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CONSIDERATIONS ON SCIENTIFIC THOUGHT EXPERIMENTS

Maja Malec*

University of Ljubljana, Faculty of Arts
Ljubljana, Slovenia

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ABSTRACT

I provide some considerations on scientific thought experiments, focusing on their epistemic value. First, I outline the distinctive features of scientific thought experiments, provide some historical background and, as an illustration, describe two thought experiments: Galileo's on falling bodies and Stevin's on inclined plane. I take thought experiments in physics as an example from which more general conclusions can be drawn – about thought experiments in other natural sciences, but also in philosophy, mathematics, and other sciences. Further, I present Kuhn's epistemic puzzle as well as some proposed solutions. This closely relates to the question what kind of processes are involved in scientific thought experimenting. The satisfactory answer must consider scientific discoveries. I outline the mental model account as the most promising account since it best incorporates the findings of cognitive science. I conclude with two issues that the account needs to resolve and the role cognitive science can play in this.

KEY WORDS

philosophy of science, philosophy of physics, thought experiments, naturalism, mental model

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*Corresponding author, η: maja.malec@ff.uni-lj.si; +386 (1) 241 1102;
Faculty of Arts, Aškerčeva 2, SI-1000 Ljubljana

INTRODUCTION

Thought experiments are employed in very diverse areas. They play a central role in philosophy which is in big part an ‘armchair pursuit’, as Williamson aptly puts it. By this he refers to the fact that traditional methods of philosophy ‘consist of thinking, without any special interaction with the world beyond the chair, such as measurement, observation or experiment would typically involve’ [1; p.1]. However, thought experiments play a significant role in most empirical natural sciences as well. Physics, for example, includes an impressive number of them. Its birth in the 17th century is characterized by some ingenious thought experiments by Galileo, Newton and Leibniz (Galileo’s falling bodies, Newton’s bucket, and Leibniz’s space shift), Einstein relied heavily on them (e.g. chasing a light beam, elevator or moving train) in the creation of relativistic physics, and they were crucial in the development of quantum mechanics (e.g. Heisenberg’s gamma microscope, Schrödinger’s cat, and EPR experiment). We often encounter them in mathematics, sociology, political science and history, but also partly in art [2]. Some find them in everyday life as well. Nersessian, for example, posits that experimenting in thought is involved in such mundane cognitive tasks as figuring out whether a large sofa would fit through the door, or what the best route from one place to another would be [3]. Others even recognize their usefulness in therapy. Gendler, for instance, suggests that fear of flying can be overcome by repeatedly imagining oneself flying safely [4].

Given the diversity, it is impossible to provide an all-encompassing definition of a ‘thought experiment’. There are, however, certain common characteristics that all thought experiments share. Namely, conducting a thought experiment involves contemplating an imaginary scenario with the aim of acquiring a piece of information. Specifics then depend on the area in which the thought experiment is conducted. Most work has been done on thought experimenting in philosophy and natural science (esp. physics), and researchers mostly agree that the differences between them are not in kind, but in degree. Moreover, thought experimenting in social sciences seems closer to such activity in philosophy than in natural sciences, so a unified account is undoubtedly preferable. Thus, in this paper I take thought experimenting in physics as an example from which more general conclusions can be drawn – about such activity in other natural sciences, but also in philosophy, mathematics, and other sciences.

First, I will outline the distinctive characteristics of scientific thought experiments, provide some historical background and, as an illustration, describe two thought experiments: Galileo’s on falling bodies and Stevin’s on inclined plane. Further, I will present the epistemic puzzle, which was first formulated by Kuhn, as well as some proposed solutions. This closely relates to the question what kind of processes are involved in scientific thought experimenting. I will conclude by presenting the mental model account which is, in my opinion, the most promising account since it best incorporates the findings of cognitive science.

THE STRUCTURE OF SCIENTIFIC THOUGHT EXPERIMENTS

Conducting a scientific thought experiment involves contemplating an imaginary scenario with the aim of illustrating, supporting or refuting some scientific hypothesis or theory. One distinctive feature of thought experimenting is that one reasons about a particular set of circumstances in order to reach a conclusion which does not pertain only to the described situation, but it is applicable more generally. That is, the conclusion, derived from this particular situation, has repercussions for certain hypothesis or theory. In the case of physical thought experiments, a certain hypothesis or theory concerning physical phenomena is confirmed or disconfirmed. (In less spectacular cases, thought experiments serve as heuristic devices, providing a graphic illustration of a scientific theory.) Another distinctive feature of thought experimenting is that the means by which we reach a scenario is imagination – we more or less vividly imagine a certain situation – and not observation.

