The Emergence of the Notion of Thought Experiments

Sophie Roux

The Emergence of the Notion of Thought Experiments[1]

Sophie Roux

(Université de Grenoble / Institut universitaire de France)

In Internet forums for model makers, one sometimes finds discussion threads entitled "Luftwaffe 1946". Participants in this scenario imagine that World War II did not end in 1945, but continued into 1946, and that the German jets, which in 1944 or 1945 were only projects or prototypes, were operational. Given this scenario, they then describe the aerial combats that could have taken place between these planes and similar ones developed by the Allies as if they had actually taken place (the most gifted among the forum members accompany their posts with very spectacular computer-generated images). A minimum of historical realism is required: one cannot imagine, for example, a mutiny of the Soviet generals, who would eliminate Stalin and demand a separate armistice. We note that a scenario of this type is all the more credible when the person who imagines it has good knowledge of aerial warfare and the aeronautics industry. The last notable element is that the computer-generated images are the most convincing when they respect the tactical principles later developed during real conflicts, for example in the Korean War. Are these elements sufficient to make a scenario of this type a thought experiment?

This question would never have been asked fifty years ago. But during the last two decades of the 20th century, a wave of thought experiments hit all sorts of areas of knowledge; in particular philosophy. Highly imaginative examples, seemingly coming straight out of a B movie, flourished in contemporary philosophy: Searle's Chinese Room, Jackson's Mary and Dennet's Mary, Putman's Twin Earth, variations on the Brain-in-a-vat, Thomson's violinist, and sundry zombies are the best known of this zoo. Historians of science and philosophy saw no reason to stay on the sidelines, and claimed the title of thought experiment for almost any argument: Hobbes' and Locke's states of nature, Carneades' plank, Descartes' evil genius, Hume's hypotheses on the annihilation of gold or paper money, Theon and Dion, Molyneux's problem, Buridan's ass, Boyle's mechanical angel, Archytas' man standing at the edge of the universe, Condillac's statue, Zeno's paradox, Leibniz' mill, Gyges' ring, Huygens' boat, the

[1] I would like to thank Christoph Lehner for discussing the issue of Einstein's thought experiments with me, and Carla Rita Palmerino for her comments on a previous version of this paper.

ship of Theseus.[2] Entire books are now devoted to collecting philosophical thought experiments of this kind.[3] Last, but not least, the field of science fiction, not to the say the broader field of literary fiction, came to be seen in general as a repository of thought experiments.[4]

Along with this came debates and attempts of philosophical clarification. In one of his seminal papers, Thomas Kuhn pointed out the paradox of scientific thought experiments: since they rely exclusively on familiar data, how can they lead to new knowledge of nature?[5] It was only in the early 1990s that a systematic debate began concerning the epistemological status and cognitive functioning of thought experiments.[6] The first question was epistemological, to decide if, as James Robert Brown argued, thought experiments are glimpses in a Platonic world of eternal laws, or if instead they are arguments relying on previous experiences, as the empiricist John Norton argued.[7] Another related but nevertheless distinct question concerned the kind of knowledge involved in thought experiments: to say, like Norton, that thought experiments are arguments which may imply (and indeed implied for Norton) that there are only verbal inferences disguised in vivid and picturesque narratives. Against what could be called "the inferentialist position" of Norton, different non-inferentialist positions were formulated, according to which thought experiments cannot be reduced to arguments and inferences from one proposition to another, because they involve other cognitive mechanisms. Tamar Szabó Gendler explicitly defended an imaginarist position, but the non-inferentialism was already implied by the references to the notions of embodied knowledge (David Gooding) or mental models (Nancy Nernessian).[8]

As for Kathleen Wilkes, she cast doubts on the use of highly counterfactual thought experiments in ethics, most particularly concerning the questions of personal identity. An important point in her argument was the distinction between scientific and philosophical

---

[2] Ierodiakonou, "Ancient Thought Experiments," established a list of arguments that are now considered as thought experiments, although they were not conceived as such by ancient philosophers; the same could be done for other periods as well.

[3] Cohen, *Wittgenstein's Beetle*; Tittle, *What If…* .

[4] This trend can take inspiration from Ursula Le Guin, who analysed explicitly her own novel *The Left Hand of Darkness* as a thought experiment on gender; see Le Guin, "Introduction," 156; Le Guin "Is Gender Necessary?" 163-167.

[5] Kuhn, "Function for Thought Experiment," 241; Horowitz and Massey, *Thought-Experiments in Science*, 1.

[6] Horowitz and Massey, *Thought-Experiments in Science*; Sorensen, *Thought Experiments*, and Sorensen, "Thought Experiments and the Epistemology".

[7] Brown, *Laboratory*; Brown, "Platonic Account"; Brown, "Thought Experiments Transcend"; Norton, "Thought Experiments in Einstein"; Norton, "Are Thought Experiments"; Norton, "Why Thought Experiments". In their contribution to this volume, Goffi and Roux start from the weak thesis that thought experiments are arguments, to be distinguished from the strong Nortonian thesis that thought experiments are *only* arguments.

[8] Gooding, "What is Experimental"; Gendler, "Galileo"; Gendler, "Thought Experiments Rethought"; Nernessian, "In the Theoretician's Laboratory". In his contribution to this volume, Zeimbekis puts to the test the thesis that thought experiments are simulations.

thoughts experiments. According to her, scientific thought experiments describe adequately their background, deal with natural kinds, and rely on impossible assumptions that are not relevant for the conclusion, while philosophical thought experiments give an inadequate description of the background, deal with indeterminate notions, and rely on impossible assumptions that are directly relevant for the conclusion.[9] A debate on the eventual distinction between scientific and philosophical thought experiments was thus opened, the distinction being generally made in order to condemn speculative philosophical thought experiments.[10]

The purpose of this introduction is not to answer each of the questions that may have been asked these past twenty years. Most of these questions are touched upon or even answered in the contributions of this volume. Instead, it is to raise the curiosity of readers by asking them to step back from the trivial use of thought experiments that has now become the rule. The essays gathered in this book are not concerned with contemporary scientific thought experiments. However, it is in contemporary science that the notion of thought experiments was first developed; nowadays, scientific thought experiments are supposed to work, and thus to constitute the standard according to which thought experiments in other domains are judged. That is the reason why I shall begin by exploring the texts in which the origins of the scientific notion of thought experiments are usually said to be found. My general claim is simple: the emergence of the notion of thought experiments relies on a succession of misunderstandings and omissions. I shall then examine, in a more systematic perspective, the three characteristics of the broad category of thought experiments nowadays in circulation: thought experiments are counterfactual, they involve a concrete scenario and they have a well-delimited cognitive intention. My aim in exploring these characteristics is twofold. Firstly, it is to show that each of these characteristics, considered individually, may be taken in a more or less strict sense, and consequently to explain the proliferation of thought experiments. Secondly, it is to suggest that the recent debates on thought experiments might have arisen because these three characteristics are not easily conciliated when they are considered together. Finally, in a third and last section, the nine essays of this book will be presented.

1. The Confused Origins of the Scientific Notion of Thought Experiments

[9] Wilkes, *Real People*.
[10] Rescher, *What if?* In asking the question of how to distinguish thought experiments that work and thought experiments that do not work, Atkinson and Peijnenburg, "Thought Experiments Poor," initiated a salutary change. In his contribution to this volume, Engel discusses the possibility of philosophical thought experiments.

Depending on whether it is the term, the epistemological description, or the scientific practice of thought experiments that is considered, the origins of the notion of thought experiments are usually traced to Hans Christian Ørsted, to Ernst Mach, or to Albert Einstein. In this narrative, Ørsted created the term; Mach ennobled the notion by making it a specific scientific procedure; Einstein invented scientific thought experiments that continue to nourish our imagination. As often, these alleged origins are not proper explanations: it was only once ‘thought experiment’ prevailed as a catchword that we began reading Ørsted, Mach, and Einstein in this light. An examination of their works is nonetheless instructive to understand the misunderstandings and omissions on which the notion of thought experiments was constituted. The term ‘thought experiment’ is indeed to be found in Ørsted, but not in relation to a well-defined procedure; contrary to what is sometimes written, Mach never allowed for counterfactual thought experiments; lastly, Einstein certainly practised thought experimenting, but it was in scientific and epistemological circumstances so specific that it might be doubted if his practice might be an epistemological warrant for thought experiments in general.

1.1. Lichtenberg sometimes invoked the possibility of “experimenting with thoughts”, especially when reasoning on particular cases.[11] However, the first to use the term ‘thought experiment’ (*Gedankenexperiment*, *Gedankenversuch*) in a scientific context may have been Hans Christian Ørsted.[12] In his “First Introduction to General Physics” (1811), he defended, against the excessive speculations of the *Naturphilosophie*, the thesis that the natural sciences cannot dispense with experience, whether everyday experiences, observations, or scientific experiments.[13] However in that context he insists that there is a higher level of the experimental art that sets the mind into “creative activity” (§§ 16-17). This kind of activity manifests itself not only in the natural sciences, but in mathematics as well, in so far as mathematical objects may be engendered by the mind. It is at this point that thought experiments enter the scene. Allowing a point to move in order to draw a line, or using certain procedures of the differential and integral calculus would be ‘thought experiments’ that do not only show that something is in a certain way, but why it is in this way. According to Ørsted, a similar genetic method should be introduced in physics; on that occasion, he refers to Kant’s

[11] Schildknecht, *Philosophische Masken*, 147 sqq.; Kühne, *Gedankenexperiment*, 220-221.

[12] As was first pointed out by Witt-Hansen 1976; see further Kühne, *Gedankenexperiment*, 130-165; Cohnitz, “Ørsteds Gedankenexperiment”. Kühne, *Gedankenexperiment*, 151-161, examines as well some counterfactual situations that Ørsted calls “thought experiment” in his scientific writings.

