Thought Experiments and Their Epistemic Roles in Natural Sciences

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"Complications arose, ensued were overcome." Captain Jack Sparrow confided to Joshamee Gibbs. (*Pirates of the Caribbean: Dead Man's Chest*). Sparrow did it all alone. I was not alone to shape and hone my arguments in the thesis.

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I have to add that the order in which the names appear here doesn’t necessarily mean anything particular.

For everything that is stated above and for everything that is not stated above, therefore, if I haven’t thanked you, I will.

Contents

INTRODUCTION

'*Eureka*' and the streaking Archimedes seem to be the most popular expression and image associated with scientific results. According to the legends, the idea of Archimedes principle struck the natural philosopher while he was in a bathtub[1]. Tales may be mere conglomeration of the pixels of imagination. But the above tale of Archimedes offers two morals to a philosopher of science. One is the mindfulness required in problem solving. Second, and the seemingly more important one, is that one has to really get some new experience through some experiment to get knowledge about the external world. Archimedes solved his problem not with mere thoughts. He was helped by his experience in the bathtub. We could say that Archimedes unintentionally performed an experiment and the bathtub was his instrument in the laboratory called bathroom! This suggests that one has to channel her thoughts through an experience (at least through a bathtub!) to arrive at knowledge about the external world.

Though the story of Archimedes was well-known, for a long period, philosophers of science, following the logical positivist ideals of science, were not mindful of experiments. Science was perceived as travel from theory to theory, occasionally through experiments[2]. In the light of the above overstatement, progress in science was considered as the progress of theories. The post-positivist philosophy of science of 1980s deviated considerably from the above ideal of science. Ian

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[1] The story goes as follows. Archimedes was asked to determine the purity of gold used to build a crown without altering the shape of the crown. Generally, purity of a metal is checked by knowing the density of the material. In order to get the density, first one need to know the volume of the material. Following was the common practice. First, melt the object and turn it into a regular shape. Measure the volume and weigh the object. Divide the weight by the volume of the object to get the density. But, Archimedes has to measure the volume of the crown without disturbing its shape. Vexed by the problem, Archimedes went for a bath. In the bathroom, he noticed the rise of the water level in the bathtub when he got himself in. He realized the applicability of this idea in deciding the volume of the crown and there by density of it. In the ecstasy of the discovery, Archimedes ran naked through the streets, crying out *eureka.*

[2] I am indebted to Prof. Kulkarni for this succinct way of expressing the status of philosophy of science envisaged by the logical positivists.

Hacking was one among the first philosophers of science to challenge the status of experiments in philosophy of science. According to Hacking, experiments do have a life of their own and philosophers of science have to pay attention to the nitty-gritties of experimentation. Hacking's position was widely accepted and consequently, contemporary philosophy of science no more considers science as an enterprise dominated by theories. This emphasis on the role of experiments in a sense is an augmentation of empiricism, which suggests that in order to know about the external world, one has to have some empirical input. Some of the important features of experiments as a method are:

1. Experiments allow one to causally intervene in the nature. The causal intervention is impossible in mere thought.
2. We do experiments to know about the world. It means, we are employing an experimental system to study the larger world. What is special about experiments is that the same material causes are working in the experimental system and the target system. Therefore, it is legitimate to assume that what is true about the experimental system is true about the larger world. In other words, the experimental system and the target system shares the same materiality.

The above two features marked the unique nature of experimentation as a method of epistemological inquiries. The turn of attention to experimentation and thereby to scientific practice, as I have described above, could be seen as an augmentation of empiricism in epistemology of science. It strongly affirms that mere thoughts cannot conjure up knowledge about the external world.

Thought experiment (TE), which was one of the oldest tools of philosophers and scientists apparently raised a challenge to the above mentioned empiricist view of science. A TE, as it was generally conceived, is an imaginary experiment executed only in thought. In other words, in TEs we are playing with imaginary situations to reason out some claims. But this fiddling in imaginary situations or experiments performed in mere thought, often, seem to yield true claims about the external world. Galileo Galilei, to name one scientist from the history of science, one of the foremost and earliest experimentalists, employed a number of thought experiments to make true claims about the external world. Unlike in the case of real experiments, no causal or empirical interventions are possible in a TE. The system in the TE and the targets system are not sharing the same ontology. But TEs appear to provide knowledge about the external world. If mere thought, when contrived in the form of a TE can produce knowledge about the external world, it appears as an epistemic miracle and a mystery eying for attention from empiricist philosophers of science. This is the issue I discuss in the first chapter.

Philosophy and history of science present two extremes of empiricisms and rationalism in the epistemology of thought-experiments. "Pierre Duhem dismissed all thought experiments as bogus precisely because they are "not only not realized but incapable of being realized". That is, either they can be turned into real experiments - and, thus the "thought" dimension is inconsequential-or they are to be dismissed because they are not "experimental" all. Alexandre Koyre on the other hand, argued that the idealizing function of thought experiments is essential to scientific thinking. Idealization is required for the "mathematization" of nature and this can only be carried out in the mind, not in the laboratory. Thus, Koyre concluded thought experiment supplants real-world experimentation and demonstrates the synthetic *a priori* nature of scientific knowledge" (Nersessian 1992, 291). Do thought experiments come up with new knowledge? If so,how do TEs produce new knowledge without employing any new data? An account of thought experiments is required to address these worries. In other words how does a thought experiment work or how do we make sense of the working of a thought experiment are the questions to be answered in any adequate epistemological account of thought experiments. These questions are also taken up in the first chapter. In a nut shell, the first chapter titled **(De) mystifying Thought Experiments** discusses the epistemological problem of TEs. It also discusses the various the virtues and limitations of various epistemological approaches to TEs in contemporary philosophy of science.

Chapter 2: The Life and Demise of Thought Experiments

As I have already discussed, experiments are considered as an important tool of scientific inquiry. Hacking emphasized the importance of experiments by suggesting that experiments do have a life of their own. 'The life of experiment' metaphor" now seems to be a part of the lore of philosophy of experiments. In the conventional wisdom, experiments makes sense only when they are wedded to a scientific theory. It means that experimentation as a practice is subservient to theory and without the light of theories experimentation is not at all possible. Against this conventional view, Hacking and others argue that experiments can stand even when they are divorced from theories. By this they mean to suggest that experimentation practice can be pursued without the direct influence of theories. They are not claiming that experimentation make sense in the absence of theories. But the claim is that experiments can be done and in fact many have been performed, without the help of well-developed theories. With the life metaphor, they intent to suggest that experimentation practice can stand on their own.

Curiously, Hacking claims that TEs do not have a life of their own. As we have already seen, TEs do not have the power to make any causal interventions. Apart from this, TEs are always performed within the light of a theory. Also, TEs do not share or need not necessarily share the same ontology of the external world. This is because TEs are performed in imagination where one can legitimately speak about perfect bodies moving in a frictionless plane. Such talks are allowed only within theories. Hence, Hacking contended that TEs are struck up with theories for they are always wedded to theories. But Experiments are not stuck with theories. They can be improved by adapting to the new situations by employing new experimental structures. They can be repeated with improved tools. None of this is possible in the case of a TE. Therefore, TEs, according to Hacking, do not have a life of their own. I respond to this contention in the first part of my second chapter.

Progress in science enriches the tools of scientific inquiry. Computer simulation (CS), compared to TE, is a recent addition to the repertoire of scientific practice. A CS, in its most elementary form, is a model executed in a computer. Following Wendy Parker, we could say that a CS is an attempt to mimic a target system on a computer on the basis of a mathematical model of the target system. In the process, one has to follow at least the following steps.

1. Fixing the target system.

Finding the target system to modeled and simulated.

2. Identifying the relevant mathematical model of the system.

It might be possible to have different mathematical representation of the same target system. So, one should identify the correct mathematical model of the target system depending up on the objectives of her research project.

3. Finding the Continuous model equations.

Frequently, if not for all cases, it is impossible or difficult to find exact solutions to the equations associated with the mathematical model. So, scientists transform the equations of interest in various ways such that they can be solved using numerical methods. This set of equations, generally differential equations, are called continuous model equations.

4. Preparation of the Computer Simulation Model

The continuous model equations are to be solved using a digital computer. A computer program will be written to perform the above task. When actually implemented on a digital computer, this program is a computer simulation model—a physical implementation of a set of instructions for repeatedly solving a set of equations in order to produce a representation of the temporal evolution (if any) of particular properties of a target system" (Parker 2008, 166)

5. Computer Simulation

"The execution or 'running' of the computer simulation model with specified initial and/or boundary conditions is a computer simulation" (Ibid.)

This suggests that we execute theoretical or mathematical models of the targets system in a computer to know about the target system. Often, the mathematical models are analytically intractable and hence they not only require a CS but only a CS can produce the result. This poses a lot of interesting philosophical puzzles about CS. But the point of interest here is the parallel between CS and TE.

CSs, just like TEs, do not exactly share the ontology or materiality of the target system. This is because, we are implementing the model of a target system in a computer and no real causal interactions are happening in the model we implemented in the computer. But we employ CS to study the external world. The success of CS in providing good results about external world is so enormous such that fields like aerodynamics have almost completely replaced concrete experiments with CS. CSs do not make any causal interventions. But, just like TEs, CSs too produce knowledge about the external world. This calls for comparisons between TE and CS. Apart from mere comparisons, seduced by the success of CSs in handling complex scientific problems, some philosophers argued for the replaceability of the older tool TE by the more powerful and younger tool CS in contemporary science. Chandrashekaran *et al* (2013) argued in the above line. In their view, contemporary science is too complex for TEs to deal with. Moreover, TE was a tool employed in a period in which the scientific problems were less complex and the tools available were less sophisticated. The contemporary period has better technology to deal with the complex scenarios. Therefore, TEs will be replaced by CSs in contemporary science. I discuss this view in the second part of the second chapter. I argue that the arguments suggested by Chadrasekharan *et al* are less that convincing and their characterization of thought experimentation and its functions is uncharitable to the practice.

Chapter 3: **Phenomena Conceivability and Thought Experiments**

In the third and final chapter I attempt to provide a novel account of the epistemology of TEs in natural sciences. This chapter is divided into three sections. In the first section, I discuss the data-phenomena distinction introduced by Bogen and Woodward. Following Basu (2012) I argue that the above distinction is multilayered and context dependent. In the section two, I attempt to show the importance of data-phenomena distinction in the epistemology of TE. I discuss two TEs two show the centrality of the data-phenomena distinction in the epistemology of TE. Next section is a discussion on the notion of model-dependent conceivability. With the help of two brief case-studies from the history of science, I argue that model-dependent conceivability is a central notion in scientific reasoning. In the last section, I employ the notion of model dependent conceivability to develop an account of epistemology of TEs. I argue that TEs are models of phenomenon. The success or failure of TE depends on the conceivability or inconceivability of the phenomenon under discussion. I also attempt to show that this way of reasoning is a part of scientific practice. Some plausible objections to the model-dependent conceivability account and replies to the objections are also discussed at the end of the chapter.

