The Work of Thought Experiments
Translating Abstract Concepts into Familiar Situations

Brenna Sobanski

Introduction

This paper has two aims: to examine the use of thought experiments in the popularization of physics, and to suggest what this use can tell us about the nature and importance of thought experiments in physics more broadly. I begin with some background on thought experiment scholarship, and provide a rationale for looking at the use of thought experiments in the popularization of physics. I argue that most of the work on thought experiments has been concerned with whether the knowledge we gain from them is justifiable. Instead of addressing their truth-value, I look at thought experiments in terms of what they do. I argue that their distinguishing feature is that they translate abstract concepts into relatable situations. If this is true, I propose that we should find thought experiments employed in the popularization of physics. The next section of the paper supports this point through an analysis of how thought experiments have been used in a range of 20th and 21st century popular physics books. Finally, I argue that the experiential element of thought experiments is absolutely central to their efficacy as tools of explanation, and I suggest that for scientists as well as lay people, thought experiments function as explanatory tools.

Background

Academic debate about thought experiments in science has been shaped by the work of James Brown and John Norton. Norton contends that thought experiments are essentially "picturesque arguments."[1] In his view all thought experiments can be translated into arguments consisting of a series of premises and some conclusions which follow logically from the premises. Furthermore, Norton argues that whatever insight thought experiments can provide is a direct result of their use of things the experimenter already knows, either explicitly or tacitly, about the world. Norton's point is that whatever we can usefully gain from thought experiments is a result of empirical knowledge about the world, which is incorporated into the thought experiment in the form of a premise. In sum, Norton thinks thought experiments are really just 'disguised' argumentation, and their utility rests in their use of empirical knowledge.[2]

On the opposite side of this debate is James Brown. He holds what is often referred to as a 'Platonic' interpretation of thought experiments.[34] Brown asserts that thought experiments can

[1] John Norton, "Why Thought Experiments do not Transcend Empiricism," in *Contemporary Debates in Philosophy of Science*, ed. Christopher Hitchcock (Blackwell Publishing, 2004), 64.
[2] Ibid., 45.
[3] Letitia Meynell, "Imagination and Insight: A New Account of the Content of Thought Experiments," in progress, 2013, 1.

sometimes reveal knowledge about nature *a priori*. His view is thus in direct contrast to Norton's focus on empiricism. For Brown, thought experiments tap into an intuitive element of human thinking that sometimes allows us to gain insight about the world that goes beyond what our direct experience can provide.

Both Brown's and Norton's analyses are focused on trying to establish how, and with what degree of validity, thought experiments can offer insight into the natural world. Norton refers to this as the "epistemological problem of thought experiments."[5] The more recent work of Meynell is also focused on this problem. She suggests that analyzing thought experiments as "Waltonian fictions," or "props for imagining fictional worlds," will allow us to "characterize their content and ultimately assess their epistemic function."[6] This epistemological problem is an important one. The question of how our thinking can reveal something about the natural world lies at the heart of the mystery and power of thought experiments as they are used in physics. Despite the importance of this problem, I propose to examine thought experiments from a different angle. Instead of questioning their validity, I examine thought experiments in terms of what they actually do for the thought-experimenter.

By what thought experiments *do*, I mean apart from presumably illuminating the science in some way, what does this fairly distinctive blend of thinking, imagination, and experiment that we call a thought experiment achieve for the thinker? What does a scientist gain from employing a thought experiment that she may not gain when approaching her questions in some other way? While Norton and Meynell both address this question to some degree, for them it is simply a preliminary analysis necessary to answer the real question of epistemology. In contrast, I propose an analysis of thought experiments that focuses primarily on a discussion of what they do.