[13] Ørsted, “Introduction,” 289, 292-293. The English edition that I am following here is actually a translation of the 1822 version of Ørsted’s essay, published in German in the *Gehlens Journal für Chemie und Physik*.

Metaphysical Foundations of Natural Science as the book that includes "the most beautiful examples of this kind of presentation".[14] The mention of Kant may indicate that thought experimentation would amount to constructing concepts in intuition. In any case, Ørsted in the end proposes to bring together mathematics and physics by presenting both as "a series of thought experiments".[15]

The next paragraphs (§§18-19), while continuing to speak of thought experiments, present nonetheless considerations of a totally different order.[16] Here, thought experiments are no longer tied to the genetic method that should be used to reform mathematics and physics, but are assimilated to conjectures made in the context of the hypothetico-deductive natural sciences, that begin with the assumption of a hypothesis, continue with the examination of its consequences, and end up in confrontation to actual experiments. Since we are not able to truly confirm a hypothesis by checking that all the consequences that can be deduced from it actually occur, Ørsted finally notes that a hypothesis can never be certain and describes some procedures that would increase its probability.[17]

It should be concluded that, for Ørsted, thought experiments are not a specific epistemological procedure: rather, they are in a more general fashion the workings of thought itself, in so far as it is able to move from one proposition to another. Indeed, the point in common between what Ørsted calls a thought experiment in mathematics (§§ 16-17) and a thought experiment in physics (§§ 18-19) seems to be that in each of them one is led to follow a certain train of thought when examining the consequences that follow, either from the construction of a mathematical object, or from the position of a hypothesis in physics. Thus, it seems difficult to say that there is a specific and well-delimited notion of thought experiments in Ørsted. As I shall now show, the situation improves a bit when we turn to Ernst Mach; he was indeed the first to construct explicitly a notion of thought experiment, but, I shall argue, it does not include counterfactuality.[18]

1.2. In *The Science of Mechanics* (1893), Mach discusses Stevin's necklace, still considered one of the canonical examples of thought experiments. Stevin's necklace has a

[14] Ørsted, "Introduction," 296-297.
[15] For tentative interpretations of these obscure lines, with references to the mathematics and philosophy of mathematics of the early 18th century, see Kühne, *Gedankenexperiment*, 138-147; Cohnitz "Ørsteds Gedankenexperiment".
[16] Kühne, Gedankenexperiment, 137-138, 147, notes as well this conceptual discontinuity.
[17] Ørsted, Introduction, 297-299. For latter versions of the same argument (1851), see Kühne, *Gedankenexperiment*, 149.
[18] There is no historical evidence that Mach read Ørsted's essay; nevertheless see Kühne, *Gedankenexperiment,* 166-167, 187-188. For alternative discussions of Mach, see Sorensen, *Thought Experiments*, 51-75; Kühne, Gedankenexperiment, 167-214.

well-delimited cognitive intention, to prove the law of the inclined plane, stating that the ratio between a weight and the force needed to balance this weight on a given inclined plane is equal to the ratio between the length and the height of this plane – that is to 1/sin*a*, *a* being the angle of inclination. As a thought experimenter, who wants to prove this law in his armchair, Stevin asks you to consider the following concrete scenario. You have a triangle whose sides are inclined planes of the same height and whose hypotenuse is parallel to the horizon, and you surround it with a necklace of identical and evenly spaced beads. When you ask yourself what the 'power' of one of the beads on an inclined plane is, that is, the vertical force needed to balance its weight, your reasoning is as follows: Mechanical perpetual motion being impossible, you know that the necklace is in equilibrium. You know that if you remove equal things from equal things, you have equal things; hence if you eliminate the part of the necklace that is under the inclined plane, the remaining parts on the top and the slope are still in equilibrium. But, by construction, the number of beads on a plane is proportional to its length. You finally conclude that the power of a bead on a plane is inversely proportional to the length of this plane.[19]

Commenting on this scenario, Mach asks the unavoidable question for an empiricist: how is it that its result seems to us more certain than the result of a real experiment or than the outcome of a deduction, and that there is a generality in it that goes beyond the particular set-up imagined? His answer is that a thought experiment taps into a store of instinctive knowledge and summons up beliefs from this store with respect to a specific problem:

> Everything which we observe imprints itself uncomprehended and unanalysed in our percepts and ideas, which then, in their turn, mimic the process of nature in their most general and most striking features. In these accumulated experiences we possess a treasure-store which is ever close at hand and of which only the smallest portion is embodied in clear articulate thought. The circumstance that it is far easier to resort to these experiences than it is to nature herself, and that they are, notwithstanding this, free, in the sense indicated, from all subjectivity, invests them with high value.[20]

The idea that mechanical science relies on an instinctive knowledge that we build up thanks to our common experience of the things of the world and owing to more elaborate practices involving our artificial machines, is a main idea in *The Science of Mechanics*.[21] What

[19] *De Beghinselen der Weeghconst* (1586), I, theor. 11, prop. 19, analysed in Mach, *Science*, 32-34. As for the term 'thought experiment', Mach introduces it somewhat belatedly: "It is not essential that the experiments should have been actually carried out, if the result is beyond doubt. As a matter of fact, Stevinus experiments mentally" (Mach, *Science*, 38). And this is no systematic use: he speaks as well of Stevin's "deduction" or "fiction" (ibid., 35, 601-602).
[20] Ibid., 36.
[21] Ibid., 1-5, 103.

differentiates this instinctive knowledge from scientific knowledge is that it is neither conscious nor reflected; the very use of the term "instinct" shows that Mach casts his reflections in an evolutionary framework where humans and animals only differ in degree, and where certain truths, for example the principle of causality, are acquired by "the development of the race".[22] Inasmuch as instinctive knowledge is unconscious and pre-reflected knowledge, it is, as it was, the spokesman of nature itself, "free of all subjectivity".[23] This in turn explains why it enjoys our exceptional confidence, even though it is subject to error.[24] But, as a good empiricist, Mach insists that we should not be compelled to create a new mysticism out of this instinctive knowledge: it does not come from sources other than past experiences.[25]

Mach's empiricism has serious consequences regarding thought experiments. When faced with Newton's bucket, Mach strictly marked off the epistemological limits of thought experiments. You may recall that Newton's bucket is supposed to prove the existence of absolute space: Inasmuch as rotation has real effects (when the water in the bucket begins to rotate with the bucket, it does not have any motion relative to the bucket, but the surface of the water becomes concave), it should be measured with respect to absolute space. Mach's objection, first expressed ironically — "try to fix Newton's bucket and rotate the heaven of fixed stars and then prove the absence of centrifugal forces" — is an epistemological objection. Facing an offspring of the Bucket worked out by Carl Neumann, who, unlike Newton, explicitly assumed that the rest of the universe disappeared, Mach criticises him for having made

> too free a use of intellectual experiment […]. When experimenting in thought it is permissible to modify *unimportant* circumstances in order to bring out new features in a given case; but it is not to be antecedently assumed that the universe is without influence on the phenomenon here is question.[26]

Newton's experiment is a real experiment indeed, but inferring from what happens to the bucket to the existence of an absolute space is clearly extending our principles beyond the boundaries of experience: Mach condemns such an extension as "meaningless"[27], and calls

[22] Mach, *Science*, 1, 581.
[23] This is linked to Mach's sensationalism that appears briefly in Mach, *Science*, 578-579, 611.
[24] Ibid., 34-36, 91-92, 94.
[25] Ibid., 27, 94. Kühne, *Gedankenexperiment*, 172-175 insists on the anti-metaphysical and anti-Kantian background of this assertion.
[26] Mach, *Science*, 340-341.
[27] Ibid., 279-280.

absolute space a “monstrous conception”: monstrous, precisely because it is created by the mind without the safeguard of experience.[28]

The nature, the function, and the domain of thought experiments are pretty clearly delimited in *The Science of Mechanics*. If we perform thought experiments, this does not imply that they are of a different nature than real experiments and that we resort to an extra-sensory faculty: they are performed because we have unanalysed real experiences stored in our memory at our disposal — today we would rather say that they constitute our ‘implicit’ or ‘tacit’ knowledge. As for the function of thought experiments, it is to trigger, through a specific scenario, a mental process that allows us to mobilise our instinctive knowledge in order to develop new explicit knowledge. Lastly, the domain of thought experiments seems consequently restricted to the domain of elementary mechanics, in which we can rely on previous experiments we have had with bodies, raising them, pushing them, pulling them, sliding them, rotating them in order to invent specific scenarios.

In *Knowledge and Error* (1905), which resumed a paper first published in the *Zeitschrift für physicalischen und chemischen Unterricht* (1896), Mach did not give up his empiricism, but extended the limits of experiments so far that they become almost as loose and indeterminate as in Ørsted’s *First Introduction to General Physics*. Here is how he actually introduces the notion:

> Besides physical experiments there are others that are extensively used at a higher intellectual level, namely thought experiments. The planner, the builder of castles in the air, the novelist, the author of social and technological utopias is experimenting with thoughts; so, too, is the hard-headed merchant, the serious inventor and the enquirer. All of them imagine conditions, and connect with them their expectations and surmise of certain consequences: they gain a thought experiment. However, while the former combine in fantasy certain conditions that never occur together in reality, or imagine these conditions accompanied by consequences that are not connected with them, the latter, whose ideas are good representations of the facts, will keep fairly close to reality in their thinking. Indeed, it is the more or less non-arbitrary representation of facts in our ideas that make thought experiments possible.[29]

According to this text, thought experiments in general result from a basic tendency of the mind to imagine conditions resulting from the combination of ideas with one another and to examine their consequences: this is what Mach called the mutual adaptation of thoughts. However, there is a species of thought experiments that deserves a special mention because it implies as well an adaptation of thoughts to facts, namely, thought experiments that unlike the

[28] Ibid., Preface to the 7th edition: xxviii.
[29] Mach, *Knowledge*, 136.

fanciful scenarios of dreamers and novelists, combine “ideas that are good representations of the facts”.[30] In that sense, true thought experiments are so to speak loaded with experience upstream. They also have connections with experience downstream. Two kinds of thought experiments are indeed distinguished by Mach: those very few that by themselves can be carried to a definite conclusion (as was the case with Stevin’s necklace) and those which, lacking a definite outcome, call for physical experiments.[31] In the latter case, thought experiments “precede and prepare” physical experiments; they are mental anticipations that help us conceive experiments properly and bring them into being.[32] According to Mach, these mental anticipations constitute the true *ars inveniendi* in the sciences, but it is only an *ars inveniendi*, and by no means an *ars demonstrandi*. For example, Galileo knew that speed increases in free fall and made a guess concerning this increase; this guess allowed him to design the proper experiment; if he had not performed the experiment, it would have remained a conjecture in want of a proof .[33] Hence, as in *The Science of Mechanics,* though via different paths, Mach tied up thought experiments and physical experiments in *Knowledge and Error*.