Thought experiments, as their name already indicates, are liken to actual experiments, the main difference being that the latter are not conducted in thought, but in the real world. In both cases, we are supposed to draw from a particular situation some general conclusion concerning the actual world. A major difference, however, is that actual experiments can fail to confirm our predictions, while it is not immediately clear how thought experiments can fail.

This is why P. Duhem objects to the justificatory use of thought experiments in physics. He argues that by invoking a 'fictitious experiment' a physicist 'is justifying a principle not by means of facts observed but by means of facts whose existence is predicted, and this prediction has no other foundation than the belief in the principle supported by alleged experiment'. This is a vicious circle, Duhem argues, and concludes that thought experiments cannot teach us anything about the world, at most they can suggest hypotheses which can be tested only indirectly after the whole theory is constructed and its consequences compared with an actual experiment [5; pp.202-205].

In general, Duhem considers physical theory as "a system of mathematical propositions, deduced from small number of principles, which aim to represent as simply, as completely, and as exactly as possible a set of experimental laws" [5; p.19]. As such, it is not explanatory, but descriptive, a logical construction of given physical phenomena. It is therefore not surprising that thought experiments as well as models in his account merely serve as illustrations of the theory, thus facilitating our understanding. They are not a means of discovery.

Certainly, Galileo, one of the founding fathers of modern physics, would disagree with Duhem's disregard for thought experiments. His falling bodies thought experiment results in a rejection of the Aristotelian theory that heavier bodies fall faster than lighter ones, but also in a new proposal that all bodies, regardless of their weight, fall with an equal speed. Concretely, Galileo imagines two stones of different weights being tied together and asks about the speed of their fall. Obviously, the heavier stone, which on its own falls faster than the lighter one, will now, tied to the latter, fall a bit slower, while the latter will now fall a bit faster due to the faster speed of the first. The speed of the fall of the two bodies tied together is therefore in between the speeds of the two bodies falling separately. However, the two bodies tied together form a unity as well and this new body is the heaviest of them all and it should therefore fall the fastest. Contradiction! The new body cannot fall with two different speeds at the same time, and Galileo argues that the only way out of this paradox is to posit that the speed by which a body falls is independent of its weight [6].

When we, together with Galileo, imagine the proposed scenario and let it run, the falsity of Aristotelian theory becomes immediately obvious to us, and we do not need to perform any actual experiment to make sure as Duhem would have it. His contemporary, E. Mach, who was first to systematically study scientific thought experiments, has a more favourable opinion of them. In general, thought experiments help to prepare actual experiments, but some deliver results so convincingly that they make an actual experiment redundant. Thought experiments, such as Galileo's, are crucial for scientific progress since they lead 'to enormous changes in our thinking and to an opening up of most important new paths of inquiry' [7; p.138]. He believes that their value resides in their ability to access unarticulated knowledge that we acquired in our previous contacts with the world: "Everything which we observe imprints itself uncomprehended and unanalysed in our precepts and ideas … 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" [8; p.28].

Mach describes this kind of knowledge as instinctive and points out that we feel at once that the result of a thought experiment is correct. The thought experiment he analyses is Stevin's inclined plane thought experiment by which he established the force needed to prevent an object to slide down a frictionless inclined plane. Stevin imagines an endless chain wrapped around a triangular prism with a horizontal base. There are two possibilities: the chain is in equilibrium or not. If it is not, then it must move continuously, thus constituting perpetual motion, which we immediately recognise as absurd. Therefore, the chain must be in equilibrium. Next, he imagines that the lower part of the chain, hanging over the prism, is cut off. Thus, only the links along the two diagonal planes remain, and clearly, the system is still in equilibrium. From this, Stevin infers that two bodies on two different inclined planes are in equilibrium if their weights are proportional to the lengths of the two planes. The description of the thought experiment is accompanied by two diagrams of the two main stages in the experiment – the prism with the endless chain wrapped around it and the prism with shortened chain – which adds to the persuasiveness of the experiment [8].

Stevin did not have to actually perform the experiment in order to confirm his finding. The thought experiment is persuasive enough to justify the conclusion. In fact, the experiment, which requires frictionless plane, could not be performed at all – a reminder that also real experiments rely not only on observation, but also on abstracting away certain conditions and on predicting what would the results in idealized circumstances be.