Translating Abstract Ideas into Familiar Terms: The work of thought experiments

Norton argues that although thought experiments involve distinctive features such as narrative, ultimately this is unimportant to their essential character as arguments. Meynell takes issue with this stance and argues that we need to take seriously the narrative character of thought experiments. One of the difficulties with Norton's position is that it opens up the question of why anyone would bother to dress up their argument in the narrative form of a thought experiment. If a thought experiment is nothing more than an argument, why, especially in science writing where literary considerations are not a crucial component, would one create a thought experiment? In light of this objection, I follow Meynell's lead and view the narrative and experiential character of thought experiments as fundamental to their essence. A rigorous definition of thought experiments appears to be rather elusive, but there is general agreement that one of the distinguishing characteristics of thought experiments is their use of narrative and development of a fictional world.[7]

The narrative and fictional worlds that are so essential to thought experiments enable the experimenter to translate abstract ideas into familiar situations and experiences. This function can

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[4] James Robert Brown and Yiftach Fehige, "Thought Experiments," in *The Stanford Encyclopedia of Philosophy* (Fall 2011 Edition), ed. Edward N. Zalta. Accessed through http://plato.stanford.edu/archivesfall2011/entries/ thought-experiment/.

[5] Norton, "Why Thought Experiments do not Transcend Empiricism", 44.

[6] Meynell, "Imagination and Insight", 1; 2.

[7] Ibid.

be seen in numerous different thought experiments. One of the oldest surviving thought experiments centres on the question of whether the universe is finite. The universe is itself a rather abstract concept, and trying to determine its finitude is a situation very much removed from daily experience. Archytus of Tarentum, Lucretius, and Alexander of Aphrodisias all approach the question through use of a thought experiment involving either throwing a spear at the edge of the universe, or extending one's arm while standing at the edge of the universe.[8] The thought experiment takes an abstract concept and question and translates it into a sensory experience-based situation. This same translation from abstract concept to relatable experience is also achieved by more recent thought experiments. Einstein's theories of special and general relativity are associated with three famous thought experiments: riding or running beside a beam of light, the train thought experiments, and the elevator thought experiments. All three take the abstract concepts of space and time and their relationship to motion, and make them manifest in a concrete situation peopled with everyday objects such as trains, elevators, and clocks.

Of course, if the thought experiment only dealt with the familiar, there would be no need for it. Physics is generally not concerned with explaining our everyday experience in familiar terms. Thus elements of the thought experiment and its result are necessarily strange and unfamiliar. Thought experiments about the finitude of the universe therefore involve a person standing at the edge of the universe, and Einstein's train travels near the speed of light. My point is not that the abstract and unfamiliar is not present in thought experiments, but rather that it is incorporated into a familiar situation thereby making it more tangible and accessible.

Assuming this to be the case, thought experiments should be ideally suited to explaining science to non-scientists. The use of thought experiments in this context may also provide further insight into their nature and function. In the following section, I address the use of thought experiments in popular physics texts.

Thought Experiments in the Popularization of Physics

I examined nine books written between 1960 and 2013 popularizing either Einstein's theories of relativity, quantum mechanics, or both. Six of the books were written by physicists, two were written by professors with physics or engineering backgrounds but who are not practising physicists, and one was written by a non-physicist. The disciplinary distinctions seemed to have no effect on the authors' use of thought experiments.

The books could easily be divided into three categories based on their use of thought experiments. Five[9] of the nine books used thought experiments extensively. In some cases, this meant including numerous different thought experiments throughout the book, while in other cases the entire book was written as a sort of extended thought experiment. So, for example, Einstein's *Relativity: The Special and the General Theory* (1960) is in large part a continual encounter with versions of the train thought experiment. Two books[10] made moderate use of thought experiments. There was more or less an even mixture of other discussions and

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[8] Katerina Ierodiakonou, "Remarks on the History of an Ancient Thought Experiment," in *Experiments in Methodological and Historical Contexts*, eds. Ierodiakonou, Katrina, and Roux, Sophie (Leiden, Brill, 2011).

[9] These books were: Landau and Rumer (1960), Einstein (1961), Zukav (1979), Topper (2013), Fischer (2013).