For a comprehensive outline it should finally be noted that this is in a sense counterbalanced by the end of the chapter, where Mach insisted on the method of continuous variation. His idea was if adaptation of thoughts to each other and to facts emerges from a biological need, science should help this adaptation by systematic procedures. The method of continuous variation, which consists in imagining how known facts would vary when one of the relevant parameters varies, as much as possible in a continuous manner, would be one of these procedures.[34] Inasmuch as this method is used in mathematics, Mach extended to mathematics the use of thought experiments; finally, he ended up blurring the outlines between experiments and deductive thought.[35] This should not surprise us: in so far as the notion of thought experiments promoted in *Knowledge and Error* is linked to the biological need of adaptation of thoughts and to the reflexive method of variation, it tends to lose all reference to specific set-ups and to be assimilated to general epistemological processes. Hence my conclusion on Mach’s notion of thought experiments is twofold. Firstly, in *Knowledge and Error*, there is a tendency, as was already the case in Ørsted’s *First*

[30] On the distinction between free fiction and non-arbitrary science, see as well p. 137: “Since the physicist always turns his thoughts towards reality, his activity differs from free fiction.”
[31] Mach, *Knowledge*, 136, 138, 142, 148. Stevin’s necklace is actually mentioned in the previous chapter as an example of mutual adaptation of thoughts (126).
[32] Ibid., 136, 138, 141, 148.
[33] Ibid., 142. This example is developed in Mach, *Science*, 158-163.
[34] Mach, *Knowledge*, 137-138, 149.
[35] Ibid., 144-146.

Introduction to General Physics, to dilute the notion of thought experiments in other more general epistemological processes. Secondly, in *The Science of Mechanics,* as in *Knowledge and Error*, Mach stressed that thought experiments are no substitute for physical experiments; they always presuppose well-established facts; in most cases, they simply offer hypothetical anticipations of physical experiments to come. According to Mach, highly counterfactual thought experiments are of no use in physics.

1.3. Every elementary textbook on thought experiments begins with or at least includes a catalogue of Einstein's famous thought experiments: Einstein's trains, Einstein's lift, Einstein's chase after a beam of light… However, Einstein himself did not use the term 'thought experiment' for what is now referred to as "Einstein's thought experiment": with variations from one text to the other, he spoke of "example", "argument", "analogy", "illustration", "idealised experiment" etc. He opened, for example, his special relativity paper of 1905 by focusing on the case of the electro-dynamic interaction between a magnet and a conductor in relative motions. This is the first example discussed in Norton's seminal paper on thought experiments in Einstein's works, but for Einstein himself, this was not a thought experiment, but an "example" of the principle of special relativity which he introduced at this point as a "conjecture".[36] As we will see and comment in some detail, in the popular book he wrote with Leopold Infeld, the law of inertia, the lift thought experiment, and an electrical circuit reduced to a point were called "idealised thought experiments".[37] And if we eventually jump to the end of Einstein's career, in his *Autobiographical Notes*, the mechanics of people who might know only a small part of the earth and who would not see any star at all is an "analogy" to let us understand Mach's critique of mechanics; his chasing a beam of light at the age of sixteen is a "paradox"; lastly, the so-called EPR thought experiment is a "reasoning".[38] The absence of the term 'thought experiment' cannot be explained by Einstein's ignorance: on the contrary, it is well known that Einstein read Mach's *Science of Mechanics* in his earlier years and that he drew inspiration from its discussions on relativity.[39]

[36] Norton, "Thought Experiments in Einstein," 135-136 and Einstein, "On the Electrodynamics," 140. Einstein and Infeld, *Evolution of Physics*, 125-128, makes clear that this example relies on a comparison between two well-known real experiments, the one by Ørsted and the other by Faraday. Hence, it is a thought experiment only in so far as we admit thought experiments with a weak counterfactuality (on weak, average, and strong counterfactuality, see more below).

[37] Einstein and Infeld, *Evolution of Physics*, 6-8, 144, 214.

[38] Einstein, *Autobiographical Notes*, 27, 49-51, 79-81. For the same conclusions and other examples, see Kühne, *Gedankenexperiment*, 227-228.

[39] Kühne, *Gedankenexperiment,* 234-236 assumes that Einstein could not ignore Mach's notion; for an account of Mach's and Einstein's relations, see Holton, "Mach, Einstein".

And if we look hard, we can even find a few scenarios that Einstein did indeed call 'thought experiments'.[40]

These facts may raise a doubt: if Einstein chose as a rule not to use the term 'thought experiment', even though he was perfectly familiar with it, we can wonder if this is a pertinent epistemological notion to analyse his works. And yet, beside the fact that this doubt would lead to a very drastic reduction in our use of the category of thought experiments, the Ørsted episode shows that we cannot let ourselves be guided by words alone. In this case, even if Einstein barely used the term 'thought experiment', he did employ specific methods of argumentation, which we can designate, in accordance with the now well-established usage, as thought experiments. In order for this to be totally legitimate, we must preliminary explain that as a rule he avoided the term 'thought experiment'. An episode from the first reception of the theory of relativity will allow me to answer this preliminary question.

In a popular presentation of relativity (1917), Einstein had introduced what are now called "the trains/embankments thought experiments", which he himself presented as "illustrations" to help his intended readership grasp the essentials of the theory of relativity without being obliged to cope with the mathematical apparatus of theoretical physics.[41] Philipp Lenard, in *Über Relativitätsprinzip, Äther, Gravitation* (1918), turned Einstein's arms against him by inventing his own scenarios intended to establish the counter-intuitive character of general relativity. If a train suddenly brakes near a church, he argued for example, objects in the train are thrown about; it would hurt the "plain common sense, that could also be called healthy" to attribute these effects to a change of motion of the nearby church. In a discussion with Lenard that occured at the congress of the *Gesellschaft Deutscher Naturforscher und Ärzte* in Bad Nauheim (1920), Einstein stressed that the criteria of intuitiveness (*Anschaulichkeit*) as understood by Lenard could not be used: physics is not intuitive, but conceptual; moreover, the Galilean episode shows that intuitiveness is historically variable. In particular, although he could have retracted by arguing that trains and embankments were only illustrations introduced in a popular book, he fully accepted their use and designated them as thought experiments:

> A thought experiment is an experiment that can be carried out in principle (*ein prinzipiell ausführbares Experiment*), even if not in fact (*faktisch*). It is used to give a clear view of a set of genuine experiments (*wirkliche Erfahrungen*), so as to draw the theoretical consequences of them. A thought experiment is

[40] Kühne, *Gedankenexperiment*, 236-244, examines them and holds that they are insufficiently well determined scenarios to give rise to experiments, or a strategy of mockery of objections that are insufficiently physically grounded.
[41] Einstein, "A Popular Account," 310 and 248 for the intended readership.

only forbidden if it is impossible to be carried out in principle (*prinzipiell unmöglich*).[42]

In this discussion at least, Einstein used the term 'thought experiment' in reference to his own tools of argumentation. We also find a plausible explanation why he did not use the term often. As we have said, Einstein knew *The Science of Mechanics* perfectly well, in particular the passages in which Mach, defending his own principle of relativity, declares that thought experiments not guided by past and future physical experiments are meaningless. Yet one of the most striking characteristics of Einstein's thought experiments, that he defended here, is that they are counterfactual. Of course, he noted that not just any counterfactuality will do, since a thought experiment must "be possible to carry out in principle". But he did not tell us — and I think because it is extremely difficult, not to say impossible — where the line runs between what can be carried out in principle and what cannot.[43] In other words, my conjecture is that Einstein generally avoided the term 'thought experiment' because he was aware that in introducing counterfactuality into physics, he set himself against Mach's legacy without having a clear procedure for distinguishing acceptable and inacceptable counterfactuality.

Now that the preliminary question of why Einstein avoided the term 'thought experiment' has been answered, I would like to go further by concentrating on one of the most famous Einsteinian thought experiments, the lift thought experiment. Of course the lift is not the only thought experiment created by Einstein, and Einstein was not the only physicist, who proposed thought experiments in those years. Just think, for instance, of the series of thought experiments linked to the interpretation of quantum mechanics that would peak in the EPR paradox, or of Heisenberg's microscope and Schrödinger's cat. A detailed discussion would be needed for each of them, if we wanted to grasp the epistemological function of each of them. But the discussion of the lift thought experiment will be sufficient to enlighten the counterfactuality of Einstein's thought experiments, and to relate it, in this case, to its epistemological context.