The thesis at a glance

The epistemic mystery of TEs and the various attempts to demystify it is the problem attempted in this thesis. The relations between TEs, experiments and are also taken up in the discussion. The thesis has three substantive chapters. First chapter, titled (De) mystifying Thought Experiments, discusses the epistemological problem posed by TEs. It also discusses the various epistemological accounts of TE in the contemporary philosophical science. Chapter two, titled The Life and Demise of Thought Experiments, is a response to Ian Hacking (1992) and Chandrashekharan *et al*. (2010). Both Hacking and Chandrashekharan *et al* argue, for different reasons, that thought experiments are relatively insignificant in contemporary sciences. I attempt to show that contrary to Hacking and Chandrasekharan *et al* thought experiments are significant in contemporary sciences. Third chapter, titled Phenomena, Conceivability and Thought Experiments, is an attempt to provide a novel epistemological account of TE. In the third chapter, I attempt to show the importance of the data-phenomena distinction in the epistemology of TE. Then I discuss the notion of model-dependent conceivability and its role in scientific reasoning. Finally, I contend that TEs are models of phenomena where the success or failure depends up on the conceivability of the phenomena within the model.

CHAPTER 1

(DE)MYSTIFYING THOUGHT EXPERIMENTS

The debate between empiricism and other epistemologies is as old as philosophy itself. When the philosophers of science began discussing the epistemology of thought experiments, initially, it appeared like a debate between the empiricist and the rationalist epistemological approaches to science. This is evident from the early debate between John Norton, a committed empiricist and James Brown, an aspirant rationalist, on the epistemology of TEs. Norton's claims that "empiricism is overwhelmingly the predominant epistemology in philosophy of science, so that an account that accommodates thought experiments to empiricism in a simple and straight forward manner ought to be accepted as the default, as opposed to some more extravagant account. I claim this default status for the view advocated here" (Norton 2004, 50). Brown was ready to concede Norton's points and he replies that "I think he's right about this. The current philosophical climate favors empiricism and opposes abstract entities. Since my view flies in the face of this, the burden of proof is on me" (Brown 2004, 36). Norton and Brown's claims regarding the epistemology of TE could be considered as the beginning point of the discussion on the epistemology of TEs. In this chapter I discuss

1) The apparent epistemic mystery of TEs
2) Various attempts to demystify the apparent mystery of TEs
3) Limitations of the standard epistemological accounts
4) Evidential significance of TEs.

1.1 The Mystery of Thought Experiments

The epistemological questions posed by thought experiments in natural sciences are best formulated by Thomas Kuhn. The history of science, according to Kuhn, shows importance of the roles which TEs have performed in the development of physical sciences. Kuhn suggests that TEs do not construct new empirical data. For a thought experiment to be successful it should be built up on the empirical data which have been well known and generally accepted. Kuhn then asks, "[H]ow, relying exclusively upon familiar data, can a thought experiment lead to new knowledge or new understanding of nature? (Kuhn, 1977, 241). This apparently is a challenge to empiricism, which was we have already seen, is the default philosophy of contemporary philosophy of science for some philosophers. This problem, the production of new knowledge without employing new data, seems to be the puzzle generally taken up by the epistemologists of TEs. This puzzle or mystery can be formulated explicitly as follows:

1) More than once TEs have played crucial roles in the development of sciences.
2) TEs produce new knowledge.
3) In order to produce new knowledge, TEs rely only on accepted old data. It means that TEs conjure up knowledge about the external world through mere thought.

1.2. Epistemological accounts of Thought Experiments

The different epistemological accounts of TEs could be understood as a response to the apparent mystery discussed in the last section, i.e. the conjuring up of empirical knowledge via mere thought. On the basis of the difference in the methods, one can identify the following five epistemological responses to the mystery of TEs[3].

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[3] Another way to classify the responses to this puzzle is as follows. One could have three different answers to the question:

1. Platonism: Some TEs transcend empiricism by directly percievng laws of nature.
2. Argument View: TEs are picturesque arguments.
3. Mental Model account: Epistemology of TE is that of model-based reaoning
4. Fictionalism: Thought experiments are stories with a moral.

The Three Desiderata

Hayley Clatterbuck (2013) provides three desiderata that every epistemological account of TEs need to satisfy. It should be worthwhile discussing the three desiderata before we start discussing the different epistemological accounts of TEs. This will help us arbitrating among different epistemological accounts of TEs. The following are the three desiderata which every account of TEs need to satisfy. If some account fails to satisfy all or some of the desiderata then the other account that satisfies the desiderata will gain some advantage over the former[4].

The Modelling Criterion: The epistemological account should accurately model the process in the way the practitioners of TE actually do. Here we are not interested in the actual psychological

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1. Thought experiments do not produce any new knowledge about the external world. (Extreme Eliminativism)
2. Thought experiments do produce new knowledge but the thought experimental reasoning requires no new epistemological account. Thought experimental reasoning can be reduced to standard accounts of reasoning without any epistemic loss. (Moderate Eliminativism)
3. Thought experiments do produce new knowledge. Thought experimental reasoning cannot not be reduced to standard accounts of reasoning without epistemic loss. (Non -Eliminativism)

Answers 1 and 2 could be understood as extreme and moderate versions of eliminativism. In the strong sense 1, thought experiments are only heuristically important but epistemologically they do not pose anything novel. The moderate version 2, claims that thought experiments do provide new knowledge but the epistemological function of thought experiments is explainable by reducing them into any of the standard accounts of reasoning. Pierre Duhem advocates the view suggested by extreme eliminativism. But very few philosophers, in the contemporary philosophy of science, accept 1 as an answer.

[4] Evaluating epistemological accounts in this way may lead us to complicated situations. For example, let E1 and E2 are two accounts of TE and D1, D2 and D3 are the desiderata. E1 and E2 can satisfy (or violate) the three desiderata in 8 possible combinations. There may be matching and non-matching situations. For example, both E1 and E2 may satisfy D1 and D2 and violate D3. There may be situations where E1 satisfies D1 and D3 while E2 satisfies D2 and D3. Clatterbuck has not suggested any way to overcome such situation. In this discussion, I am not venturing into such debates. Following, Clatterrbuck, I only suggest that *prima facie* the three desiderata provide possibilities of some comparison between different epistemic accounts of TEs.

process behind reasoning. Rather we require an accurate functional description where the different steps in a TE and the relation between these steps are explained. Also, the account should be able to explain the importance of each in the execution of a TE.

Parsimony Criterion: The epistemological account should not make ontological commitments that are not necessary for the explanation.

Unification Criterion: The belief forming process in the epistemological account should be a part of a more general and preferably well-supported kind of process[5].

1.2.1 The Platonist account of Thought Experiments

Platonists accept TEs ability to conjure up knowledge. James Brown is a pioneer among the philosophers who hold a Platonist account of TEs. In this section, I discuss Brown's epistemological approach to TEs.

Brown contends that though TEs generally include idealization and abstraction in its reasoning there are a few TEs which do not rely on idealizations to reason out their conclusion. Brown's example is Galileo's Free Falling Body TEs where, he contends that we do not require idealizations that are absolutely impractical[6]. One of the reasons for this suggestion is that we can perform the Free Falling Body TE in a laboratory. So, the idealizations, if any, employed in the TE is not crucial in some TEs. Therefore, the point to be emphasized, according to Brown, is the production of knowledge (the result of the TE) through mere thinking. Consider Galileo's TE,

[5] It is possible to have a conflict between the parsimony and unification criterion. A realist may be committed to the entities posited by the theory but an anti-realist might make the same commitment. The realist may try to show that controversial entities like moral truths are sufficiently similar to mathematical truths. From this it may be argued that the rejection of former truths entails the rejection of the latter and leads to an unwanted skepticism. Since this altogether is a different discussion I am not venturing into it.

[6] This is not a correct characterization of Galileo's TE. The limitations of such characterization becomes evident in the second chapter where we discuss Galileo's TE in detail. In order to make Brown points explicit, let us grant that he is correct. In fact, his position on the feasibility of idealization is correct in some cases, like, the Photon Box TE.

which in fact is the only candidate of a platonic[7] TE. According to the Aristotelian understanding, the speed of a falling body in a medium is proportional to its weight. Galileo asks us to imagine the fall of two bodies of different weight tied together. Since the total weight of the two bodies tied together is greater than that of the heavy body alone, naturally, the speed of the bodies tied together will be greater than that of the heavy body alone. But, at the same time, since the lighter body having lesser speed retards the heavier one in their fall, the speed of the system will be lesser then that of the heavier body's speed. Thus we reach a contradiction from the Aristotelian theory of free fall. In order to solve the problem Galileo proposes that the speed which bodies obtain in free fall is the same irrespective of the difference in their weight. Through the TE, according to Brown, we gain knowledge about the free fall 'without even looking at the world'. Therefore, in such cases, TEs transcend empiricism and they are named as platonic TEs. According to Brown, "[A] platonic thought experiment is a single thought experiment which destroys an old or existing theory and simultaneously generates a new one; it is *a priori* in that it is not based on new empirical evidence nor is it merely logically derived from old data; and is an advance in that the resulting theory is better than the predecessor theory" (Brown 1991 77).

Reasons for *a priori* nature of Platonic Thought Experiments

There are three reasons for the *a priori* nature of platonic thought experiments.

1. Three is no new data in a thought experiment. This is an obvious case for a thought experiment is build up only on the available data. If one can reach new knowledge without the aid of any new data then it is a clear case of *a priori* reasoning and according to Brown, this is what happening in platonic thought experiments. Galileo's thought experiment does not use any new data and it transcends empiricism.
2. The new theories suggested by the TE, Galileo's theory of free fall in this context, is a not a

[7] Brown concedes that his Platonism is a Platonism with lower case 'p' because TEs can err.

logical deduction from the old data. The thought experiment derives a contradiction from the Aristotelian theories of free fall. But according Brown, it is not possible to derive Galileo's theory of free fall i.e. all bodies fall at the same rate, from the contradiction. It can be derived in the trivial sense that anything can be derived from a contradiction.

3. The transition from an old theory to the new one, here from the Aristotelian theory of free fall to the Galilean theory, is not just a case of making adjustments to the old theory. The degree of rational belief in Aristotle's theory declines rapidly after the thought experiment. Or the degree of rational belief in Galileo's theory increases rapidly. According to Brown, we have achieved this not by making any adjustments in the old theory.

Arguments for a Platonic Account

Brown, substantiates his platonic account of TEs in the following manner. In order to make this account feasible, he assumes the validity of mathematical induction and a realist account of natural laws. Mathematical intuition, which Kurt Gödel and others posit, suggests that numbers and other mathematical objects exist independent of human beings and we can perceive or intuit them. Since no ordinary sense perception is involved in this case it is a case of *a priori* reasoning. Brown accepts this form of Platonism in mathematics. In the realist account of natural laws, "… universals stand[ing] in certain relationship may logically necessitate some corresponding generalization about particulars and when this is the case the generalization in question expresses a law" (Brown 2004, 33). Therefore, a law is a link between properties but it is not necessarily a regularity. In other words, a law may contain a regularity but a regularity may not always feature in a law. Thus laws are differentiated from accidental generalizations and these exist independent of us. Such laws can be used not to summarize but to explain events.