[10] Gamow (1966), March (1970).

explanations, and thought experiments. Finally, there were two books[11] that made little use of thought experiments.

Based on this inventory, it is clear that thought experiments are an important element in the popularization of Einstein's relativity theories and quantum mechanics. This result matches the findings of Velentzas, Halkia, and Skordoulis (2007). They studied textbooks and popular physics books, finding that thought experiments were the primary, and often exclusive, means of introducing concepts from relativity and quantum physics.

Despite the fact that thought experiments appear to be a favoured tool in the popularization of physics, two of the books in this sample made very minimal use of them. Hawking's *A Brief History of Time* (1988) included a summary of Heisenberg's microscope thought experiment, but without referring to it as such, or setting it up using thought experiment-type narrative. Cooperstock and Tieu's *Einstein's Relativity* (2012) used three thought experiments, but they comprised only one small section of the book. I propose that the lack of thought experiments in these two books is a result of the difference between their goals and intended audiences, and the intended audience of the majority of the other books in the sample.

Hawking's book is aimed at a very general audience. In the "Acknowledgements" he writes, "Someone told me that each equation I included in the book would halve the sales. I therefore resolved not to have any equations at all."[12] He also writes that his aim is to address questions such as "Where did the universe come from? How and why did it begin? Will it come to an end, and if so, how?"[13] From these statements it is clear that Hawking is not concerned with explaining theories or justifying the basic concepts used in them. His interest is not an explanation of science, but rather an explanation of the answers to significant cosmological questions. This is in marked contrast to Cooperstock and Tieu (2012), Einstein (1961), Fischer (2013), Landau and Rumer (1960), and Gamow (1966), all of whom express an interest in explaining theories, as can be seen in the titles of their books.

While Hawking seems to be aiming for a more general, and therefore less advanced, audience than the majority of the books I examined, Cooperstock and Tieu (2012) seem to lean the opposite way. They target a more advanced audience. I deduce this from the fact that their book included significantly more mathematics than any of the other books. If Hawking's statement about each equation halving the sales is even somewhat accurate, the amount of mathematics (and thus equations) in this book suggests it is intended for a smaller, more advanced audience. Cooperstock and Tieu state explicitly that they have decided to use space-time diagrams as their principal explanatory tool. It is reasonable to assume, therefore, that their lack of use of thought experiments is the result of this conscious pedagogical choice, and not happenstance.

The lack of thought experiments in these two books, combined with Hawking's sensitivity to his audience, and Cooperstock and Tieu's concern with pedagogy, suggests that thought experiments are very useful, but only within certain parameters. Based on the small sample I analyzed, they appear to be a mid-level tool, aimed at an audience that has an explicit interest in the theories behind modern physics, but that is unlikely to engage with these theories in more advanced study through the use of mathematics. The thought experiments seem ideally suited to explaining and justifying the basic concepts used in, or introduced by, the theory. Thus the thought

[11] Hawking (1988), Cooperstock and Tieu (2012).
[12] Ibid., vi.
[13] Ibid.

experiments used in explaining Einstein's relativity theories demonstrate the need for his specific conceptions of space and time.

The most-used thought experiments were Einstein's train and elevator thought experiments, and, in quantum mechanics, Heisenberg's microscope thought experiment. While authors often extended or changed the thought experiments slightly, there was a clear preference for thought experiments based on 'originals' as opposed to new thought experiments developed by the authors themselves. This may be caused, in part, by concerns about credibility. Because of their role in the development of science, 'original' thought experiments in a sense *are* science. They may therefore be more convincing as scientific explanations than a newly created thought experiment, which could be met with scepticism and dismissal. Interestingly, Einstein's thought experiment addressing the contraction of rods from the 1905 paper was only mentioned once, in one of the two books that relied the least on thought experiments. I speculate that this experiment is used less because it does not involve as much of an experiential element. The train thought experiment, which is used regularly in discussions of special relativity (including by Einstein himself in his 1961 book popularizing the relativity theories), relates more to readers' daily experience, and therefore may be better suited to translating abstract concepts into tangible situations. Overall, the most used thought experiments were ones that were both based on originals and also used settings or objects familiar to readers.