Einstein's lift is intended to defend the extension of this principle of special relativity to the case of accelerated motion, in other words, the equivalence of a homogeneous gravitational field with a uniformly accelerated frame of reference. It consists in imagining, in

[42] Einstein, "Lectures in Bad Nauheim," 354-355, my translation; as noted by the editors (109), the transcription of these discussions is incomplete. On the historical context of the Bad Nauheim encounter and Lenard's anti-Semitism, see idem, 101-113. On Lenard's subsequent positions on thought experiments in the context of his Aryan physics, see Kühne, *Gedankenexperiment*, 259-260.

[43] In his contribution to this volume, Virvidakis suggests that this line may be drawn following Kant's analysis of transcendental conditions of experience; but even if Einstein were a Kantian, the distinction between logical possibility and transcendental possibility would not help him to decide if a given experiment is likely to be carried out in principle.

an area devoid of gravity, a closed opaque box, which is pulled with a constant force, so that it has an accelerated motion. An observer inside this box feels a pressure in his legs and sees all the bodies in the box falling with the same acceleration. This observer, having consequently no way of distinguishing his situation from the situation of a man in a box at rest in a gravitational field, would have good reason to think that he is in a gravitational field. Some details differ in the various presentations of this thought experiment: in one of them, there are actually two physicists inside the box, who happen to be there because they were put to narcotic sleep; the box is an opaque chest or a great lift of a skyscraper much higher than any real one; the objects that fall in the box may be either unspecified objects or a handkerchief and a watch.[44]

It is in papers intended for a broader readership that this thought experiment was presented, while, as noted by Norton, in more scientific papers the argument appeared, so to speak, naked, without the thought experiment.[45] Hence, it cannot be doubted that, as Einstein's trains and embankments, Einstein's lift had an illustrative and didactic function. He resorted to it in popular writings, in which he avoided mathematical formalism as well as physical technicalities: it was a striking illustration that put its seal on a theory that was otherwise well established, without in and of itself being what establishes this theory. But while it has this illustrative and didactic function, it is not the only function it has. Based on the few explicit declarations from Einstein about his epistemology, we can in fact show that it also has a heuristic function: it guides us in the formulation of new principles and allows for the constitution of new forms of intuitiveness.

In the work, in which he is the most explicit regarding the status of his lift thought experiment, Einstein describes it as an "idealised experiment", similar to the one Galileo used to formulate the founding statement of modern physics, the law of inertia. In order to formulate this law, Galileo had suggested against intuitive conclusions based on immediate observations to contemplate a body moving forever with no friction nor any other external forces acting on it; in the same way, it would be legitimate to propose experiments in which lifts are pulled by immaterial beings in radical voids devoid of any gravitational field. The two texts — the text in which Einstein explained how Galileo invented the law of inertia and

[44] Einstein, "Present State of Gravitation," 208; idem, "A Popular Account," 318-320. Einstein and Infeld, *Evolution of Physics*, 214; the "idealised reader" is depicted in the Preface: "We had him making up for a complete lack of concrete knowledge of physics and mathematics by a great number of virtues" (n. p.).

[45] Norton, "Thought Experiments in Einstein," 138, referring to Einstein, "Influence of Gravitation," 379-380 and idem, "Tetrode and Sackur," 150.

the text in which he justified his own use of thought experiments — are quite coherent. According to them, "idealised experiments" present the following characteristics:

— they are "fantastic", they can neither be derived from experiment nor actually performed;
— they are consequently created "by thought" and even by "speculative thinking";
— they are however "consistent with observation" and lead to "a profound understanding of real experiments".[46]

In what follows, I will show that this description is consistent with what we know more generally about Einstein's epistemology, but that considering that the law of inertia and the lift fall under the same description irons out one decisive difference between them.[47]

The young Einstein was certainly an empiricist, as indicates his reaction to a letter in which his friend Michele Besso explained that in the theory of relativity speculation had revealed itself to be superior to empiricism (1918). In his answer, Einstein insisted that a theory "must be built upon generalisable facts", even adding that "no genuinely useful and profound theory has ever really been found purely speculatively". But what Einstein called "facts" in this letter might already be a surprise: the impossibility of *perpetuum mobile*, the law of inertia, the equivalence of heat and mechanical energy, the constancy of light velocity.[48] However, only gradually did he come to realise how much his own epistemology differed from classical empiricism, in particular because he thought that all concepts, even those apparently closest to experience, are not derived from experience, but freely chosen and constructed, provided that they are not in contradiction with experience.[49]

His position was adequately described in a letter to Solovine (1952). To make his epistemological position understood, Einstein made a diagram showing three levels: from top to bottom he showed the axioms (A); the statements deduced from them (S); the variety of immediate experiences (E). According to Einstein, the only logical connection is the connection between the As and the Ss: the two other relations — the relation of the Ss to the Es and the relation of the Es to the As — are qualified as "intuitive", "psychological", and "extra-logical".[50] We can thus understand the function of idealised experiments such as the

[46] Einstein and Infeld, *Evolution of Physics*, 214, 6-8. As I will explain in the next part of this introduction, the fact that Einstein described these thought experiments as idealised experiments led to confusion, that should, however, be avoided.
[47] Einstein's epistemology is extensively discussed in Einsteinian scholarship, in particular to determine whether it evolved or not, and whether Einstein should or should not be categorised as a realist. See in particular Holton 1970; Fine, *The Shaky Games*; Brown, *Laboratory*, 99-125. These issues do not need to be discussed here.
[48] Einstein to Michele Besso, 28 August 1918, in Einstein, *CPAE*, Vol. 8, 633; see further idem, 638.
[49] Einstein, *Autobiographical Notes*, 13, 19-21.
[50] Einstein to Solovine, 7 May 1952, in Einstein, *Letters*, 137-138.

lift thought experiment according to Einstein. They are devices that allow us not to attribute any form of necessity to the relationship between Es and As, but rather to heuristically guide the intuition, which, based on the variety of experiences and observations (Es), identifies the principles (As) that can be taken to be axioms in the deductive system of theoretical physics. Note moreover that the As are such general principles that, once we have grasped them, we are able to deal with counterfactual situations that we have never experienced. This is what is at issue with Einstein's lift: its goal is to go back from the experience we have of a gravitational field to the principles that allow us to imagine it in the framework of a new theoretical physics — here, laws of gravitation formulated for all coordinate systems, not only for inertial coordinate systems.

This function of thought experiments is decisive when a new principle theory is introduced, as was the case with the theory of relativity. Remember that Einstein considered the theory of relativity as a principle theory, not as a constructive theory. The difference between these two types of theories according to him is the following. Constructive theories build up a picture of more complex phenomena out of a simple theoretical hypothesis: for example the kinetic theory of gases builds the mechanical, thermal and diffusional processes out of the hypothesis of molecular motion. In contrast to this, the starting point of principle theories are "empirically observed general properties of natural phenomena, principles from which mathematical *formulae* are deduced of such kind that they apply to every case that presents itself: we recognise here the 'facts' of the letter to Besso, and, indeed, Einstein gave the example of the science of thermodynamics that starts from the fact that perpetual motion is impossible.[51] But a problem arises when phenomena are already subsumed under other principles: what kind of empirical reference can justify the change from one set of principles to the other? The lift thought experiment is a kind of justification, by constructing a simili-fact that makes us simili-experience the possibility of shifting from the old set of principles to the new set of principles. This explains the profound affinity between Galileo and Einstein: for both of them, thought experiments allow the introduction of new overarching principles of great comprehensiveness, different from those previously admitted. Considering their great comprehensiveness, these principles cannot be derived from or confirmed by real experiences; but it is possible to use thought experiences as guides for elaborating intuitions. In this respect, Einstein's lift seems the exact equivalent of Galileo's cabin, in which butterflies fly, fish swim and drops of water fall exactly in the same way whether the ship is, relative to the

[51] Einstein, "Time, Space and Gravitation," 213; Brown, *Laboratory*, 103-117, uses differently the distinction between the two types of theories.

earth, standing at rest or moving inertially. In both cases, there is a situation that can be interpreted according to two different frameworks.

Nonetheless, although Einstein assimilated his approach with that of Galileo, it seems inevitable to distinguish them. What triggers Galileo's cabin is the fact that we live two types of experiences which cannot be distinguished as experiences: the experience of being in the cabin of a ship that stands still, and the experience of being in the cabin of a ship sailing on a calm sea. It is because of these two types of experiences that the theoretical equivalence of being at rest and being in inertial motion is experientially convincing; and, of course, once we have established this equivalence, the reasoning can be extended to the earth. In contrast, despite the vivid details offered by Einstein, we have no occasion to compare experiences that would convince us that being in a gravitational field and being in Einstein's lift are equivalent; we have only *one* lived experience, the experience of being in what we call a gravitational field. Hence, Einstein's point cannot be that two distinct experiences should be seen as one single theoretical case, but on the contrary that one single experience can be interpreted according to two distinct theoretical frameworks. In this respect, it is not immaterial that the human beings in the lift are physicists, who not only live experiences, but formulate physical theories in a mathematical apparatus. To put this in a nutshell, Galileo's ship and Einstein's lift share many resemblances: both are associated with a radical change in the principles of mechanics; both are material set-ups designed for the transportation of things and living beings; both result in presenting two elements as equivalent. But the elements presented as equivalent are not the same: in the case of Galileo's ship, they are two experiences; in the case of Einstein's lift, they are two possible theoretical views (either a gravitational field or an accelerated frame of reference) of one and the same experience (being in a terrestrial lift). In other words, even though Einstein insisted that his approach is similar to Galileo's, his thought experiment has counterfactuality that has no equivalent in Galileo.[52] In this respect, Einstein's lift is exemplary enough to reveal a general characteristic of thought experiments, as we now understand them: not only do they have a well-determined cognitive intention and involve a concrete scenario, but also they are counterfactual. This third characteristic emerged in Einstein physics, and the intellectual authority he held allowed for the crystallisation and spreading of a category of thought experiments fashioned from these three characteristics. Now, I would like to examine this category in a more systematic fashion.