After assuming the validity of mathematical intuition and realist account of natural laws together, Brown argues that thought experiments (at least in some cases) transcends empiricism. The argument can be elucidated as follows:

1. According to Platonism in mathematics we can intuit mathematical objects, which are abstract entities.
2. From 1 it follows that at least in principle we can intuit entities.
3. According to the realist account, natural laws are abstract entities.
4. 1 and 2 together suggest the possibility of intuiting laws of nature.
5. In some thought experiments we seem to have a special access to facts of nature. Galileo's Free Falling Body TE is the best example for such a TE.
6. Therefore, it is possible to claim that thought experiments allow us to possibly intuit laws of nature.
7. Intuitions are non-sensory perceptions of abstract entities.
8. From 5, 6 and 7 it is evident that (some) thought experiments transcend empiricism and provide *a priori* knowledge of some laws of nature.

Features of Brown's Platonism

Some of the important features of Browns platonic account of TEs can be elucidated as follow:

1. The structure of TEs are very important in its reasoning and hence Brown do not support any form of eliminativism. Eliminativists claims that either TEs are epistemologically irrelevant or that TEs can be reformulated into any of the standard forms of reasoning without any epistemic loss.
2. The Platonism advocated is fallible. This suggests that not every platonic TE provides knowledge.
3. A platonic TE enables the experimenter to see or intuit natural laws directly.

Limitations of the Platonic Account

1. The platonic account seems to violate all the three desiderata discussed earlier.

Modelling criterion is not satisfied because scientific practice does not follow a platonic route. Clearly, the parsimony criterion is violated because the Platonism posits commitment to abstract entities. Also, the unification criterion doesn't seem to be a part of the platonic account. (See Clatterbuck 2013)

2. Platonic account, does not seem to provide reasons for the failures of TE. Even though, Brown's platonism is fallible but it does not suggests the reasons for failure. This in turn fails to give an account of reliability of TE.
3. The Platonic account is too limited in its application. As Brown himself has suggested the platonic TEs are very rare. In fact there is only one (Galileo's free falling Bodies) successful platonic TE in Brown's list. Therefore, even if we accept a platonic account for some TE the rest of the TEs requires a different epistemological account.
4. The Platonic account seems to have no suggestion regarding the TE anti-TE scenarios

1.2.2 The Argument-Views

The argument view of the epistemology of TEs has two forms. In the strong and eliminativist view, it suggests that TEs are picturesque arguments and they can be reformulated in the form of an argument without any epistemic loss. In the strong view the form in which TEs appear doesn't have any epistemic bite. The moderate and non-eliminativist view, suggests that the underlying reasoning in every TE is that of an argument but the reformulation of TEs in the form of arguments results in some epistemic loss. For the non-eliminativists the form in which TEs appear has significant epistemic bite. In this section, I discuss the eliminativism of John Norton and non-eliminativism of Julian Reiss and Hayley Clatterbuck.

1.2.2a Eliminativism of John Norton

Norton places his account of TEs squarely opposite to that of Brown's Platonism. Norton argues that TEs never produce knew knowledge and so they never transcends empiricism. According to Norton, "Thought experiments are arguments which 1. posit hypothetical or counter-factual states of affairs and, 2.invoke particulars irrelevant to the generality of the conclusions" (Norton 1996, 336). Since no new empirical data is employed in a TE it can only reorganize or generalize what we already knew about the world. They may make the known facts explicit. If only derivation or manifestation of already known is happening in a TE then it is a deductive argument and if there is generalization then it is an inductive argument. This is not to claim that TEs are deductive or inductive arguments only. Rather, the claim is that an epistemic evaluation of TEs should be done by considering them as arguments. Norton uses the term argument in a wider sense of the term to include informal arguments.

Norton's account of TEs is based on the presumption that pure thought cannot conjure up knowledge of the physical world. What a TE can perform is the manipulation or transformation of what is already known. Norton contends that "[I]f thought experiments are to produce knowledge, then we must require that the transformations they effect preserve whatever truth is in our existing knowledge; or that there is at least a strong likelihood of its preservation. The only way I know of effecting this transformation is through argumentation; the first case is deductive and the second inductive" (Norton 2004(b), 49). Norton' account of TE is supported by two theses:

a) Reconstruction Thesis

b) Reliability Thesis.

Reconstruction Thesis: "All thought experiments can be reconstructed as arguments based on tacit or explicit assumptions. Belief in the outcome-conclusion of the thought experiment is justified only in so far as the reconstructed argument can justify the conclusion" (Norton 1996, 339). The reconstruction thesis suggests that every TE can be reformulated in the form of an argument where all the implicit and tacit assumptions in the TE are made explicit[8]. Then the validity or probability of the conclusion of the argument can be evaluated by employing the rules of standard logic. This suggests that what is achieved employing a TE is already contained in the data up on which it is built. Therefore, Norton argues, that TEs do not transcend empiricism and hence there is no epistemic mystery in the case of TEs. The apparent mystery, if any, can be resolved by reconstructing a TE in the form of an argument.

Norton augments the virtues of his argument-view of TEs by applying it to resolve the problem of thought experiment anti-thought experiment puzzle. An anti-TE is a TE with a conclusion that is opposed to that of another TE. In the history of science there are instances where the conclusion achieved by a TE is countered with another TE[9]. The TE and the anti-TE purport equally compelling conclusions which are mutually opposite. This is a puzzling scenario because both the TEs appear compelling. Norton claims that his argument-view offers an easy solution to this puzzling scenario. According to the arguments-view the TE and the anti-TE can be reconstructed as arguments. We can always have arguments whose conclusions contradict and hence there is nothing puzzling about a TE anti-TE scenario. The reconstruction will show that one of the arguments employs incorrect premise(s) or unsound conclusion or fallacious reasoning. The TE which stands for the bad argument will be rejected. Thus we have an easy and direct diagnosis of the problem of TE and anti-TE cases. This, according to Norton, also points out a stark contrast of the argument-view, to that of the platonic account of TEs because the latter cannot account for a TE anti-TE scenario.

[8] See Norton 1996 for the reconstructed version of a number of TE including a *reductio* form of Galileo's Free Falling Body TE.

[9] See Norton 2004(b) for a number of TE anti-TE pairs.

Reliability Thesis: "If thought experiments can be used reliably epistemically, then they must be arguments (construed very broadly) that justify their outcomes or reconstructible as such arguments" (Norton 2004(b), 52). TEs often err. Einstein's clock-in-the-box and EPR are good examples of erred or failed thought experiments. So, in order to consider TEs as a reliable mode of inquiry one needs to have some criteria which will enable one to make a demarcation between good and bad or right and wrong TEs. Reliability in a naive sense can be seen as the history of successful predictions. But TEs do not have such a history. So, there should be some mark that can account for the reliability of TEs. The mark cannot be something external like some special capacity of the experimenter or the context of the TE. This is because TEs are repeatedly reconstructed by many people to yield the same result. If the reliability mark is something external to the TE then it is hard to explain the effective repetition of the same TE by different people leading to the same result. According to Norton, only the argument-view answers the question about the reliability of thought experiments. According to the argument-view, the reliability of a TE is the reliability of the argument reconstructed from it. Therefore, the reliability of a TE depends up on the reliability of the premises of the reconstructed argument. Since the information employed in the reconstruction is provided by the TE alone the reliability of a TE depends only on the TE. In other words, the reliability of a TE is guaranteed by the fact that it either uses an argument form or it can be reconstructed as one. Therefore, logic guarantees the reliability.

Features of Norton's argument-view of TEs

1. TEs are nothing but picturesque arguments in disguise.
2. Every TE can be reconstructed in the form of an argument without any epistemic loss.
3. Reliability of TEs can be accounted for by pointing out the reliability of arguments

in general. Also, the reliability of a TE is an intrinsic property of the TE.

4. Failure of TEs can be accounted for by appealing to the reasons for the failure of the reconstructed argument.

5. TE anti-TE scenarios are answered easily.

6. Unlike the platonic account of Brown the argument-view is applicable to every TE.

1.2.2b Inductivism

Hayley Clatterbuck proposes a weak version of argument-view of the epistemology of TEs. In this view inductive argumentation is the underlying logic of thought experimental reasoning. And hence TEs are arguments. But, at the same time, she does not accept the position that TEs are constructible as arguments. The reconstruction of TEs in the form of argument always results in some epistemic loss. In the following section, I discuss the inductive-reasoning approach of Hayley Clatterbuck[10].

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[10] Julian Reiss has proposed another variety of induction to account for the epistemology of TEs. According to Reiss, Baconian induction is the method of thought experimental reasoning. According to Reiss, inductive methodology of Bacon has three stages (1) observing or experimentally creating. (2) classifying, and (3) causally explaining phenomena. The above general process is aided by what Bacon calls as "prerogative of instances" i.e the techniques and methodological principles that support general inductive process (Reiss 2002, 31). According to Reiss, TEs falls into group of the Baconian "prerogative instances" as the twenty-eighth prerogative. TEs help us in different ways. The four important functions they perform, according to Reiss are (a) concept formation, (b) establishing causal hypotheses, (c) nomological refutation, and (d) suggestion of new works (*Ibid* 31). All of these functions can be explained employing the Baconian schema. In the Baconian view, we move from our experiences to generalizations about the external world. Observations provide us the data. In a TE this data is the already known. The next step is classification. The classification may be performed by employing some theory. In other words, according to the available conceptual categories we classify the observed data. If we think about the Galileo's Free Falling Body TE, the classification of the observations was performed according to the Aristotelian theory of motion. While causally explaining the phenomenon, the Galileo's TE shows a contradiction in the Aristotelian theory. By relying on plausible observations and harmless idealizations, which are part of plausible experiments, Reiss contends, the TE illuminates the incoherency of the Aristotelian theory of motion. This is the role of prerogative instances. The TE also points to new concepts that can avoid the purported contradiction. But the validity of that, according to Reiss, depends on further experimentation.

Inductive account of Clatterbuck

According to Clatterbuck, "when a reasoner is performing a thought experiment, she is running through an inductive argument from justified experiential knowledge to form beliefs about unknown cases" (Clatterbuck 2013, 318). What makes this account different from the strong argument-view is that in this view TEs are arguments but their picturesque features are epistemically important. In other words, the reconstruction of TEs as mere arguments results in epistemic loss. This is elaborated further as follows. The narrative form in which a TE appears enables the reasoner to perform the simulation in a context that is not experientially familiar to her. Also it is the narrative form that allows the reasoned to select the proper representative case and this eventually sanctions the Dewey-induction. (We will discuss this later.). This epistemological account has the following four steps: (1) Simulation (2) Idealization (3) Simulation in unfamiliar context and (4) Dewey-Induction

1. **Simulation:** A phenomenon is simulated by the reasoner in a context to which she is experientially familiar. Think about the Galileo's TE. The situation in the TE familiar to the reasoner. So one can easily simulates the situation in her mind

2. **Idealization:** The contingent details of the familiar experiential context are removed from the simulation by employing idealization. In the above TE, the friction of the medium is removed from the simulation by employing idealization[11]. Also, the size, color or shape of the objects are also removed as a part of idealization. This allows the reason to think about a general scenario.