Now, it is difficult to be a sceptic about physical thought experiments since they clearly work – the history of physics is a proof of that. There are many examples of thought experiments by which physicists confirmed or disconfirmed a certain physical hypothesis or theory. The real puzzle occupying philosophers of science is rather whether one really acquires new knowledge of the real world by simply contemplating imaginary scenarios. If the answer is affirmative, then one needs to explain what kind of knowledge is so acquired and by what process in particular. And if it is negative, then one needs to explain why it seems to us that we learned something new and how this comes about.

THE EPISTEMIC PUZZLE

The formulation of the puzzle is due to Kuhn, who belongs to the next stage of systematic research of thought experiments from the 1950s through the 1970s, another important researchers from these stage being Popper and Koyré. He states it in the following way: "How, then, relying exclusively upon familiar data, can a thought experiment lead to new knowledge or to new understanding of nature?" [9; p.241].

As we have seen above, Duhem denies that thought experiments can be a source of knowledge and allows them only as a source of hypotheses, which are later, if incorporated in the theory, compared with observation. Mach, on the other hand, acknowledges their epistemic value – some thought experiments are crucial for scientific progress since they give access to unorganized, non-propositional knowledge that we previously acquired through experience. The acquired knowledge is therefore empirical knowledge of our physical world, which we actually already possessed, but was before a thought experiment unavailable in propositional form.

Kuhn himself views thought experiments in the context of scientific practice and recognizes their importance in times of scientific revolutions. They help scientists to recognize the limitations of the old paradigm and facilitate acceptance of the new. This is not a simple case of uncovering inconsistency in the scientist's conceptual apparatus. Kuhn points out that our concepts always come with physical implications, expectations about their use. Consequently, a certain concept can be in a perfect logical order and yet its use does not correctly reflect what the world is like. The function of thought experiments is to reveal such cases. The imagined situation explicitly presents already available, but not yet assimilated empirical information which the current scientific concept cannot capture. This shows that the conceptual apparatus does not fit all situations and it must be revised.

Kuhn solves the epistemic puzzle in such a way that thought experiments without any new empirical data teach us something new about our scientific concepts and their physical implications, and by this about the world itself. As Kuhn puts it, thought experiments can 'disclose nature's failure to confirm to previously held set of expectations', and second, 'they can suggest particular ways in which both expectation and theory must henceforth be revised' [9; p.261].

From 1990s onwards, the presented solutions were further developed, new ones were proposed, and research on scientific thought experimenting was enriched by forming closer relations with research on thought experimenting in other domains. One proposal is platonic rationalism defended by Brown [10]. He argues that there are some special cases of thought experiments which at the same time destroy an old theory and establish a new one; in other words, these experiments are simultaneously destructive and constructive. Such is, for example, Galileo's falling bodies thought experiment in which Aristotelian theory that heavier bodies fall faster is rejected and replaced by the theory that all bodies fall at the same speed. He calls them Platonic thought experiments since they afford us a direct insight into the abstract realm of universals. By grasping, or 'non-sensorily perceiving', relations between universals we acquire *a priori* knowledge of truths regarding the laws of nature, which are in his account necessitation relations between independently existing universals. In this he follows the Dretske-Tooley-Armstrong account of the laws of nature.

Brown argues that in conducting scientific thought experiments, we sometimes grasp the laws of nature *a priori*, solely by intuition. An opposite view, thoroughly empiricist in character, is defended by Norton [11]. According to him all knowledge about our world ultimately derives from experience, so Brown's interpretation of thought experiments as a source of *a priori* knowledge of the laws of nature must be rejected. He strenuously objects to intuition, or quasi-perceptual rational insight being a means by which we acquire knowledge since its working is utterly mysterious. On the other hand, thought experiments are not real experiments since they are only conducted in the head, and therefore cannot provide new empirical data either. This leaves only one option, namely, as Norton puts it, thought experiments 'can only reorganize or generalize what we already know about the physical world and make it explicit' [11; p.335]. Thought experiments thus provide new information about the physical world based on the rearrangement of old data. Moreover, he argues that thought experiments are nothing more than arguments which take us from our assumptions to the conclusion, namely to the outcome of the thought experiment. Now, if assumptions are only reorganized, then a thought experiment is a deductive argument, and if generalization is involved, then it is an inductive argument. Either way, thought experiments as epistemic devices are to be evaluated as arguments.