[52] That Galilean thought experiments are much more restricted in scope than sometimes described, is amply established in Palmerino's contribution to this volume.

2. The extensible category of thought experiments

As I have said earlier, if we try to determine what thought experiments are, we will most probably end up with the following three characteristics: they are counterfactual, they involve a concrete scenario, and they have a well-determined cognitive intention. Like any characterisation, this one raises two questions. Firstly, the question of its empirical coverage: does it truly include the cases usually described as thought experiments? And secondly, the question of its coherence: do its three characteristics not present certain tensions, if not contradictions as such? The first question has been regularly asked as a preliminary question, with the objective to indicate in advance the limits of a definition that would then be given.[53] I shall approach this question differently by showing that the category of thought experiments is more or less inclusive, depending on the leeway with which we take each of its characteristics. The second question, however, has never been asked. Therefore I would also like to suggest that bringing together these three characteristics, especially if some leeway in each of them is allowed, might lead to tensions.

2.1. Like the model-maker scenario that opens this introduction, as opposed to real experiments, a thought experiment does not have to take place in reality. We can reach its result merely by thinking: it is, as we say in philosophical parlance, counterfactual. It is in relation to this characteristic that we hear about spectacular thought experiments that deal with situations, which we believe were never carried out, or which may be altogether impossible to carry out. Between zero counterfactuality, which corresponds to reality, and maximal counterfactuality, which deals with metaphysical and logical impossibilities, it seems useful to distinguish among various degrees of counterfactuality at this point.[54] I would especially like to suggest that there is a distinction between weak, average and strong counterfactuality:

i) Weak counterfactuality concerns thought experiments that are physically possible and that could have been produced in reality considering human ability and technical means available at the time they were proposed. It just happens that they were not carried out, for example because their actual implementation appeared redundant

[53] See for example Kuhn, "Function for Thought Experiment," 241; Brown, "Platonic Account," 122; Nernessian, "In the Theoretician's Laboratory," 295.

[54] Albeit the distinction between weak and strong counterfactuality is broached in other words in Wilkes, *Real People,* 3; Brown, *Laboratory*, 36. Brown, however, does neither include Stevin's necklace nor Galileo's ship in his category of "merely imagined thought experiments".

regarding what the person proposing them accepted as common beliefs and shared knowledge; or too demanding in terms of time, money, and other resources, etc. Thus, there is no call to place a necklace of beads around an inclined plane to observe the law of the inclined plane; we do not need to build and take apart the ship of Theseus to grasp certain paradoxes tied to identity; it is unnecessary to lock yourself in a room and transcribe messages in Chinese to understand the objection advanced by Searle against the computationalists in the 1970s, and so on.[55]

ii) Average counterfactuality involves scenarios which not only did not happen, but which could not happen considering our beliefs concerning human capacity to intervene in the world. This is the case, for example, with Einstein's lift: we do not believe that we might construct a box in an outer space devoid of any gravitational field and impress a constant force on it. This scenario seems to deal not only with a contingently unrealised possibility, but also with a technical impossibility. Since our perception of what is technically possible changes over time, the demarcation between cases of weak counterfactuality and cases of average counterfactuality is relative. The Einstein-Podolsky-Rosen (EPR) argument nowadays is famous not only because it appeared in 1935 as a crucial argument to show that either quantum mechanics is complete, or we have to renounce the principle of separation, but also because, almost fifty years later, it was finally put to the test by Alain Aspect, Philippe Grangier and Gérard Rogier in a paper suggestively entitled "Experimental Realisation of Einstein-Podolsky-Rosen-Bohm *Gedankenexperiment*: A New Violation of Bell's Inequalities".

iii) Lastly, strong counterfactuality concerns cases that we judge impossible with respect to the laws of nature of our world or even to our metaphysical tenets. In the early 17th century, not only were the technical means to produce a physical void not available, but some natural philosophers thought that it was a metaphysical impossibility, with the argument that a void is nothing and that attributing existence to nothing amounts to a contradiction. A thought experiment involving a void for them was consequently a case of strong counterfactuality, and they could argue against it that it is of no use when the point is to identify the behaviour of bodies in our real world.[56]

---

[55] Thought experiments involving weak counterfactuality are examined in the Lautner´s contribution to this volume.
[56] In their contribution to this volume, Knuuttila and Kukkonen present the conceptualisation that some medieval commentators proposed of thought experiments beginning with impossible premises.

This distinction between three types of counterfactuality should be granted in principle. The only question is, how far do we want to extend weak counterfactuality. Perhaps because of a taste for the exotic, or to impress the layperson, contemporary literature usually highlights cases of strong counterfactuality.[57] Under these conditions, it is natural to counterbalance this trend and to recall that there are cases of weak counterfactuality. Consider however the following case of extrapolation: Galileo wanted to establish a law concerning bodies falling in a void, but he did not have the technical means to produce a void. He carried out experiments on bodies of various specific weights falling in mediums of greater or lesser resistance, observed that the inequality of the bodies´ speed decreases when the resistance of the medium decreases, and so concluded by means of a controlled extrapolation that in a medium of zero resistance – a vacuum – the speed inequality is zero.[58] Should we include this extrapolation among thought experiments? If we do so, all extrapolations and idealisations should be included in the category of thought experiments. Physical experiments concerning ideal bodies, devised by isolating the relevant parameters in thought, mean we might end up with a physics peopled solely with thought experiments.[59]

The following reflection may help us distinguish idealised experiments and thought experiments, even if the literature has conflated the two categories since Einstein. Thought experiments are performed "in the laboratory of the mind," as James Brown aptly said. Even if we do not concede to him that such a laboratory is closed to experience, his bit of metaphor is a good description of the fact that it is our thinking, which performs the experiment in thought experiments. By contrast, idealised experiments are experiments, which are in the first place performed out there in the real world, and only then integrated into our system of thoughts. This integration may indeed be described as an idealisation and it involves the introduction of some counterfactuality, but we cannot say that it is our thinking, which performs idealised experiments. Thus, a thought experiment is counterfactual because it is achieved in thought. Whereas introducing some counterfactuality in a real experiment does not make it necessarily a thought experiment.

2. 2. A demonstration in mathematics is carried out in thought, and is often based on counterfactual hypotheses, which do not correspond to what exists in our world. For example,

---

[57] Against this tendency, see Brown, "Thought Experiments Transcend," 25; Rescher, *What if?* 3-4.
[58] Galilei, *Two Sciences*, 75-76.
[59] The assimilation, not to say the confusion, between idealisation and thought experimenting is made in Koyré, "Le De Motu gravium de Galilée," 225; Koyré, "Pascal savant," 382-385; McAllister, "Evidential Significance," 245-268; McAllister, "Thought Experiments and the Belief," 1168-1170. Einstein's use of the term "idealised experiments" for thought experiments explains this confusion in part.

in the first book of *Principia mathematica*, Newton calculates the trajectory of bodies subjected to a law of attraction proportional to their distance, not that this law corresponds to anything real, but just because he enjoys developing the logical consequences of mathematical hypotheses.[60] But we certainly do not want to count this kind of mathematical counterfactual reasoning as thought experimenting; this would amount to seeing the whole of mathematics as resulting from thought experiments.[61] In order to exclude most mathematical reasoning from thought experiments, I need to avail myself to my second set of characteristics: unlike mathematical reasoning, thought experiments present vivid specific cases that may be called ‘scenarios’. This characteristic appears a bit anecdotal due to the fact that thought experiments are often associated with the names of their inventors, accompanied by those of their main protagonists, whether a person or an object (Leibniz’ mill, Thomson’s violinist, Stevin’s necklace, Schrödinger’s cat, Maxwell’s demon, Jackson’s Mary, Dennet’s Mary etc.). Indeed, we find some concrete scenarios in mathematics that have appellations of the same kind — the Infinite Monkey Theorem, Buffon’s needle problem, the Sleeping Beauty Paradox — but they do not represent mathematics as a whole, and it can be argued that they are only illustrations of abstract problems.

Thanks to these concrete scenarios, thought experiments have an attraction that we might call aesthetic and that may involve our imagination. They are, however, more like sketches than realistic paintings: we must strip them bare and isolate the significant details of the problem in question, so as to draw a conclusion that goes beyond the specific case described. For example, in the case of Galileo’s two falling bodies strapped together, it is significant that the strapped bodies are not animated bodies (a baby and her mother, a cat and a dog), since animated bodies have spontaneous motions that modify their fall. But it is not significant that the bodies are cannonballs or musket balls, made of lead or made of wood, raw materials or polished works of art. There is nothing specific to thought experiments here: this is the case with real experiments as well, where, to give exaggerated examples, the star sign of the experimenter or the mileage on the car she has left in the lab’s parking lot are not mentioned.

There is however a difference between experiments and thought experiments in one respect. In the reports of standardised experiments we find in today’s science, all details

[60] *Principia mathematica*, book I, proposition 44, problem 40.
[61] As I showed earlier in this introduction, this extension of thought experiments to mathematics was suggested by Ørsted, *Introduction*, 296-297, and Mach, *Knowledge*, 144-145. More recently, it was implied by Brown, *Laboratory*, 49-75. For the distinction between mathematics and physics in medieval thought experiments, see Grellard´s contribution to this volume.

mentioned are supposed to be significant with respect to the cognitive aim of the experiment. Thought experiments, on the other hand, include particulars that do not intervene in the outcome of the thought experiment itself, but which are mentioned in order to help us imagine the case. Hence, all the particulars involved in a thought experiment have not the same function: some of them are part of the argument itself, and some of them are just a way of making the argument psychologically convincing. For example, in one of the versions of Einstein's lift, the physicists are supposed to wake from narcotic sleep, during which they were presumably transported in the closed box where they observed bodies and exchanged theories.[62] One is tempted to say that this particular does not fundamentally change Einstein's thought experiment, but it helps us to imagine how it might be that two physicists can be found discussing gravitational fields in an opaque box.