3. The idealizations allow the reasoner to perform the simulation in a context that is not experientially familiar.

Since this is only another inductive account, I do not discuss it in any further detail. See Reiss 2004.

[11] A detailed discussion of the role of idealization in Galileo's TE is given in chapters 2 and 3.

4. **Dewey Induction:** Generally, when a conclusion is drawn about unobserved instances from a class of known instances, we call it an inductive inference. The validity of such an inference rests on the bridge between the observed class and the unobserved instances. Generally, the well-known rules of statistical sampling provide the strength of the inductive bridge. For example, size of the sample class, control over confounding variable, proper random selection etc. are some of the important part of statistical inference. In the case of Dewey-induction, size of the sample class is not important. Rather, the strength of the induction relies on identifying the proper representative kind. In other words, "one has to base the inference on some kind of natural connection, a combination of laws, mechanisms and etiologies" (*Ibid* 320). According to Clatterbuck, TEs are instances of Dewey-induction. In a TE, Clatterbuck points out, the reaosoner identifies a proper representative individual case and generalizes from that case. The inference is supported by fact that the case under consideration in the TE is proper a representative case and something that is true about such a representative case must hold true for other instances of a similar case. The idealization and generalization from idealizations (Steps 2 and 3) enable the reasoner to establish a proper representative case. From that by employing Dewey-induction, the reasoner applies the instance of phenomenon to another context by adding relevant particular details of the new context to the idealized simulation.

The similarity between the TE case and actual case licenses the inductive step. The justification of the inference depends on the selection of the proper representative class. This selection, according to Clatterbuck, is heavily dependent up on the TE narrative. This is because, the data for making the inductive leap is provided by the TE. While deciding the nature of the representative class, we are left with only the information in the thought experimental narrative. This enables the reaonser to simulate the situation. A reconstruction might not be suffice both in the simulation case and in selecting the representative class. Therefore, Clatterbuck argues that "the process involved in running the thought experiment is an ineliminable part of any account of the epistemology of thought experiments…" (*Ibid 322*).

Features of Clatterbuck's inductive reasoning account

1. The reasoning behind TEs is Dewy-induction. Since inductive reasoning is a part of general empiricist methodology, this accounts suggests that there is nothing mysterious about TE.
2. Thought experimental reasoning employs mental simulation of a familiar scenario.
3. The form of a TE is important in recognizing the proper representative class and in enabling the simulation. Therefore, the narrative form in which TEs appears is ineliminable.

Limitations of arguments Views

1. Unlike platonic view, the argument view seems to satisfy the three desiderata. It clearly satisfies the parsimony and unification criteria. The eliminativist account of Norton, according to Clatterbuck, fails to satisfy the modeling criteria. This is because, as she has argued, the form of TE is important in the reasoning.
2. Inductivism seems to assume that in every TE we rely on our experiences to draw our conclusions. But this is not true. In most of the TEs in quantum mechanics the experimenter seems to have no experience about the quantum word for the subtle world is not the one with which human agents directly engage. This shows the inability of inductivsm to explicate to the situations of TEs in quantum mechanics. Hence the scope inductivsm is limited. It should be noted that Norton's eliminativist view does not suffer this limitation because it does not rely on the experience of the reasoner in any TE.

3. The simulation in step 2 in Clatterbuck's schema seems to assume that the agent has some clear idea about the functioning of the target system. But as we have already seen above this is not true about the quantum world. Because we have no direct information about the quantum world. At best the reasoner can simulate a theoretical model in the cases of TEs in quantum mechanics. In such cases, the simulation doesn't seem to have any particular role. Norton's eliminativism doesn't face this difficulty.

4. Some TEs like the Galileo's Free Falling Bodies TE appear deductive in character. It is far from clear why one would require a complicated Dewey-Induction to explain such a TE when it is easily explainable by employing a deductive argument. Norton's eliminativism does not seem to face this problem.

1.2.3 Thought-experiments as Mental-models

Mental-model account or model-based reasoning account in general suggests model-based reasoning as the mode of reasoning underlying TEs. In this account, TEs are available in the public domain as a narrative. This narrative enables a competent reasoner to construct mental models of the target system and by simulating the models in head the reasoned reaches the conclusion. In this section I discuss the mental model-account of TEs independently by Nancy Nersessian and David Gooding.

1.2.3a .Nersessian's Mental-modeling account of Thought-Experiments

Thought experimentation, according to Nancy Nersessian, is a process of simulative model-based reasoning. Its cognitive basis lies in the reasoner's capacity for mental modeling. Executing a thought experiment, according to Nersessian, is the construction and simulation of mental models to check the happenings under the specified manipulations. A propositional articulation of TEs as arguments, as it was proposed by Norton is at most, a codification of the reasoning process that was already carried out by other means. In other words, for the reconstruction of a TE in the form of an argument the mental-model construction and simulation need to be carried out earlier. Thought experimental narratives designed after the initial experimentation are aimed at providing a reasoning which parallels the original mental execution of the experiment. This illuminates the importance of the form of TEs. The narrative and the particulars given in it are important in transforming the reasoner to a vicarious participant. This, Nersessian contends, cannot be achieved by an argument reconstructed from the TE.

The epistemic importance of a TE, according to Nersessian, lies in the problem-solving context of its execution. This point can be strengthened by considering the fact that scientific TEs are "selective constructions and make clear which aspect of the world can be discounted" (Nersessian 2008, 174). This aspect also gels well with the suggestion that the particulars given in a TE are important. The selective construction ensures that only the relevant part of the target system is considered.

Experimenters make thought experimental reasoning by "constructing and manipulating a mental model of the situation depicted by the narratives, rather than using inference rules to a system of propositions representing the content of the text" (Nersessian 2008, 175). In other words, the thought experimental referent of the text stands for an internal model of the situation rather than a description. A carefully crafted narrative directs the reasoner to the formation of a mental model of the situation narrated in the TE. Simulating the consequences of the situation affords epistemic access to the particular aspects of the world represented in the TE. Though by presenting the situations in a particular way a TE may not be able to give solutions to the problems in hand but they show hints of possible change.

Nersessian considers TEs as "temporary structures constructed in working memory for a specific reasoning task" i.e., mental models are constructed from the thought experimental narrative and employed in reasoning. A mental model, she adds, is a structural analogue of a real-world or an imaginary situation. The causal structures connecting the events and the entities depicted in the experimental narrative and the spatio-temporal relations among them are embodied in the mental model. Two important points to be noted are: (1) mental models are non-propositional in form; (2) "Mental modeling does not require introspective access to an image in the mind's eye. It only requires the ability to reason by means of an analogue model" (*Ibid* 294). The linguistic expressions of the narrative assist the follower in constructing the mental model and reasoning about the situation through simulating the model.

1.2.3b David C Gooding and the embodiment thesis

Gooding considers TEs as another form of experimental reasoning. The mystique surrounding TEs are due to the fact that TEs are easy to replicate and they are more reliable than material and literal trappings of real experiments. The force of an experimental test involves criticizing a theory by performing something in the way as prescribed by the theory in the world as represented by the theory. "Empirical criticism is possible to the extent that a TE recovers enough of the situated contextual knowledge that experimenters need to make experimental processes work in the world" (Gooding 1992, 280).

TEs are accessed through the experimental narrative. An experimental narrative is the prosaic description of the experiment by the experimenter. Empirically informed criticism is possible because the experimental narrative invokes the contextual knowledge of the experimenter to perform the experiment in the world that experiment and theory are meant to share. This experimental know-how is made available to the followers and by following the narratives they become vicarious participants of the experiment in thought and in real world. If the experimenter's know-how to enable replication, conveyed through its narrative, is ineffective then such experiments hardly make any impact.

Gooding argues that, it is the personal participation in TEs that makes them an experiment rather than the mere form of argumentation. Personal participation in a TE is enabled by following the experimental narrative. "…Experimental narratives… enabled readers to make vicarious observations through their mental participation in the practices described. This lent credibility to the phenomena reported to be produced by those practices" (*Ibid* 283). Gooding regards TEs as process-narratives to which visualization is essential. Here he emphasizes the role of embodiment in the epistemology of TEs. TEs allow idealizations to avoid a lot of chaotic nature of real world. In real-experiments observers are usually disembodied or (s) he is not considered as an important component. Sometimes the embodiment of the experimenter is considered as an unavoidable discrepancy. Because in some cases the presence of the observer makes irrecoverable changes in the measurable quantities. In a TE the embodied experimenter is an important component for the reason that they are performed in the mental world of the experimenter. This appears to be trivial but it is an important feature of many TEs. More than once, in TEs, the reasoner is directed towards her experiences to either validate the data employed or to enable the construction of mental models of the situation. The embodiment of the reasoned becomes crucial here because the directed experiences are called for the experimental aspect of the TE. The importance of embodiment can be explained further as follows. In a real experiment we have observations and measurements. In TEs we do not have these. Rather we are alerted to our day to day experiences and its relevant feature. Many of these experience cannot be intuited to the thought experimental scenario without the presence of the reasoner. Gooding, rightly directs us to this feature of TEs. In a real experiment, the presence of the experimenter, as Gooding contends, is not generally an important feature[12].

[12] It appears that the role of measurement and experimenter in quantum mechanics is not considered here. Since Gooding has entertained TEs from quantum mechanics, his approach is only partially correct. The general idea is that in an experiment if we replace the experimenter with a robot and make the measurements and observations, the result of the experiment is expected to be the same. But this, according to Gooding, is not true for many TEs.

Apart from his focus on the embodiment aspect Gooding's account of TE appears to be in agreement with that of Nersessian. Both of them agree that the reasoning in a TE is simulative model-based reasoning.

Features of Mental Modeling account

1. Thought experimental narratives enable a follower to create mental models.
2. Simulative mental model based reasoning is the inferential process underlying TEs
3. A mental model is a structural analogue of a real world scenario. This structural analogousness guarantees the validity of model based reasoning.
4. Mental models are non-propositional.
5. Mental model account does not support eliminativism. The narrative structure is important in forming mental models. A TE, reconstructed as an argument does not make a follower a vicarious participant. Therefore, the reconstructed argument does not support the construction of mental models.
6. Mental-model account satisfies the three desiderata. Since it does not suggest any new ontological commitment the parsimony condition is not violated. Simulative model-based reasoning is a general reasoning practice which, according to Nersessian, is employed in the contexts of day to day life. This suggests that the mental-model account is not an account of reasoning suggested exclusively for accounting the epistemology of TEs. Therefore, the unification criterion is also met. (See Nersessian, 1987, 2009) The modelling criterion also seem to be satisfied only in the sense that the underlying basis of any reasoning is model based reasoning. But this appears far general an assumption. Because there are TEs that appears to include manipulation of mathematical equations to reach its result. The Photon Box cases (See chapter 3. Section 3.2.2 for the Photon

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This feature of TEs might not hold well in the cases of TEs employed in the debates on the interpretation of quantum mechanics.