Brown and Norton propose diametrically opposed solutions to Kuhn's puzzle. They agree that thought experiments provide new empirical knowledge in the absence of any new empirical data, but draw different conclusions from this. Brown concludes that new data must come from some other source and that in a thought experiment we gain a rational insight into this source which is an abstract realm of universals and consequently of the laws of nature. Norton, on the other hand, concludes that new knowledge is elicited from old empirical data by deductive or inductive arguments.

Both solutions are quite unappealing. Norton's 'argument view' totally disregards the special nature of thought experiments. Why would we bother devising an imaginary scenario by dressing arguments up if a basic argument does the job? There must be some function that is particular to a thought experiment and that an argument cannot perform on its own. Moreover, a thought experiment is a twin of real experiment, and if the first is just a disguised argument, then so is the latter. Indeed, a real experiment can also be stated as an argument, but does this mean that it is nothing more than an argument? Surely not, but why would then be any different in the case of a thought experiment?

Brown's 'Platonistic view' fares even worse since the proposed epistemic method is unfamiliar and in need of explanation. Brown tries to strengthen his position by drawing parallels with Platonism in mathematics, but physics and mathematics differ significantly in character and aims. Mathematics is highly abstract, and while mathematical reasoning can provide predictions about nature, this is not its main purpose. On the other hand, providing such predictions is the main task of physics. Physical theory describes and explains the physical world, and it must be supported by observations and experiments. Why would then physical laws or the laws of nature, as Brown calls them, be about some mysterious universals inhabiting the Platonic, abstract realm? If it does not make much sense metaphysically, it makes even less sense epistemically. How do we come to know such laws directly? How does this special 'sense' work? It would be easier to claim that we discern them from the regularities that we observe in the physical world, but this option is unavailable to Brown. In Platonic thought experiments, the old theory is rejected and replaced by a new one without any new empirical information being provided, solely based on rational insight into abstract realm.

Brown and Norton both understood Kuhn's puzzle as wondering how new knowledge can be gained given that thought experiments are conducted entirely in one's head without any new empirical data being provided. However, besides knowledge, Kuhn also mentions a new understanding of nature, and his own solution is that thought experiments provide a better understanding of physical concepts and their applications to the physical world. If novelty is not limited to knowledge, the number of possible solutions increases. For example, Elgin [12] and Stuart [13] further explore the connection of thought experiments with understanding. One possibility is also Mach's suggestion that thought experiments provide access to non-propositional knowledge. This idea is further developed in the mental model account [14, 15]. Additionally, its proponents Nersessian and Miščević claim that thought experiments can also result in new experiences, concepts, beliefs, or abilities etc.

Another question that an epistemological account of scientific thought experiments must answer is what is involved in this experimenting, namely, what processes are involved. Norton denies that there is anything epistemically distinctive about it – we merely conduct ordinary deductive or inductive reasoning, we execute an argument. True, an argument is 'disguised in some vivid picturesque or narrative form', which gives it 'special rhetorical powers', but epistemically, it is irrelevant [16; p.1139]. Brown, on the other hand, posits intuition as a special faculty by which we access the abstract realm and acquire *a priori* knowledge of the laws of nature. However, he cannot plausibly explain how it works, and can only claim resemblance with mathematics where the use of intuition is quite established.

While it seems more plausible that thought experimenting is epistemically distinctive, as Brown claims, it is not very likely that we possess some special faculty reserved exclusively for this task. It is far more likely that we employ a set of various cognitive processes that primarily evolved in order to perform some more mundane tasks, and were only later adopted for this more sophisticated use. And because of this, I believe that scientific thought experimenting can be satisfactorily explained only if we turn to cognitive science and its findings for support.

One such example is the naturalistic version of the intuition based account. For example, Gendler claims that in scientific thought experimenting, due to focus on a specific scenario (and not on a general schema), quasi-sensory intuitions are evoked, which results in new beliefs on contingent features of the natural world [4]. Consequently, the distinctive feature of intuitions involved in scientific thought experimenting is not their subject matter – similarly as observations, they deal with the contingent features of the natural world – but the way in which we come to possess them – they are not the result of some explicit reasoning process that we are conscious of, but they appear immediately in our mind while contemplating an imaginary scenario.

In explaining the nature and functioning of intuitions as well as of the imagination which is at the core of thought experimenting, the naturalist account relies on the findings of cognitive science. One difficulty to be addressed is the evolutionary explanation of the capacity to intuit, which seems to cast doubts on the reliability of intuitions. Much work still needs to be done, and both could profit from this interaction.