This seemingly elementary distinction between particulars that are part of the argument and particulars that are only a psychological crutch for our deficient imagination may be associated with a thesis on how thought experiments work. Indeed, the status of the particulars involved in the scenario may change whether one does or does not adhere to the inferentialist conception of thought experiments. In the first case, these particulars are irrelevant to the outcome of the thought experiment, since thought experiments are just arguments disguised in a pleasant way. In the second case, they are indispensable for the thought experiment to take place: it is due to the particulars that we may imagine ourselves in the situation depicted by the thought experiment and finally conclude what its outcome may be. Thus there is nothing surprising about Norton saying that the narcotic sleep of the physicists in the lift is irrelevant to the generality of the conclusion, while Nernessian judges that it reinforces crucial aspects of the thought experiment.[63]

Just as I asked, how far we want to go with weak counterfactuality, it is now time to note that, if we include any counterfactual concrete scenarios in the category of thought experiments, all sorts of fiction should be counted as thought experiments. At least philosophical and scientific fiction, like the depiction of the state of nature in early modern political philosophies, Descartes' genesis, or Plato's cave, but also our initial computer-generated scenario, the fabulous peregrinations of Lucian of Samosata, the transformation of a caliph into a beggar in *The Arabian Nights*, the voyage of Gulliver to the land of the Yahoos, the variable gender of the inhabitants of the planet Winter in *The Left Hand of Darkness*, or

[62] Einstein, "Present State of Gravitation," 208. The example is given by Norton, "Thought Experiments in Einstein," 130.
[63] Ibid., 129; Nernessian, "In the Theoretician's Laboratory," 296.

the ecological and political themes emerging in *Dune*… These works of fiction indeed contain a good deal to think about, and, in certain cases, definitively have a speculative intention. Except if you beg the question by presupposing a difference between literary and non-literary thought experiments, you seem once again committed to include much more in thought experiments than you initially wished for. Hence the need for a final characteristic, namely that thought experiments are designed for framing a specific, preconceived thought goal, or that they have a well-determined cognitive intention.

2.3. In order to introduce this last characteristic, let us consider a well-known example coming from Bernard Williams' discussion with the Utilitarianist John Jamieson Carswell Smart.[64] Williams reproaches the fact that Carswell — and the Utilitarianists in general — set aside all questions arising from circumstances in which a moral agent can be found, and from the capacity of the moral agent to act effectively. He consequently depicts a situation of civil war, where a captain in a South American army makes Jim, a perfect stranger to the conflict, the offer to kill an Indian among a group of prisoners; if he does so, the other nineteen Indian prisoners will be freed; if he does not do it, they will all be shot. According to Williams, a genuine Utilitarianist will find it obvious that the stranger must accept the offer so as to save lives; but the way in which the Utilitarianist asks the question is problematic because it is disembodied; he does not put himself in the place of Jim. Through a vivid narrative, William invites his readers to identify themselves, at least temporarily, with Jim, and make his reactions their own; according to him, the readers who genuinely identify themselves with Jim will not easily adopt the Utilitarianist conclusion.

This thought experiment includes a counterfactual and concrete scenario that could very well figure in a novel written by Conrad. But obviously it is a thought experiment not only because of that, but also because Williams had a well-determined point concerning ethics. He wanted his readers to ask themselves not necessarily if it is possible to agree with the responses given by Utilitarianists, but if it is possible to be satisfied with the questions they ask. What confers the specificity to thought experiments when compared with any other fiction is that, just as crucial experiments are supposed to do, they clearly delimit a before and an after in what we know and what we think. Whether the point is about answering a question, raising a problem, testing a declaration by highlighting some paradoxes, or even giving proof of a previously unknown result, thought experiments have well-delimited

[64] Williams, *Utilitarianism*, 98-100. Williams' thought experiment is commented in Zeimbekis' essay.

cognitive intentions.[65] Thus, there is no absolute response to the question whether or not fiction should be included among thought experiments. It simply depends on the context in which it is inserted. Take, for example, Putnam's Brain-in-a-vat, or the Cartesian evil genius. These specific set-ups could be the beginning of literary fiction; insofar as they are inserted in argumentative contexts where well-delimited questions are asked, they are thought experiments.

To conclude this third characteristic, it should be noted that 'having a well-determined cognitive intention' is related to 'being an argument' without being identical with it. Just like thought experiments, arguments have well-delimited cognitive intentions, they clearly delimit a before and an after in our thinking, and they imply changes of beliefs. But it is a mistake to infer from the analogy between arguments and thought experiments to their identity. Similarly, it is a mistake to conclude from the terminal points of a process to the process itself. A belief can be expressed in a proposition; a change of beliefs can be seen as a transformation of one proposition into another; but the transformation itself does not necessarily result from propositions. Here again, it can be useful to think of real experiments. If I give up the belief that there is a butcher just around the corner for the belief that there is no butcher just around the corner, this change of beliefs may result from the fact that I have actually gone around the corner. This fact is not in itself propositional, even if, in explaining why I switch over to a new belief, I give the argument that I have actually gone around the corner. In other words, the well-determined cognitive intention of thought experiments is manifest in argumentative contexts, but to count the well-determined cognitive intention among the characteristics of thought experiments does not commit us to any position with regards to the inferentialist/non-inferentialist debate. On the contrary, it could easily be argued that thought experiments are necessary or simply useful because all that we know cannot be expressed as a chain of deductions.

I have explored the three characteristics of thought experiments. The benefit of this characterisation is twofold. Firstly, it easily succeeds in eliminating idealised experiments, mostly mathematical reasonings, and works of fiction not related to a well-determined cognitive intention. Of course, my point was not to eliminate for the sake of eliminating, but to make clear what criteria can either justify or invalidate the indefinite extension of the category of thought experiments that we have recently witnessed, and which undoubtedly has not yet come to an end. Secondly, this characterisation reveals that the category of thought

[65] In her essay in this volume Ierodiakonou shows that ancient thought experiments start with an assumption that opens two possibilities to be explored.

experiments is affected perhaps not exactly by contradictions, but at least by tensions. For example, if a thought experiment has a well-delimited cognitive intention, why worry about concrete details that obviously do not change anything in its result? If a thought experiment is counterfactual, how can it allow us to know anything about the world?

3. Nine historical and methodological perspectives on thought experiments

We can now understand why the category of thought experiment has been applied so wildly to different kinds of textual devices, and why some debates on thought experiments resembled a dialogue among deaf people. The crystallisation that Einstein and some other physicists of the 20th century brought about did not result in the constitution of a robust category; the protagonists of contemporary debates talked at cross purposes because they did not have the same characteristics of thought experiments in mind, or were not thinking of the same thought experiments. This does not mean that the category of thought experiment is not an interesting category: it is due to its boundaries are vague that it raises questions.

This book was consequently guided by the idea that, since we cannot forge a strict definition of thought experiments, we should somehow tame the contemporary wild usage of this category by analysing the textual devices that we now retroactively qualify as thought experiments. All the essays in this volume have therefore both a historical dimension, since they rely on thought experiments borrowed from various periods in the history of philosophy, and a methodological dimension, in which they seek to clarify how thought experiments work, what their limits are, and what their conceptualisation could be.

The book is organised in three parts. The first one is devoted to the question of how to define and use the notion of thought experiments in different historical contexts, with essays by Ierodiakonou, Lautner, and Grellard. Howsoever thought experiments may be defined, different methodological objections can be raised regarding their very possibility: the second part deals with such objections, with essays by Knuuttila and Kukonnen, Palmerino, and Virvidakis. Finally, the essays by Engel, Goffi and Roux, and Zeimbekis try to provide a description of the way thought experiments are supposed to work.

3.1. As we have already explained, many questions have been asked in modern literature concerning thought experiments proposed in contemporary philosophy and in contemporary science. Are they distinct and is it possible to give a common definition? Are they heuristic devices, specific arguments, and paradoxes? Are they comparable to real experiments? But equally imaginative thought experiments are already found in ancient and medieval texts. The essays in the first part, provided by Ierodiakonou, Lautner, and Grellard, pay tribute to these prime historical examples of thought experiments, and show that historical perspectives help answering contemporary questions and, conversely, that these questions favour a better understanding of these texts.

Ierodiakonou focuses on the first recorded thought experiment, namely the thought experiment of the man who stands at the edge of the universe extending his hand or his stick. First, she explores the different versions of this thought experiment in antiquity: confronting Archytas' original version of this thought experiment with its Hellenistic appropriations, she examines its variations and shows that different philosophical schools took advantage of it. As it turns out, it was used to show that the world is indefinite (Archytas, according to Simplicius), it was related to the doctrine of the plurality of the worlds (Lucretius), or it was meant to prove that there is an infinite void beyond the heavens of our world (the Stoics, according to Posidonius). Furthermore, Ierodiakonou provides, based on Archytas' thought experiment, a tentative characterisation of ancient thought experiments. All of them imply a hypothetical scenario that starts with an imaginary assumption. If this assumption is the contrary of what the thought experiment is supposed to prove, then the thought experiment is indeed a *reductio ad absurdum* argument; but this is not invariably the case. Neither is it relevant whether the initial assumption is possible or not. The distinctive characteristic of ancient thought experiments, concludes Ierodiakonou, is that the assumption they start with opens two different possibilities that one needs to investigate, while it is not at all clear from the start which of the two one should follow.