The Importance of Narrative/Experience in the Scientific Work of Thought Experiments

In the popular physics books, thought experiments were not used simply as examples, but were often used to introduce a concept itself. For example, the principle of relativity and its application in the special theory are introduced to the reader using a train thought experiment in Einstein's *Relativity: The Special and General Theory* (1961). Einstein does not explain the principle and then reinforce it with a thought experiment, but rather the presentation of the idea occurs through the use of the thought experiment. Thought experiments were a primary mode of explanation in the popular physics books.

As previously mentioned, the books used thought experiments that are often associated with the development of the theories or principles they are explaining. While this may have been for convenience sake, or some claim to authenticity, I propose that it may also say something about the use of thought experiments more generally. Clearly, the thought experiments used by physicists in developing their theories are more or less directly useful and applicable in explaining those theories to lay readers. I have interpreted this efficacy as resulting from the way thought experiments take abstract concepts and translate them into something tangible. If the thought experiment is doing this for a lay reader, it must also be accomplishing this goal (amongst, perhaps, others) for the scientist who invented it. I hypothesize, therefore, that thought experiments are actually a way for physicists to pose questions and explain phenomena to themselves.

Further, it seems thought experiments are most useful to physicists in helping them to understand or clarify the concepts used in their theories. Thus Einstein's train thought experiment clarifies our understanding of the concepts 'space' and 'time' through demonstrating the relativity of simultaneity. The suggestion that thought experiments are particularly suited to explaining or clarifying concepts used in theories is reinforced by the fact that in popular physics books one of their main functions is to introduce concepts such as relativity or uncertainty.

Thought experiments are clearly serving some type of function for physicists. It seems what they do best is allow the physicist to conceptualize and 'get at' certain concepts used in modern physics. The ability of thought experiments to act as explanatory tools is a result of the way they take abstract concepts and make them accessible by incorporating them into familiar situations. While thought experiments epistemic validity may still be in question, it is clear they are valuable tools in the practice of science, and their narrative and experiential character are an essential part of what makes them valuable.

Conclusions

Scholarly work on thought experiments has focused on the problem of epistemology—trying to figure out how a process that takes place in someone's head can lead to insight about the world. In this paper I have focused, in contrast, on what I see as a key distinguishing feature of thought experiments: their ability to translate abstract concepts into the realm of daily experience through the creation of a fictional situation containing familiar objects. This feature makes thought experiments ideal for use in the popularization of scientific theories and ideas. Through an analysis of nine popular physics books, I demonstrated that, regarding Einstein's theories of relativity and quantum mechanics, thought experiments do indeed play a central role in popularization. Importantly, the same thought experiments used in theory-development were employed in popularization. This suggests that thought experiments may be serving the same function in both of these settings. That is, for scientists, as well as for lay people, they turn abstract theories and ideas into something tangible. The narrative and experiential element of thought experiments is key to their ability to do this. I therefore argue, contra Norton, that thought experiments are not simply arguments in disguise. Or, if they are, their disguise is absolutely essential to their utility. In keeping with Norton, however, I consider thought experiments' empirical basis to be important, as it is the encounter with the abstract in the realm of empirical daily experience that makes thought experiments useful.

The conclusions offered in this paper are based on exploratory work on the use of thought experiments in the popularization of relativity and quantum mechanics. Work on thought experiments used in other areas of physics is necessary in order to know whether these ideas apply to scientific thought experiments generally, or are specific to these two cases. Further, my sample of popular physics books was chosen based on what was available at the Dalhousie and the University of King's College libraries. I managed to include books spanning a fifty-year period, published in three different languages (English, Russian, and German), so there is diversity within the sample, but a properly representative sample is necessary in order to develop truly generalizable conclusions.

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