Box TE) is a good example. In Bohr reply, a reasoner has to go through the equations to reach the conclusion of the TE. It seems inappropriate to assume that a reaoner manipulates all this equation in her head.

Limitations of Mental Model account

Mental-model account seems to be a plausible suggestion explaining the human reasoning in many instances. But this does not guarantee that TEs are mental-models. One of the difficulties is that this account seems to have no answer for the failures of TEs. Since, model-based reasoning, like any other human reasoning practice, too can err this account does not seem to suggest a plausible account of failures of TEs. This makes the problem more complex by suggesting that the mental-model account in itself cannot differentiate between a successful TE and unsuccessful TE. An account of TE should explain why TEs are reliable. This means, an account of TE has to explain not only the success but also the failure of TEs. But mental model account is unable to explain the failure of TEs. Therefore, mental-model account also fails to explain the reliability of TEs.

1. Simulative model-based reasoning in Nersessian's view regards a mental-models as a structural analogue of the target system. This claim does not seem to support TEs in quantum mechanics. The structure of the target system (a quantum system) available is the structure provided by the quantum theory. Therefore, the structural analogue will become trivial because such structures are built into the theory. Apart from this, many TEs are too complex and some require manipulation of mathematical equations. The original EPR TE and Photon Box cases are good examples of TEs of the above sort in quantum mechanics. (See Chapter 2.1.4.1a for a detailed account of the EPR.) Simulating all such situation by merely following the TE narrative seems to a little farfetched.

2. Embodiment is not a necessary component of many TEs. Many of the TEs in quantum mechanics (See discussion of the EPR TE or The Photon Box TE in chapter 2) do not require the embodiment feature to reason out the conclusion.

3. The TE anti-TE puzzle seems to have no answer in the mental-model account. This is because every TE narrative enables the vicarious participation of the resoner, and by doing so the reasoned will successfully reach the conclusion of every TE. This suggests that the conclusion of both TE and its anti-TE are equally plausible in the mental-model account.

1.2.4 Fictionalist Responses to the Mystery of TEs

The epistemological mystery of TEs in the factionalist jargon is as follows. "The objects and situations pictured in these models are very unlike real objects in the real world of interest to the sciences. Yet they are supposed to teach something, indeed something important, about that real world. How? " (Cartwright 2010, 19). In other words, the problem is that TEs employ a bunch of unrealistic descriptions to talk about the real world and what sanctions such an employment of such unrealistic situations. In this section I discuss Nancy Cartwright's response to the mystery of TEs where she answers that TEs work like fables.

Cartwright tries to defend the use of highly unrealistic descriptions to talk about realistic situations. The Galileo's TE, which we have discussed, is an experiment in thought about what would happen if we were to conduct it. It is about frictionless planes and we do not have such planes in real life. But still we use the result of TEs like this to talk about stone and feather falling in air or real balls rolling on real planes. But, how do we connect the results of such TEs to the external real world? According to Cartwright, such models are like fables from which we draw morals. Consider the following fable.

"A marten eats the grouse;

A fox throttles the marten; the tooth of the wolf, the fox.

Moral: the weaker are always prey to the stronger" (Cartwright 2010, 20).

Like the characters in the fable, objects in the models are also highly special and usually do not resemble the ones we want to learn about. Just as we have never seen a frictionless plane, we might not have seen a marten or a wolf. "But the conclusion of the model, like the moral of the fable, can be drawn in a vocabulary abstract enough to describe the things we do want to learn about" (*Ibid*, 20). Similarly, the abstract description in the TE also applies to cricket balls and many other concrete things. According to Cartwright, "a description of what happens in the model that does not fit the target gets recast as one that can, just as the moral of the fable can apply to a broader range than the kinds of individuals pictured in the fable"(*Ibid* 20). To underline this she uses Menno Rol's idea that "climbing up the ladder of abstraction can take one from falsehood to truth. One immediate problem that may arise here is that, unlike most of the fables, all parables do not have their morals built into it. Or one may draw different morals from the same fable. In order to climb up the ladder of abstraction from falsehood to truth in a fable, parable or in a model, we need to know which is the ladder to climb up. This is not given to us by the fable or the model alone but we capture it from the rich context of the science in which it is embedded.

The Problem of Unrealistic Assumption: The models we employ in TEs are descriptions of imaginary situations. But we want them to discuss and describe the real world target systems. So, we are using unrealistic model to draw conclusions about realistic systems. Cartwright restricts her discussion to models in which the results are derived by deduction. In such cases due to the deductive nature of the model we are sure that the consequences drawn from the models are genuine. If the unrealistic assumptions do not play a role in the deduction of the intended results then such assumptions are irrelevant to the conclusion of the TE. But in most of the cases, the unrealistic assumptions play huge roles. This gives rise to the problem of unrealistic assumption. "How can a result that must occur given characteristics different from those in the target inform conclusions about what will happen in the target? The conclusion is supposed to be guaranteed because it follows deductively from the premises. How does that provide information about what conclusions to expect when the premises are different? " (Cartwright 2010, 22).

Solution1. Galilean Thought Experiments

Unrealistic assumptions do not always stand in the way of drawing lessons about the real world. Some models function as Galilean TEs and for them the unrealistic assumptions are not a hindrance but a necessary part of the reasoning process. A real Galilean experiment, a Galilean experiment performed in a laboratory, isolates a single factor in the best possible way to observe its natural effect when it operates on its own without other causes at work. For example, in the Galilean TE, the motion of object under the influence of gravity alone is an example of such a process where we are interested in a single factor. In a TE we imagine the situation and its consequences. In a real experiment, the result is produced according to the natural laws. "In a model that pictures a Galilean TE, it is the principles built into the model that dsetermine what the effect must be. So real experiments and thought experiments have complementary virtues" (*Ibid* 23). In the real experiment, we can never be sure about the elimination of confounding factors but we are sure that the results produced are in accordance with the natural laws. In contrast, TEs have only those factors which are stipulated and hence we are sure that there is no more confronting factors. But we cannot be sure about the results because the results depend on the principles we have provided in the models. "With respect to those models that serve as Galilean thought experiments, unrealistic assumptions that suppose the factor is at work all on its own, with no alternative causes at work, are no more of a problem than they are for real Galilean experiments. If we can learn about target situations with more "realistic" arrangements from actual Galilean experiments despite the "unrealistic" assumptions necessary to the experiment, the same is true for Galilean thought experiments (so long as the basic principles used in the model to derive the consequences are accurate enough)" (*Ibid* 24). So for some models and some kinds of unrealistic assumptions, the unrealistic assumptions pose no problems.

The problem of Unrealistic Assumption: Over constraint

Many causes cannot just act without the involvement of the specific setting in which they are placed. They need a concrete situation in which they can work. Consider, for example, a model to study the effect of skill-loss during the unemployment on future employment levels. To be a Galilean model, there must not be further causes that influences the given situation. But this stringent condition is hardly met in many models. There may be many reasons other than mere unemployment that influence the skill-loss. Therefore, the demand to eliminate all alternative causes is almost an impractical one to meet.

Matters are often arranged in such a way that they can be traced in calculations and deductions. So, often, mathematically tractable descriptions are preferred over more real ones. Hence Galilean models may have unrealistic assumptions than they should have. Cartwright calls such models as 'over constrained'. Galilean experiments take place in well-set conditions with unusual specifications. So our results are special results that we cannot expect in other Galilean experiments. In other words, the settings over-constrain the results.

Fables and Models, their Morals and Lessons

Following Gotthold Lessing, Cartwright suggests that "[T]he relationship between the moral and the fable is that of the general to the more specific and it is "a kind of misusage of the word to say that the special has a similarity with the general, the individual with its type, the type with its kind. Each particular is a case of the general under which it falls" (*Ibid* 26). The moral is to be fitted out by the fable. Moral describes just what happens in the fables. But the fable fits it out in a special way-"a way true to the moral but not necessarily shared by all cases of which the moral is true" (*Ibid* 27). This is like children in dress. They are children whether dressed up in one way or other but when dressed up they are filled out and there are more to them. From this Cartwright borrows the following two conditions:

"1. A concept or claim that is abstract relative to a set of more concrete descriptions or more concrete claims never applies unless one of the more concrete descriptions or claims also applies. These are the descriptions/claims that can be used to fit out the abstract description or claim on any given occasion.

2. Satisfying the associated concrete description/claim that applies on a particular occasion is what satisfying the abstract description/claim consists in on that occasion." (*Ibid* 27)

So, like the fables, the models fit-out the more abstract lessons. When a situation satisfies the more concrete result expressed in the language of the model, which is what it is for that situation to satisfy the more abstractly expressed result. According to Cartwright, thinking TEs as fables points out two methodological lessons: 1) Though the results of an experiment or of a TE may be over constrained, this may be inevitable since the abstract exists only in the concrete. 2). To get a conclusion that is true both in the model and in a variety of other cases, it may well be necessary to climb up the ladder of abstraction (*Ibid* 29).

Problem with Unrealistic Assumption: not Fables but Parables

Now consider the parables of the prodigal son or the workers in the Wineyard (these are parables from Bible). These parables differ from Lessing's fable of Marten and Grouse in which no moral can be attributed to itself. Here the moral is not built in but supplied from elsewhere. Cartwright suggests that the same is the case with models having unrealistic assumptions. In many cases the correct lessons to be drawn are more abstract than those described immediately in the concrete situation. Since, the moral is not built in we can seldom cast our models as fables. But we can cast them as parables where the instructions for correct reasoning come from elsewhere. Theories and the rich context in which the models are described play a huge role here. What is important is that we can move from falsehood to truth via abstractions.

The TEs like that of Galileo's, almost appear like perfect deductions. Such cases, which Cartwright calls, Galilean TEs, the result is guaranteed by the validity of the assumption and laws built into the model. The unrealistic assumptions do really threaten the validity of the application of the results of such TEs to concrete situations. But not every TE is a Galileon TE. Therefore, in non-Galilean TE cases, according to Cartwright, we should consider the TE as a parable. What is peculiar to parable is that the moral to be drawn is not built into the parable. One has to consider the context of the parable and the various assumptions taken in it to draw a conclusion. This also allows for multiple morals to a single parable. TEs when considered in the form of parables, Cartwright points, work in a similar way. One has to consider the theories employed and the context of the employment. The validity of the theories has real impact here. If the theories are incorrect the model is not going to give a result applicable to concrete situations. Similarly, the context also needs to be taken into account while extending the result to concrete cases.

Features of the Fictionalist account

1. TEs are considered as fables or parable with a moral.
2. Galilean type TEs are closer to fables where the moral is built into the model.
3. Non-Galilean type TEs are like parables. Just like the moral of a parable needs to be fitted-out the result of the TE model needs to be fitted-out by considering both the theories employed and the context of employment.

Limitations of the Fictionalist account.