Ierodiakonou looks for a formal characterisation of ancient thought experiments in general. The conclusion of Lautner's essay states that thought experiments might be differentiated according to the domains of knowledge in which they are introduced. Starting with a definition of thought experiments slightly different from the characterisation suggested in this introduction, he focuses on thought experiments presented in the *De anima* Neoplatonic commentaries written in the 6th century. According to the Platonic legacy, the soul was above the natural entities, but these commentaries admitted that it can be considered as a cause and that it can consequently be studied through its effects. In this context, effects are activities of the soul, such as sense-perception, and the strategy is to study these activities in order to understand the cause, that is, the essence of the soul. Lautner's point is that, contrary to what they did in natural philosophy, the commentators here drew on everyday experiences, completely free of counter-intuitive elements. Hence, the experiences that they resorted to in studying the nature of the soul can be qualified as thought experiments only if a very weak form of counterfactuality is allowed. After a detailed study of the commentators' treatment of the question, raised in *De anima* III 2, of what is responsible for the fact that we can perceive that we perceive, Lautner concludes that domain-specific considerations might be useful to sort out different kinds of ancient thought experiments. Weakly counterfactual thought experiments were indeed used in psychology and in ethics (e.g. Carneades' plank), while strongly counterfactual thought experiments were invented in physics (e.g. Archytas' stick) and in metaphysics (e.g. Theon and Dion).

Grellard's paper is devoted to what may be the golden age of thought experiments, namely medieval philosophy. As is well-known, medieval philosophers used their imagination to formulate hypotheses warranted by God's absolute power. In so far as they concern unobservable phenomena and as they imply a conceptual exploration, these hypotheses qualify as thought experiments. Grellard more precisely focuses on thought experiments that Henry of Harclay formulated in the 14th century in order to establish the existence of atoms, i.e. the existence of entities without extensions, which are the ultimate constituents of a body. The first thought experiment involves a sphere moving continuously on a plane, the second one relies on God's ability to see all the points in a line. Grellard then examines the arguments that Adam Wodeham, William of Alnwick, John Buridan, and Nicholas Oresme, who did not believe in the existence of atoms, opposed to these two thought experiments. Their arguments were twofold. On the one hand, in order to refute these thought experiments, they exhibited their logical flaws and questioned their physical plausibility. On the other hand, in order to limit their scope, they argued that they should be considered as abstract mathematical reasonings, which do not pertain to physical realities. What is revealed by the practice of thought experimenting in medieval debates on atomism, Grellard concludes, is the problem of articulating natural philosophy and mathematics.

3.2. Whatever thought experiments are considered, objections can be raised about their very possibility. Since all thought experiments begin with counterfactual suppositions, and sometimes with impossible hypotheses, the first question is what kind of conceptualisation can account for such a process. We should also wonder if counterfactual considerations can teach us anything about our actual real world. Lastly, the question of tracing the borders between legitimate and illegitimate thought experiments and of explaining the plausibility of certain thought experiments is raised. In the second part of the book, the essays by Knuuttila and Kukkonen, Palmerino and Virvidakis address those three methodological questions from a historical perspective.

Knuuttila and Kukkonen's essay deals with an important question for the methodology of thought experiments, namely the question of the kind of conceptualisation that can be given of thought experiments starting with impossible premises. Their starting point is the fact that, in Aristotle's reductive proofs, there are many arguments with premises that involve hypotheses in contradiction with principles elsewhere described as necessary. However, Aristotle never fully explained the status of these impossible premises, except when noting that impossibilities can be assumed to be possible in some sense. The problem has already been discussed in antiquity, and likewise medieval commentators of the 12th and 13th centuries tried to find a solution. Averroes argued that the impossible premises are impossible *per accident,* but possible essentially or *per se*: they are false in our world, but the nature of things does not demand their falsity. Averroes' abstractionist approach of thought experiments was later expanded by Aquinas, who insisted that something which is possible for a thing as a member of a genus can be impossible for it as a member of a species, the same holding for a member of a species and an individuated being. Hence, Knuuttila and Kukkonen continue, Averroes and Aquinas developed an earlier conceptualisation of thought experiments alternative to the one that is famously illustrated by Buridan and Oresme. Namely, it is usually admitted that the conceptual background of medieval thought experiments was the new modal theory developed in the early 14th century, the reference to God's omnipotence, and the notion that possible worlds could include features quite divergent from ours. However, neither Averroes nor Aquinas relied on this conceptual background: Knuuttila and Kukkonen's conclusion is that their conceptualisation might have been closer to Aristotle's way of thinking.

Palmerino shows that many thought experiments presented in Galileo's works derived from medieval and Renaissance sources. However, she argues, this must not be read as a sign of continuity between medieval philosophy and early modern science: rather, Galileo used a traditional way of arguing in order to build up non-traditional conclusions. More precisely, she divides the medieval thought experiments that reappear in Galileo's works into two groups: those that concerned the actual physical world, and those that hinged on worlds which God, in his infinite potency, could have created. According to her, arguments of the first type (e.g. Buridan's arrow, or Albert of Saxony's stone, which falls through a tunnel passing by the centre of the earth), served Galileo to show that medieval natural philosophers had detected some major inconsistencies in Aristotle's physics, but had not understood the disruptive implications of their critique. Arguments of the second type (concerning for example the centre of the universe or the possibility of a void) were instead used to show that what medieval authors had imagined to happen in alternative worlds could actually be the case in our own world. But, Palmerino concludes, Galileo explicitly rejected thought experiments that appealed to divine omnipotence; according to him, nothing meaningful can be said about a situation, in which the laws of physics are violated and the only way to reason about imaginary scenarios is to explain them in conformity with the ordinary course of nature.

Just like Knuuttila and Kukkonen, Virvidakis makes use of the history of philosophy to understand the methodology of thought experiments. Indeed, he takes on the challenge formulated by Brown to provide us with a fully-fledged Kantian account of thought experiments that would constitute an alternative to the existing empiricist and Platonic accounts of thought experiments.[66] However, Virvidakis´ discussion aims not so much at providing this alternative than rather suggesting that Kant's transcendental perspective indicates general criteria for the evaluation of thought experiments. Virvidakis first examines Kant's objections to thought experiments proposed by pre-critical thinkers: the problem with Descartes, Leibniz and Hume is [in his opinion] that they ignore the epistemic conditions of our mental faculties; in particular, they are not able to distinguish conceivability or imaginability and real possibility. Furthermore, Virvidakis shows that Kant's transcendental enterprise is guided by questions about the possibility of experience, and by the analysis of modalities. As a conclusion, he extends the Kantian lesson to all thought experiments, regardless of the area and topics dealt with: in order to know which thought experiments we should trust, we should distinguish between logical possibility concerning *entia rationis*, and real or transcendental possibility, which is essential for reaching conclusions about the world as it appears to us.

3.3. Finally, the last section tries to provide a description of the way thought experiments work. Of course, such a description of the functioning of thought experiments depends on where we draw the lines between thought experiments and other cognitive procedures, and this in turn may depend on the kind of thought experiments that are considered. The essays by Engel, Goffi and Roux, and finally Zeimbekis do not actually focus on the same aspects of thought experiments, or, once again, on the same thought experiments; Engel focuses on the modal claims involved in thought experiments; Goffi and Roux consider thought experiments in so far as they are arguments; Zeimbekis investigates the viability of a simulationist account of thought experiments.

[66] Brown, *Laboratory*, 156.

Drawing on classical examples of thought experiments (Lucretius' spear and Jackson's Mary), Engel suggests that every thought experiment involves a modal claim concerning the possibility of the situation described in the thought experiment and an epistemological claim concerning the knowledge we have of this situation. This leads him to review the existing epistemological conceptions of thought experiments: according to him, the debate cannot be settled unless the modal claims involved in them are clarified. It is at this point that he introduces the central thesis, recently advocated by Timothy Williamson about the Gettier cases, according to which the modal claims involved in philosophical thought experiments are just ordinary counterfactual reasonings. Engel agrees with Williamson's thesis and sees it as a way of eliminating two symmetrical opposite views about thought experiments: the ultra-rationalist view, according to which they appeal to *a priori* intuitions, and the ultra-empiricist view, according to which they appeal to empirical beliefs only. He also agrees with Williamson that Gettier's cases bear upon knowledge, not upon our concept of knowledge. However, contrary to Williamson, he argues that the existence of conflicting conceptions about knowledge entails that thought experiments are partly conceptual and partly metaphysical.

Like Virvidakis, but from an entirely different perspective, since their approach does not require the examination of transcendental conditions of experience, Goffi and Roux are interested in what makes some thought experiments work, while others do not work. They do not attempt to draw an *a priori* line between two types of thought experiments, but rather ask the following question: inasmuch as thought experiments are arguments, and notwithstanding the fact that some of them might involve the contemplation of an imaginary scenario, how is it that some of them work, while others do not? Taking inspiration from a counterfactual thought experiment presented by Nicholas Rescher, they treat thought experiments as argumentative procedures resembling tests of consistency, which invite the experimenter to seek the weakest link in her body of beliefs. Equipped with this method, they examine two well-known successful thought experiments (Galileo's two bodies strapped together, and Thomson's violinist) and discuss Mach's notion of thought experiments. Thus they reach the hypothesis that successful thought experiments respect the three following conditions: they do not deal with things, but with beliefs; they mobilise a set of beliefs shared by the interlocutors; and this set of beliefs has a hierarchical structure. Using once again examples written at different periods and taken from various disciplines (Descartes' receding bodies, Aristotle's weaving shuttles), Goffi and Roux argue that each of those conditions is individually necessary for a thought experiment to work. They finally conclude on the limits and consequences of their approach.