MENTAL MODEL ACCOUNT

Another promising naturalistic account explains thought experimenting as a form of mental modelling [14, 15]. The mental model was first developed and used in cognitive science. Nersessian further developed the original idea, supplementing it with findings from cognitive science, concluding that the relevant form is a form of 'simulative model-based reasoning, where inferences are made through constructing and manipulating models, whether conceptual, physical or computational' [17; p.310, 18].

She bases her account upon the idea that mental modelling is a fundamental form of human reasoning, which can be inferred from numerous experimental findings. The notion of 'mental model' was first used by psychologist K. Craik in 1943. He posits that on many occasions people reason by conducting thought experiments on internal models of real phenomena and that each model is structurally, functionally or behaviourally analogous to the real phenomenon. His idea was popularized in the early 1980s. Today one can distinguish at least three independent research streams within cognitive science employing his idea. The first uses the term to explain the effects of semantic information in logical reasoning. The second uses it to explain empirical findings according to which people, when reasoning about a certain situation described to them, first built a representation of the structure of a situation as a basis for their reasoning. The third does not focus on representation in working memory as the first two, but rather on the long-term representation of knowledge. It attempts to explain experimental results showing that people use organized knowledge structures related to physical systems when trying to figure out manual control systems and devices [17].

Nersessian believes these empirical findings show that mental modelling is a fundamental form of human reasoning, and further supports this hypothesis with findings from research on mental imagery, mental spatial simulation, mental animation as well as embodied mental representation. In her opinion, the main ingredient of mental modelling is simulation, which was already pointed out by Craik. Today proponents of this view speculate that the capacity evolved as a means for simulating possible ways of manoeuvring within the physical environment and for solving problems affecting the survival. The ability to anticipate future events and possible outcomes of actions is undoubtedly highly adaptive and should be possessed by many animals. Human beings are different in that they can create mental models not only from perception, but also from description. Now, in scientific thought experimenting this ordinary capability is simply more refined and adapted to scientific problem-solving or , as Nersessian says, it is put "in service of creative reasoning about nature" [17; p.312].

In conducting a physical experiment, for example, a mental model of a certain physical situation is built, which complies with the constraints related to the representation of physical phenomena. They are determined by experience and current understanding; for instance, by explicit as well as implicit knowledge of the spatiotemporal relations, entities and processes involved, the causal structure and so forth. Such restrictions are causal coherence, spatial structure and mathematical consistency. And the function of stories and diagrams is not only ornamental, but it also conveys restrictions which are consequently incorporated in the model. This enables faster reasoning that often could not even be performed in a propositional form. In addition, epistemic access to the features of representations which are not available in propositional form explains why thought experimenting can lead to new discoveries about the world. Finally, its reliability is plausibly explained given that thought experimenting is based on the mundane cognitive capacity for mental modelling [17].

Nersessian concludes her paper by pointing out that the cognitive-scientific findings on which she bases her account relate to much simpler forms of reasoning than those used in scientific thought experimenting. Additionally, they are mostly about the use of mental models in working memory, but in thought experimenting also information from long-term memory is invoked. Therefore, the next step would be for cognitive scientists to investigate if her hypothesis can be experimentally supported [18].

I agree with Nersessian that research on embodied mental representations looks promising in explaining how stored, tacit information from long-term memory connects to the working memory representation, and that it should be further developed. In general, the functioning of the mind can only be understood in the context of its relationships to the physical body interacting with the world. The importance of embodied cognition for the mental model account of thought experiments is highlighted elsewhere [19].

In that paper, we also ask whether the mental model account can be successfully applied to thought experiments conducted in other domains. We focus on philosophical thought experiments, more specifically, on those by which we are trying to determine whether something is metaphysically possible or necessary. The most common such experiments elicit essentialist intuitions concerning the nature of things, which is not something that we easily glean from our everyday interactions with the world. Characteristically, in conducting such experiments, we do not rely so much on imagination, but on the capacity to conceive, which is more abstract and thus seems more detached from perception than from imagination. The question is whether in these cases the mental model account provides adequate explanation. This is pertinent because it is preferable to have one unified account, but also because within physics itself some experiments are very abstract, and it seems impossible that the proposed situations could be imagined. Such experiments are found in quantum mechanics and the theory of relativity [19].