1. The fictionalist account does seem to satisfy some of the three desiderata discussed

earlier. It violates the modeling assumption. Even when employing unrealistic assumptions scientist do not seem to think that they are creating a fable to read out and reach the external world. The abstraction and idealization employed, in scientific practice, are validated in real experiment scenario using different experimental techniques[13]. Parsimony criterion seems to be holding here. Cartwright is silent about the ontological status of the unrealistic assumptions. So, it is charitable to assume that the account does not pose any new ontological commitment. Fictionalist account does not seem to have an idea of unification in it. At best one can argue that we sometimes reason out conclusions about the external world from fictions. But this does not guarantee that in actual scientific practice a reasoning based on the model of reading parables are happening. One can, at best, argue that the fictionalist account is a plausible meta-account of some scientific reasoning. But this view does not seem to support the unification criterion.

2. The fictionalist account seems to presuppose a fictionalist account of scientific theories. It means, the higher order theories in science need to be considered as fictions with some use. But this is an extra burden for an account of TEs because as we have already seen there are other epistemological account of TEs that do not require a commitment to fictionalist account of scientific theories. An epistemological account TE, need not commit itself to the status of laws of nature and scientific theories[14].

3. The fictionalist account seems to have no concrete suggestion as to how to explain the failure of a TE. In the parable scenario, there might be more than one moral or conclusion drawn from a TE. Often, fables support inconsistent morals depending up on the mode of interpretation. But such inconsistent conclusions are not permissible about account of the

[13] See Chapter 2 for different techniques for validating the observation in experiments

[14] See Cartwright, for a discussion on the nature of higher order laws of physics. See Giere 2009 for arguments against considering scientific theories as fiction. Godfrey-Smith 2009 provides arguments in favor of a fictionalist account of scientific theories.

external world and the fictionalist account seems to have no concrete suggestion to overcome this predicament.

3. The fictionalist account seems also to have no suggestion regarding the puzzle of TE anti-TE situations. The morals of two fables can contradict each other. Therefore, if we consider TEs as fictions, TEs with contradictory conclusions as in the case of TE and anti-TE scenario is not a puzzle at all. But TEs are employed to speak about the external world. It is inappropriate to suggest inconsistent conclusions to a problem regarding the external world. For example, in the Galileo's Free Falling Body TE, we are employing the TE to reason about the free fall in the real world. Here, it is unjustifiable to suggest that both the Aristotelian account and the Galilean account of free fall is equally true. Same is the case with TE anti-TE scenario. Factionalist account does not seem to even identify this as a problem for morals of tales can contradict and TE are tales with morals.

1.3 The Evidential Significance of Thought Experiments

What is the importance that thought experimentation has, as a practice, to provide evidence for a theory or a causal or nomological claim? One of the claims is that the evidential significance of a TE depends only on the features of that TE. Contrary to this view McAllister contends that TEs acquire evidential significance only in the context of particular assumptions and theoretical background. In this section, I discuss James McAllister's arguments on the evidential significance of TE where he contends that a TEs does not have intrinsic evidential significance but it has bearings on the background in which the TE is performed.

Evidential Significance of Concrete Experiments

In order to gain evidential significance a real experiment needs to obtain its legitimacy among the practitioners of a science at least in two ways. The experiment must satisfy the standards mandated by the particular scientific community. Proper calibration of the instruments, controlling of external factors and many of such instructions are part of these standards. More fundamental, according to McAllister, is that "the practitioners must be persuaded that experiment at all yields evidence relevant to resolving controversies in the science" (McAllister 1996, 3).

In the logicist view, evidential significance of experiments are intrinsic to them and they are not related to the argumentative context. Evidential significance of experiments and evidential significance of a particular experiment for a particular scientific claim need to be clarified here. In the second case, the relevance of the experiment clearly depends in part on the background assumptions. This is acknowledged by many, even by those who hold the logicist view. An experiment may lack evidential significance for a particular claim. But this does not undermine the belief that experiment has evidential significance. Someone holding such a belief will remain convinced that scientific claims are supported and rejected by experiments and she will search for an experiment that has evidential significance for the claim under consideration.

In Karl Popper's account, the relevance of experiment is conferred by the fact that the experiment is the source of observation statements that refute possible theories. So, evidential significance derives directly from the logical relation between observation-sentences and possible theories. Since it a logical relation it has nothing to do with the argumentative context. But contrary to the logicist conception, historical records suggest that the evidential significance is an outcome of historical and local accomplishments. "More precisely, the historical record suggests that the evidential significance of experiment is not an intrinsic property of the practice, but rather is conferred on experiment at particular times in particular areas of science by the persuasive effort of scientists" (McAllister 1996, 4).

Evidential Significance of Thought Experiments

According to McAllister, for a TE to be accepted in a science as evidence it must satisfy two conditions. “Firstly, the practitioners must be persuaded that the thought experiment is well formulated on the standards holding in that science; these standards may for instance require the scenarios envisaged in thought experiments not to violate pertinent established laws of nature. But more fundamentally, the practitioners must be persuaded that thought experimentation at all provides evidence relevant to establishing and discrediting claims in the science, i.e. that thought experiment has evidential significance there” (McAllister 1996, 8). Logicist premises hold the view that TEs have evidential significance irrespective of any assumption or they have evidential significance intrinsically. This view, according to McAllister, leads to three conclusions. Firstly, that there is a number of exemplary thought experiments, to which scientists through the centuries have added, that have an intrinsic high efficacy in establishing scientific matters of fact. Secondly, that scientists of all disciplines and epochs who are sufficiently well informed and fair minded will acknowledge the evidential significance of these thought experiments. Thirdly, that there is no such event as a process in which thought experiment acquires or loses evidential significance in a science” (McAllister, 1996, 9).

Consider Galileo's TE of Free Falling Bodies. According to Galileo, since he can deduce a contradiction from the Aristotelian theory of motion in his TE, the Aristotelian theory of motion is wrong. How does this TE attain evidential significance? The Galilean mechanics is a science of phenomenon in which contrived occurrences can serve as evidence. But the Aristotelian mechanics is a science of natural occurrences and so, evidence is vested in reports of natural occurrences. Natural occurrences are the events happening without the intervention of the experimenter. Free fall, for example, is a natural occurrence. But in the TE we are asked to assume situations where the body is moving in a medium devoid of any resistance under the influence of gravity alone. Such a situation, which is a contrived modern experimental situation is a modern scientific situation and is not a natural situation. So, for a practitioner of the Aristotelian mechanics, the Galilean TE is not an acceptable experiment because the TE is not dealing with natural occurrences. Hence, the TE has no role in establishing or discrediting claims in Aristotelian mechanics. Most of the times, Aristotelians countered Galileo's TE with reports of natural occurrences. Against the free falling body TE, they submit reports of actual fall of bodies of different weights in which the heavier bodies reached the ground before the lighter ones. This clearly indicates that the evidential significance is not intrinsic to TEs but are obtained in a large theoretical background.

McAllister's argument also illuminates the importance of the metaphysical assumptions in the evidential significance of TEs. Galileo, in his TE, was trying to argue a case favoring a phenomenon. The Galilean phenomenon is not a part of the Aristotelian conception of the world. A phenomenon, in the Galilean sense, is an exemplification of a universal principle that governs and unifies all occurrences. The mathematical structure of the theory is a representation of this prefect phenomenon. Scientific explanation, according to Galileo, is an explanation of this phenomenon. This is a departure from the Aristotelian conception of science and the world. In the Aristotelian science, the attempt is to explain the occurrences which are natural in the sense that they are happening in the real world. Natural occurrences, according to Galileo, is vexed with a lot of contingencies of the external world which he calls accidents. According to Galileo, there will always be a slight mismatch between the original experimental data and the theoretical data because of the problem of accidents (See Koertge 1977). This suggests that the Galilean TE can be easily set aside by an Aristotelian because such an experiment does not make any sense in her schema of scientific world. This suggests that the evidential significance of TEs are dependent on the metaphysical assumption with which the scientific activity is performed.

CHAPTER 2

THE LIFE AND DEMISE OF THOUGHT EXPERIMENTS

This chapter has two sections. In the first section, I discuss the paper by Ian Hackings titled 'Do Thought Experiments have a Life of Their Own?' In the second section, I attempt to reply to the article 'Computational Modeling: Is this the end of thought experimenting in science?' by Chandrasekharan *et al.* (2013). Both the papers, for different reasons, argue that thought experiments are relatively insignificant in contemporary sciences.

Why Thought Experiments do have a Life of Their Own.

In his path breaking book *Representing and Intervening* published in 1983, Ian Hacking introduced the metaphor "life of experiments". This apt metaphor worked very well in that it, along with other reasons, catalyzed the process of reconfiguring the focus of philosophy of science from being dominantly theory-centric to both theory and experiments. This metaphor seems now to be a part of the lexicon of philosophy of experiments. Interestingly though, in a paper published in 1992, while discussing thought experiments, Hacking claims that in contrast to real experiments thought experiments do not have a life of their own.

In this first section of the chapter, I will discuss Hacking's arguments in favor of a life of experiments. Subsequently, I set out the reasons for Hacking's denial of the same to thought experiments. Next I discuss the historical evolution of two thought experiments, namely the EPR and Galileo's Free Falling Bodies. In the light of that discussion, I argue that (at least some) thought experiments can and do meet the same criteria which, according to Hacking, real experiments do meet to have a life of their own. So, I conclude that thought experiments do have a life of their own. The section is divided into three main sub-sections. In the first sub-section, I review the reasons that Hacking sets out for suggesting that experiments have a life of their own. The second sub-section discusses Hacking's characterization of thought experiments. This sub-section also reviews his arguments for denying a life to thought experiments. In the sub-section three, I argue for a life of thought experiments. In this sub-section, I discuss the historical evolution of the EPR thought experiment and Galileo's Free Falling Bodies in detail to show the untenability of Hacking's arguments. From this I conclude that TEs do have a life of their own.

2.1 Experiments and their Life

Ian Hacking in his book *Representing and Intervening* states that "experiments have been neglected by historians and philosophers of science for far too long" (Hacking 1983, 149). He argues out the neglect of neglects of experiments in philosophy of science quite convincingly and hopes that his work "might initiate a Back-to-Bacon movement, in which we attend more seriously to experimental science. Experimentation has a life of its own" (Ibid, 150). Allan Franklin shares Hacking's view on the neglect of experiments in his review of *Representing and Intervening* (Franklin 1984, 381). He underscores the importance of a 'back to Bacon movement' and subscribes to the 'life of experiment' metaphor. Franklin, while discussing the philosophy of experiments, has employed the same metaphor later in 2007 and in 2012. This shows the importance of 'the life of experiment' metaphor in the lexicon of contemporary philosophy of experiments. Before examining Hacking's claims about the life of thought experiments, it will be worthwhile to explicate the notion "the life of experiment", following Hacking and Franklin.