Finally, Zeimbekis tests a number of different simulationist conceptions of thought experiments, presented by Gendler, Nersessian, and Gaut. According to those accounts, in thought experiments the mind somehow simulates processes with which it reaches conclusions. Zeimbekis's argument relies on a clear-cut distinction between thought experiments dealing with physical situations, and thought experiments dealing with mental situations. In the first case, he argues, mostly against Gendler, that thought experiments cannot simulate physical processes, but rather use mental models. In the second case, he focuses on moral thought experiments; commenting on Williams' "Jim and the Indians"-thought experiment, he shows that Williams, when he described this concrete scenario for us to simulate it mentally, *de facto* favoured moral theories that are committed to an egocentric viewpoint. Hence, the scope of mental simulation in thought experiments is primarily limited by the constraint of relevant similarity on source and target processes: on one hand, this constraint disqualifies thought from simulating external natural processes; on the other hand, it is a source of epistemic bias in moral thought experiments. Zeimbekis consequently concludes that thought experiments and mental simulations cannot be assimilated as means of acquiring knowledge.

Bibliography

Atkinson, David and Jeanne Peijnenburg: “When Are Thought Experiments Poor Ones?”, *Journal for General Philosophy of Science*, 34 (2003), 305-322.

Brown, James Robert: *Laboratory of the Mind: Thought Experiments in the Natural Sciences* (London, 1991).

———. “Thought Experiments: a Platonic Account”, in *Thought Experiments in Science and Philosophy*, ed. Tamara Horowitz and Gerald J. Massey (Savage MD, 1991), 119-128.

———. “Why Thought Experiments Transcend Empiricism”, in *Contemporary Debates in the Philosophy of Science*, ed. Christopher Hitchcock (Oxford, 2004), 23-43.

Cohen, Martin: *Wittgenstein's Beetle and Other Classic Thought Experiments* (Oxford, 2005).

Cohnitz, Daniel: “Ørsteds 'Gedankenexperiment’: eine Kantianische Fundierung der Infinitesimalrechnung? Ein Beitrag zur Begriffsgeschichte von Gedankenexperiment und zur Mathematikgeschichte des frühen 19. Jahrhunderts*”, Kant-Studien* (2008) 99-4: 407–33.

Einstein, Albert: “On the Electrodynamics of Moving Bodies”, in *The Collected Papers of Albert* Einstein. Vol. 2: *The Swiss Years: Writings, 1900–1909*, ed. John Stachel, Robert Schulmann, David C. Cassidy and Jürgen Renn (Princeton, 1989), 140-171.

———. “On the Influence of Gravitation the Propagation of Light”, in *The Collected Papers of Albert Einstein. Vol. 3: The Swiss Years: Writings, 1909–1911*, ed. Martin Klein, A.J. Kox, Jürgen Renn and Robert Schulmann (Princeton, 1993), 379-87.

———. (1912) “On the Present State of the Problem of Gravitation”, in *The Collected Papers of Albert Einstein. Vol. 4: The Swiss Years: Writings, 1912–1914*. ed. Martin Klein, A.J. Kox, Jürgen Renn and Robert Schulmann (Princeton, 1995), 198-222.

———. “The Foundation of the General Theory of Relativity”, in *The Collected Papers of Albert Einstein. Vol. 6: The Berlin Years: Writings, 1914–1917*, ed. Martin Klein, A.J. Kox and Robert Schulmann (Princeton, 1996), 146-200.

———. “On the Theory of Tetrode and Sackur for the Entropy Constant”, in *The Collected Papers of Albert Einstein. Vol. 6: The Berlin Years: Writings, 1914–1917*, ed. Martin Klein, A. J. Kox and Robert Schulmann (Princeton, 1996), 121-131.

———. “On the Special and the General Theory of Relativity (A Popular Account)”, in *The Collected Papers of Albert Einstein. Vol. 6: The Berlin Years: Writings, 1914–1917*, ed. Martin Klein, A.J. Kox and Robert Schulmann (Princeton, 1996), 247-420.

———. “Time, Space and Gravitation”, in *The Collected Papers of Albert Einstein. Vol. 7: The Berlin Years: Writings, 1918–1921*, ed. Michel Janssen, Robert Schulmann, József Illy, Christoph Lehner and Diana Kormos Buchwald (Princeton, 2002), 213-215.

———. “Discussions of Lectures in Bad Nauheim” in *The Collected Papers of Albert Einstein. Vol. 7: The Berlin Years: Writings, 1918–1921*, ed. Michel Janssen, Robert

Schulmann, József Illy, Christoph Lehner and Diana Kormos Buchwald (Princeton, 2002), 351-359.
———. *The Collected Papers of Albert Einstein. Vol. 8: The Berlin Years: Correspondence, 1914–1918 (Parts A and B)*, ed. Robert Schulmann, A. J. Kox, Michel Janssen and József Illy (Princeton, 1998).
———. *Letters to Solovine*, transl. Wade Baskin (New York 1987)
———. *Autobiographical Notes: A Centennial Edition*, trans. and ed. Paul Arthur Schilpp (La Salle, 1979), 1-94.
Einstein, Albert and Leopold Infeld: *The Evolution of Physics* (New York, 1961).
Fine, Arthur: *The Shaky Games: Einstein, Realism and the Quantum Theory* (Chicago, 1986).
Galilei, Galileo: *Two New Sciences,* ed. and tr. by Stillman Drake (Toronto, 1989).
Gendler, Tamar Szabó: "Galileo and the Indispensability of Scientific Thought Experiment", *The British Journal for the Philosophy of Science,* 49 (1998), 397-424.
Gendler, Tamar Szabó: "Thought Experiments Rethought — and Reperceived", *The British Journal for the Philosophy of Science*, 71 (2004), 1152–1163.
Gooding, David: "What is *Experimental* About Thought Experiments?", *PSA 1992*, vol. 2., ed. David Hull, Micky Forbes and Kathleen Okruhlik (East Lansing, 1993), 280-290.
Hitchcock, Christopher (ed.): *Contemporary Debates in the Philosophy of Science* (Oxford, 2004).
Holton, Gerald: "Mach, Einstein, and the Search for Reality", in *Ernst Mach. Physicist and Philosopher*, ed. Robert S. Cohen and Raymond J. Seeger (Dordrecht, 1970), 165-99.
Horowitz, Tamara and Gerald J. Massey (ed.): *Thought Experiments in Science and Philosophy* (Savage, MD, 1991).
Ierodiakonou, Katerina: "Ancient Thought Experiments: A First Approach", *Ancient Philosophy* 25 (2005), 125-141.
Koyré, Alexandre: "Le *De Motu gravium* de Galilée. De l'expérience imaginaire et de son abus", in *Études d'histoire de la pensée scientifique* (Paris, 1973), 224-271.
———. "Pascal savant", in *Études d'histoire de la pensée scientifique* (Paris, 1973), 362-389.
Kuhn, Thomas: "A Function for Thought Experiment", in *The Essential Tension* (Chicago, 1977), 240-265.
Kühne, Ulrich: *Die Methode des Gedankenexperiments* (Frankfurt, 2005).
Le Guin, Ursula K.: "Introduction to *The Left Hand of Darkness*", in *The Language of the Night: Essays on Fantasy and Science Fiction* (New York, 1979), 155-159.
———. "Is Gender Necessary?", in *The Language of the Night: Essays on Fantasy and Science Fiction* (New York, 1979), 161-169.
———. *The Language of the Night: Essays on Fantasy and Science Fiction* (New York, 1979).
McAllister, James: "The Evidential Significance of Thought Experiment in Science", *Studies*

in History and Philosophy of Science, 27 (1996), 233-50.

———. “Thought Experiments and the Belief in Phenomena”, *Philosophy of Science*, 71, (2004), 1164–1175.

Mach, Ernst: *The Science of Mechanics*, translation by Thomas J. McCormack (La Salle, IL, 1960)

———. *Knowledge and Error. Sketches on the Psychology of Enquiry*, translation by Thomas J. McCormack and Paul Foulkes (Dordrecht, 1976).

Nernessian, Nancy: “In the Theoretician’s Laboratory: Thought Experimenting as Mental Modeling”, *Proceedings of the Biennial Meeting of the Philosophy of Science Association*, (1992), II: 291-301.

Norton, John D.: “Thought Experiments in Einstein’s Work”, in *Thought Experiments in Science and Philosophy*, ed. Tamara Horowitz and Gerald J. Massey (Savage, MD, 1991), 129-148.

———. “Are Thought Experiments Just What You Thought?”, *Canadian Journal of Philosophy*, 26 (1996), 333-366.

———. “Why Thought Experiments Do Not Transcend Empiricism”, in *Contemporary Debates in the Philosophy of Science*, ed. Christopher Hitchcock (Oxford, 2004), 44-66.

Ørsted, Hans Christian: “First Introduction to General Physics”, in *Selected Scientific Works* (Princeton, [1811]1998), 282-309.

———. *Selected Scientific Works*, transl. and ed. by Karen Jelved, Andrew D. Jackson and Ole Knudsen with an introd. by Andrew D. Wilson (Princeton, 1998).

Rescher, Nicholas: *What if? Thought Experimentation in Philosophy* (New Brunswick, 2005).

Schildknecht, Christiane: *Philosophische Masken: Literarische Formen der Philosophie bei Platon, Descartes, Wolff und Lichtenberg* (Stuttgart,1990).

Sorensen, Roy: *Thought Experiments* (Oxford, 1992).

———. “Thought Experiments and the Epistemology of Laws”, *Canadian Journal of Philosophy*, 22-1 (1992), 15-44.

Tittle, Peg: *What If… Collected Thought Experiments in Philosophy* (New York, 2005).

Wilkes, Kathleen: *Real People: Personal Identity without Thought Experiments* (Oxford, 1988).

Williams, Bernard: “A Critique of Utilitarianism”, in *Utilitarianism. For and Against*,
John Jamieson Carswell Smart and Bernard Williams (Cambridge, 1973), 77-150.

Witt-Hansen, Johannes: “H.C. Ørsted, Immanuel Kant, and the Thought Experiment”, *Danish Yearbook of Philosophy* 13 (1976), 48–65.

Index