Nersessian’s tentative answer is that the mental models represent demonstratively, but that this does not mean that vivid, picture-like or movie-like imagery is required. Research in neuropsychology shows that perceptual systems play an important role in imaginative thinking, which is also supported by evolutionary considerations. On the other hand, research also shows that internal representations are sketchier than external pictorial representations. Therefore, in some thought experiments, constructed models can be even more schematic and symbolic. This is the beginning, but further details must be provided in order for the answer to be satisfactory – a task for philosophers and cognitive scientists alike.

REFERENCES

[1] Williamson, T.: *The Philosophy of Philosophy.*
Blackwell Publishing Ltd, Oxford, 2007,
http://dx.doi.org/10.1002/9780470696675,

[2] Elgin, C.Z.: *Fiction as Thought Experiment*.
Perspectives on Science **22**(2), 221-241, 2014,
http://dx.doi.org/10.1162/POSC_a_00128,
[3] Nersessian, N.J.: *Thought Experimenting as Mental Modeling*.
Croatian Journal of Philosophy **7**(20), 125-161, 2007,
[4] Gendler, T.S.: *Thought Experiments Rethought – and Reperceived*.
In: Gendler, T.S.: *Intuition, Imagination, and Philosophical Methodology*. Oxford University Press, New York, 2010,
http://dx.doi.org/10.1093/acprof:oso/9780199589760.003.0003,
[5] Duhem, P.: *The Aim and Structure of Physical Theory*.
Translated by Wiener, P.P. Princeton University Press, Princeton, 1991,
[6] Galilei, G.: *Dialogues Concerning Two New Sciences*.
Translated by Crew, H.and de Salvio, A. Dover Publication Ltd, Dover, 1954,
[7] Mach, E.: *On Thought Experiments*.
In: Mach, E.: *Knowledge and Error: Sketches on the Psychology of Enquiry*. D. Reidel Publishing Company, Dordrecht & Boston, 1976,
http://dx.doi.org/10.1007/978-94-010-1428-1_11,
[8] Mach, E.: *The Science of Mechanics: A Critical and Historical Account of Its Development*.
The Open Court Publishing Co, Chicago & London, 1919,
[9] Kuhn, T.S.: *A Function for Thought Experiments*.
In: Kuhn, T.S.: *The Essential Tension: Selected Studies in Scientific Tradition and Change*. The Chicago University Press, Chicago & London, 1977,
[10] Brown, J.R.: *The Laboratory of the Mind: Thought Experiments in Natural Sciences*. 2nd edition.
Routledge, New York & London, 2011,
http://dx.doi.org/10.4324/9780203847794,
[11] Norton, J.D.: *Are Thought Experiments Just What You Thought?*
Canadian Journal of Philosophy **26**(3), 333-366, 1996,
http://dx.doi.org/10.1080/00455091.1996.10717457,
[12] Elgin, C.Z.: *Understanding: Art and Science*.
Synthese **95**(1), 13-28, 1993,
http://dx.doi.org/10.1007/BF01064665,
[13] Stuart, M.T.: *How Thought Experiments Increase Understanding*.
In: Brown, J.R.; Fehige, Y. and Stuart, M.T., eds.: *The Routledge Companion to Thought Experiments*. Routledge, London & New York, 2018,
[14] Nersessian, N.J.: *In the Theoretician's Laboratory: Thought Experimenting as Mental Modeling*.
Proceedings of the Biennial Meeting of the Philosophy of Science Association **2**, pp.291-301, 1992,
[15] Miščević, N.: *Mental Models and Thought Experiments*.
International Studies in the Philosophy of Science **6**(3), 215-226, 1992,
http://dx.doi.org/10.1080/02698599208573432,
[16] Norton, J.D.: *On Thought Experiements: Is There More to the Argument?*
Philosophy of Science **71**(5), 1139-1151, 2004,
http://dx.doi.org/10.1086/425238,
[17] Nersessian, N.J.: *Cognitive Science, Mental Modeling, and Thought Experiments*.
In: Brown, J.R.; Fehige, Y. and Stuart, M.T., eds.: *The Routledge Companion to Thought Experiments*. Routledge, London & New York, 2018,
[18] Nersessian, N.J.: *Creating Scientific Concepts*.
The MIT Press, Cambridge & London, 2008,
http://dx.doi.org/10.7551/mitpress/7967.001.0001,
[19] Malec, M. and Markič, O.: *Miščević on Intuitions and Thought Experiments*.
In: Borstner, B. and Gartner, S., eds.: *Thought Experiments between Nature and Society: A Festschrift for Nenad Miščević*. Cambridge Scholars Publishing, Newcastle upon Tyne, 2017.