free Press, Glencoe, Illinois, 1949, pp. 113-188.

Wittgenstein, L. 1953: *Philosophische Untersuchungen – Philosophical Investigations*, Blackwell, Oxford, 1992 (reprint of English text) (quotations are from this edition).

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