2.1.1 Traditional views on Experimentation

Experimentation was traditionally considered as an activity determined by theory. In order to expound this received view, Hacking invites our attention to Justus von Liebieg (1803-73), a pioneer of organic chemistry and Karl Popper. According to Liebig, "in science all investigation is deductive or a priori. Experiments are considered as an aid to thought, like a calculation: the thought must always and necessarily precede it if it is to have a meaning. An empirical mode of research, in the usual sense of the term, does not exist. An experiment not preceded by theory, i.e. by an idea, bears the same relation to scientific research as a child's rattle does to music" (Liebig 1869 in Hacking 1983, 153). In Popper's account, theoreticians give questions for the experimenter to elicit definite answers. In other words, the theoretician must have framed his/her questions as sharply as possible for the experimenter (Popper 1954 in Hacking 1983, 155). In short, from framing of an experiment to interpretation of the data, experimentation is a theory-driven activity.

Though the scientist Liebig and the philosopher Popper belong to two different periods in the history of science and philosophy, their views on experimentation bear close similarities. Both of them point out that experimentation is an activity determined by theory. According to Liebig, experimentation, when not preceded by a theory, is an otiose activity. For Popper, experimentation is an activity to check the validity of the claims proposed by theoreticians. Both of them consider theory-testing (falsification in the case of Popper) as the only role performed by experimentation. They also suggest that from framing of an experiment to interpretation of the data, experimentation is a theory-driven activity. This was the traditional view of experiments which, according to Hacking, led to the neglect of experimentation in philosophy of science. Three important points of the traditional view on experimentation are as follows:

i. Experimentation is a theory-driven activity.
ii. Theory testing is the main and only role of experiments.
iii. Experiments are always preceded by a theory.

Hacking disagrees to all the above three points of the traditional view. This is discussed in the next session.

2.1.2 Hacking's Responses to the Traditional View of Experimentation

2.1.2a The Two versions of Theory-dominance and the Robustness of Experimental Result

In the traditional account, experimentation is a theory-dominant activity. Hacking points out two versions of this theory dominated view of experiment. The weak version says that one must have some ideas about the nature and apparatus before conducting an experiment. A mindless tampering with the nature, without any understanding or ability to interpret the result, would teach almost nothing. The strong version has it that an experiment makes sense only when it is conducted under the light of a theory or only if it is the test of a theory about the phenomena under scrutiny (Hacking 1983, 153-54). Hacking accepts the weak version but doubts the strong version.

According to Hacking, not every idea behind an experiment qualifies as a theory. Theory, for him, should be a well formulated scientific speculation. All the background information employed to conduct an experiment could not be counted as theory. This point could be illuminated further if we consider the example of microscopes. Hacking cites that there have been drastic changes in the understanding of the theory of microscopes. Microscopes had undergone such different modifications that the capability of the instrument has improved extensively. But the right theory of the working of microscopes has been known only after the works of Ernst Abbe. Despite all these changes, the results of the experiments with microscopes stood robust. In other words, despite the drastic changes in the theoretical understanding of instruments, results were shown to be the same in the cases of microscopes. This robustness in the result of experiments poses the following challenge to the strong version of theory-dominant view of experimentation. The result of the experiment (in the above case, observation data produced by microscopes) stood the same even when the theoretical understanding of the working of the instrument, and hence the experiment, were partially or completely wrong. This suggests that even wrong theoretical understanding can lead to experiments that produce correct result. But, if experimentation is theory-driven then the results of experiments should vary with respect to the changes in the theoretical domain. The robustness of experimental result questions the above understanding. It should be noted that the correctness of the experiment here means any of the following:

a) Robustness in the data produced by the experiment.

b) A numerical value that desist changes in the case of an experiment measuring quantities.

c) Repeated appearance of a phenomenon which may or may not have explanation in the present theories.

Therefore, experimentation is not an activity determined by theory as it has been indicated by the strong version of the theory-dominant view. This is one among the many reasons to claim a relatively theory-independent status for experiments. It should be noted that Hacking accepts the weaker version of the theory-dominant view of experimentation. The weaker version accepts that experiments may be framed by some theoretical understanding and background ideas. This means that experimentation as a practice is guided by some theories but not that experiments are completely determined by a theory. It should also be noted that Hacking does not claim that the result of an experiment is interpreted or understood independent of a theory. His claim seems to be that the data produced, phenomena created or phenomenological relations expressed by experiments, can have independent status irrespective of both the theoretical understandings before and after the experimentation. The experimental result may or may not receive different interpretation as well as explanation after the experiment. But the phenomenological result will remain the same irrespective of the changes in the theoretical domain.

2.1.2.b Different roles of Experiments

In the traditional view, theory-testing is supposed to be the only role performed by an experiment. This is a misleading suggestion. Though many important roles performed by experiments have direct relation to theory, they perform many roles other than that of theory testing. Following Franklin (2007, 2012), I will list some of the important roles of experiments.

1. Experiments test theories and provide basis for scientific knowledge.
2. Experiments show the incorrectness of accepted theories and call for new theories.
3. Create new phenomenon which is in need of explanation.
4. Provide hints towards the structure or mathematical form of a theory.
5. Give evidence for the existence of new entities involved in theories.
6. Measure quantities.
7. Provide evidence for future theories.
8. Finally, experiments have a life of their own. (This is not an exhaustive list.)

This list shows that experiments are not a process of mere theory validation. Hacking (1983) and Franklin (2007, 2012) have provided plenty of examples to highlight different roles of experiments. This clearly suggests that the traditional view on the role of experiments is at best an inadequate characterization of experimentation.

2.1.2c Theory, Experiment and the Order of Arrival

In the traditional view, experiments are always conducted in the framework suggested by a theory. In other words, it is far from possible to have an experiment without a theory. And it is this point that Hacking contends. By citing examples from the history of science, he argues that there are experiments which come before theory, after theory, and seemingly along with a theory. There are experiments which are conducted without a theory (in the strong sense). To prove this Hacking cites examples from the history of thermodynamics where the theoretical explanation of thermal engines came after the invention and many practical modifications of steam engines. Also there is an example of independent but simultaneous development of an experiment and a theory. The incident under consideration is the discovery of the residual temperature of the universe by radio astronomers Arno Penzias and R.W. Wilson in 1965 and the theoretical explanation of it offered by the theoretical physics group at Princeton. The experiment and its theoretical explanation of the experiment happened independently but almost simultaneously. Hacking uses examples like the ones mentioned above to contend that experiments do have a life of their own, in the sense that they could stand on their own without relying on a theory. (For more examples and a detailed discussion, see Franklin 2012). The above discussion also suggests that unlike the traditional view, experiments do have a relatively theory-independent status.[15]

2.1.2d The Life of Experiments

The above discussion clearly suggests a relatively independent nature of experimentation. The relative independence is argued out on the basis of the robustness of the experimental result. Hacking suggests that experiments evolve over time. Evolution of experiments could be understood in any of the following ways:

a) The employment of better instruments to produce better results. In such cases, both the frame work of the experiment and underlying theories may remain the same. Microscope is a good example. Resolving power of microscopes has considerably improved over time. A microscope with better resolving power obviously makes a better experiment.

b) Improved skill of the experimenter yields better result. This follows from the fact that observation is a skill. An experimenter requires different skills, both tacit and obvious which are acquired over time by tinkering in the laboratory for conducting an experiment. (See Hacking 1983, 180-181).

c) The same experiment could be conducted under the light of an improved theoretical

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15 Since observation is an integral part of any experiment, theory-ladenness of observation also demands some explanation here. One of the issues is that the instruments for conducting experiments are built on the basis of theories. Therefore, observation made by employing such instruments are necessarily laden by the theories on the basis of which the instruments are built. In order to meet the above challenge, Allan Chalmers argues that if the theory or theories on which the instruments are built have no direct bearing on the theory of the target object then the observation could be considered as not theory-laden. See Allan Chalmers 2003. Allan Franklin has set out detailed strategies for validating observation. See Franklin 2007, 2012.

understanding and this may completely change the prospect of the experiment. The famous Michelson-Morley experiment is a good example of this. Initially, the experiment was conceived by Michelson as an experiment to check the relative velocity of the earth with respect to aether and it was intended to establish the validity of aether hypotheses. The prospects and status of the experiment were changed drastically after Einstein's special theory of relatively. Later many considered Michelson-Morley experiment as a crucial test of the special theory of relativity. (See Collins and Pinch 1993, 27-56).

d) An experimental result which is initially neglected may gain attention because of new theoretical understanding. The experiments on parity violation are good example. Initial experiments that suggested the violation of parity conservation in weak interactions were neglected but similar experiments attracted attention after the theoretical suggestion of parity violation in weak interactions. (See Franklin 1989, 7-72). (the list is not exhaustive)

This discussion clearly suggests that not only do experiments but the prospects of experiments also undergo different changes and many such changes are not foreseen by theories. The suggestion is that experimentation as a scientific activity has its own independent status and is not an activity subservient to theory constructions. To conclude, experimentation has its own status which is relatively independent of theories and hence experiments have a life of their own; "maturing, evolving, adapting, being not only recycled but also, quite literally, being retooled" (Hacking 1992, 307).

2.1.3 The Life of Thought Experiments

In the previous section, we have seen that real experiments do have a life of their own. They evolve, mature and perform different roles other than that of mere theory testing. In 1992, Hacking wrote, "I intended partly to convey the fact that experiments are organic, develop, change, and yet retain a certain long-term development which makes us talk about repeating and replicating experiments. I think of experiments as having a life: maturing, evolving, adapting, being not only recycled but also, quite literally, being retooled. But thought experiments are rather fixed, largely immutable" (Hacking 1992, 307). Further he adds that, unlike good proofs in mathematics whose proof ideas are employable in different contexts, TEs are generally unemployable in different contexts. They are fixed both to the context of their inception and to the theoretical ideas that helped forming the TE. They have only one tension, the tension between two conceptual systems, to expose (). This, according to Hacking, is the one and only job of TEs. Therefore, he concludes that TEs do not have a life of their own.

Let us contrast Hacking's reasons for denying a life of TEs with the reasons that substantiated the argument for a life of real experiments.

1. According to Hacking, TEs do not evolve. Unlike real experiments there is no maturing of a TE. Therefore, a TE once executed into perfection is an icon and icons do not undergo changes. Even when we repeatedly employ a TE, Hacking contends that, we are going through the same diagrams and reaching the same conclusion. He suggests that "[P]eople do rethink through the thought experiment, even from generation to generation. But what they think is what was once thought, and continues to use the very same diagram..." (307) and this should not be counted as 'a life'.
2. TEs are always built on the basis of some theory. Therefore, the result of a TE is driven by the theoretical assumptions it has taken into account. Hence, it cannot have an independent status. Contrast this with real experiments. Hacking has shown that the result of real experiments can have independent status. (See Section **2.1.2**). This could be seen as one of the reasons for considering TEs as icons.
3. The theory-ladenness of TEs when contrasted with that of real experiments forces one to

think about the order of arrival of theory and TEs. If TEs are theory-laden in the above sense it is hard to find a TE that appeared before a theory.

4. The one and only role of TEs is to show the tension between two conceptual systems. In fact, Hacking suggests a very strong role to TEs that they can dislodge one from a particular way of describing the world and replace it with another picture (*Ibid* 307). Real experiments, in contrast to TE, perform many roles. (See section **2.1.3)**

The above discussion seems to suggest that in contrast to real experiments TEs do not have a life of their own. I will challenge the above conclusion in the next section.

2.1.4. Meeting Hacking's Demands

In this section, I will try to show that TEs can and some TEs do satisfy the criteria for a life of their own. If we employ a 'back-to-Bacon' approach we could see that TEs indeed challenge all the four points listed above. I will employ two thought experiments, namely the EPR thought experiment and Galileo's Free Falling Bodies to argue out a life of TEs.

2.1.4.1a The EPR: A Thought Experiment that Evolves

According to Hacking, TEs do not evolve. Unlike real experiments, they won't undergo changes that lead to better results. Here, I will discuss the different stages of the development of EPR thought experiment. This TE was not only recycled but was also literally retooled over a period of 50 years. It has gone through almost all the transformations-that of maturing, evolving, adapting, and retooling-which Hacking has denied to a TE.

Albert Einstein, Boris Podolsky and Nathan Rosen presented the first form of EPR TE in 1935 in *Physical Review* in the article titled "Can Quantum-Mechanical Interpretation of Physical Reality be Considered Complete?" The name EPR was later employed as the acronym for this TE. The paper begins with the following assumptions which are seemingly uncontroversial and are supposed to be satisfied by any serious physical theory.

1. There is objective reality which is independent of any theory.

2. There are differences between the objective reality and the physical concepts with which the theory operates.

3. The concepts are intended to correspond[16] with the objective reality. We picture the reality by employing these concepts (Einstein *et al.* 1935, 777)

A physical theory, according to the authors, is satisfactory only when it is correct and complete. Correctness of a physical theory is judged by the degree of agreement between the conclusions of the theory and human experience, say, experiments and measurements. According to the completeness condition, "every element of physical reality must have a counter part in the physical theory" (*Ibid*, 777). This is considered as a necessary condition for the completeness of any physical theory. Physical reality is defined in the following way, which according to the authors, is a sufficient condition. "If, without in any way disturbing a system, we can predict with certainty (i.e., probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity" (*Ibid*, 777).

Let us start the discussion of the EPR with the following preliminaries of quantum mechanics. The state of a system in quantum mechanics (in the Copenhagen interpretation of quantum mechanics) is completely described by its wave function Ψ. Wave function Ψ is a function of the variables selected to describe the behavior of a system. Corresponding to every measurable quantity there is an operator A. When $\Psi' = A\Psi = \lambda\Psi$ (where A is an operator and λ is a number) we call Ψ an eigenfunction of the operator A. When Ψ is an eigenfunction of the operator A, A has a

16 One could wonder about the different senses of "correspondence" here. But whatever be the nature of the correspondence it has very little to do with the central point of this paper. So, I am not discussing it here.

definite physical value (which is λ here). In other words, only those states of a physical system which are eigenstates can have definite and measurable physical value. According to Heisenberg's uncertainty principle, no two non-commuting operators can have arbitrarily accurate values simultaneously. i.e., if A and B are two non-commuting operators then $[A, B] = AB\text{-}BA \neq 0$. This, in quantum mechanics (in the Copenhagen interpretation) means that no two quantities corresponding to two non-commuting operators can have simultaneous physical reality. Since position and momentum, energy and time are non-commuting physical properties, according to (the Copenhagen interpretation of) quantum mechanics, a quantum mechanical description of physical system cannot have these physical realities simultaneously[17]. If the physical quantities corresponding to the non-commuting operators have simultaneous physical realities then they should have entered into the description of the system. This follows from the completeness condition. Therefore, quantum mechanics, according to Einstein *et al.*, is a correct theory but it is not a complete theory and hence not a satisfactory theory.

In the background of the above preliminaries, the EPR could be summarized as follows. Consider two systems I and II, which had an interaction between them from time t=0 to t=T. Suppose that the states of the system before t=0 were known. The state of the combined system I+II can be calculated by using Schrödinger's equation. Let Ψ be the wave function of the combined system. According to quantum mechanics, we cannot calculate the state of system I or II after their interaction without the help of some measurements on either I or II.

Let $a_1, a_2, a_3 \ldots$ be the eigenvalues of some physical property A pertaining to system I. $u_1(x_1)$ $u_2(x_1)$, $u_3(x_1) \ldots$ be corresponding eigenfunctions, where x_1 stands for the variables employed to

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17 Neils Bohr has explained this employing his principle of complementarity, which in a nutshell can be expressed as "a quantum system has no definite kinematical or dynamical state prior to any measurement" (Jan Faye 2014). For a detailed but introductory account of Copenhagen interpretation of quantum mechanics. see Jan Faye 2014.

describe the system I. Now, the wave function Ψ which is considered as a function of x_1 can be described as

$$\Psi\ x1, x2\ = \sum_{n=1}^{\infty} \Psi_n'\ x_2\ u_n\ x_1\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where x_2 stands for the variables employed to describe the system II. Suppose that the property A is measured and its value is found as a_k. So, after the measurement, the system I and II are left to the state described by the wave functions $u_k(x_1)$ and $\Psi_k\,(x_2)$ respectively. The wave function described by the infinite series in (1) is now reduced to the state of $\Psi_k\,(x_2)\ u_k(x_1)$.

Suppose that $b_1,$ b_2, b_3... are the eigenvalues of the physical property B and $\upsilon_1(x_1)$, $\upsilon_2(x_1)$, $\upsilon_3(x_1)$ are the corresponding eigenfunctions. It was the choice of the physical property A that determined the set of wave functions $u_n(x_1)$ as mentioned above. If the choice of physical property was B instead A, then instead of (1) we would have obtained a different equation as follows.

$$\Psi(x1, x2) = \sum_{s=1}^{\infty} \varphi_s\ x_2\ \upsilon_s\ x_1\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2$$

Now, if we made a measurement on the system I for the quantity B and the property was found to have a value b_r, we can conclude that after the measurement the system I and II are left in the states given by $\upsilon_r(x_1)$ and $\varphi_r(x_2)$ respectively. This allows one to say that "as a consequence of two different measurements performed up on the first system, the second system may be left in states with two different wave functions" (*Ibid* 779). At the time of the measurement, the systems no longer interact together and they are kept far apart. According to the special theory of relativity, no signal can travel faster than the speed of light. Therefore no signal, if any, sent by the first particle, after a measurement is performed on it, can instantaneously influence the second particle. This allows one to keep the assumption of locality, i.e the measurement over the system I has no instantaneous influence over the system II. Hence, the measurement carried out on system I cannot influence the system II instantaneously. Therefore, "**it is possible to assign t**wo different wave functions (ψ_k and φ_r) to the same reality (to the second system after the interaction with the first)" (*Ibid*, 779. emphasis original.)

Let the two wave functions, ψ_k and φ_r are eigenfunctions of the two non-commuting operators P and Q, say that of position and momentum. Suppose that the system I and II are two particles which are far apart but they had an interaction between them from time t=0 to t=T. In the light of the above discussion, one can show that it is possible to assign two different wave functions that of position and momentum to the same reality (to the second particle after the interaction with the first). By recalling the definition of reality, one can now assign elements of physical reality to the position and momentum of a particle simultaneously. This shows that physical quantities with non-commuting operators can have simultaneous reality. If the wave function is a complete description of physical reality then it must be able to predict such values, say, that of position and momentum of a particle, simultaneously. But the Copenhagen interpretation of quantum mechanics prohibits the assignment of simultaneous physical reality to the position and momentum of a particle. Keeping the assumption of locality and the definition of completeness along the thought experiment we can formulate the following argument:

1. Either the wave function is not a complete description of physical reality or two non commuting operators of physical quantities do not have simultaneous physical reality. (~P or ~Q)
2. Two non-commuting operators of physical quantity can have simultaneous physical reality. (Q)
3. The wave function is not a complete description of physical reality. (~P)

Therefore, "the quantum mechanical description of physical reality given by wave functions is not complete" (*Ibid* 780).

The EPR-Bohm: Retooling of the EPR

Position and momentum are the non-commuting measurables employed in the original EPR thought experiment. In 1951, David Bohm introduced spin instead of position and momentum into the EPR thought experiment (See Fine, 2004). Assume that an atomic particle is decayed into two particles of spin 1/2 and -1/2 and these are flying apart. The particles do not interact after the decay and hence the total spin remains zero. In the Bohm version of the thought experiment we measure the spin components of the fragments whose values will be anti-correlated. If we measure a positive spin for one particle with respect to the orientation axis orthogonal to the direction of the fragment, the spin of the other particle would be negative with respect to the same axis. The particles can be moved far apart. Like the position and momentum operators, the spin operators for different orientations do not commute. Also the angular spin of the system is conserved and hence the total spin of the system would remain the same before and after the fragmentation. This helps one to mirror the EPR thought experiment in Bohm's version. Suppose that an atomic particle is decayed into particles A and B. Suppose that one measures the spin of the particle A along x-axis and finds it as + 1/2. From this measurement she could predict the value of the spin of the other particle B along x-axis and which will be -1/2. Suppose that instead of measuring the spin of the part B along the x-axis, she measures it along the y-axis. From this, she could predict the spin of the particle A along the y-axis with any arbitrary amount of accuracy. This allows one to conclude that the particle has spin along x-axis and y-axis simultaneously. But the uncertainty principle does not permit this. Following the uncertainty principle, quantum mechanics prohibits one to assign simultaneous reality to non-commuting components of spin.

The possibility of an instantaneous influence is ruled out by keeping the particle far apart while measuring. But whenever a measurement is performed over one particle, A and the spin is found + 1/2, the other particle, B, if measured in the same orientation seems to assume the opposite spin, -1/2. Before the measurement, according to the quantum mechanics, the particle's spin is not determined and it is in a state of superimposition of the two possibilities i.e. +1/2 + -1/2. The thought experiment shows that the particle has spin in different orientation simultaneously. According to the EPR, if quantum mechanics is a complete theory of physical reality, it should be able to tell us the value of the spin of the particle B on any of the axes. But, according to quantum mechanics, the particle B has no spin along an axis before a measurement. Thus Bohm's version of the thought experiment (later known as EPR-Bohm) mirrors the original EPR.

Einstein *et al* concluded the EPR thought experiment with the following suggestion: "While we have thus shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible" (Einstein *et al* 1935, 780). Bohm, following Louis de Broglie, has proposed a different interpretation of quantum mechanics which suggests that quantum mechanics is a complete description of physical reality. According to Bohm, a system of particles is only partly described by its wave function. The description is made complete by specifying the actual positions of the particle. This is described by a guiding equation which expresses the evolution of the system in terms of the wave function. This interpretation is known as hidden variable interpretation. The Bohmian interpretation is both local and deterministic (See Sheldon 2013). It should be noted that along with the retooling of the EPR Bohm has suggested a different interpretation of quantum mechanics to solve the problem posed by the EPR. This advancement in the theoretical domain was clearly motivated by the discussions around the TE.

Bell's Inequality[18]

In 1964, John Stuart Bell formulated an experimentally verifiable theorem regarding the status of quantum mechanics with respect to the EPR thought experiment. Assume that the state of a system is completely determined by its local environment. Also assume that there are some hidden variables that determine the state of the system. With these assumptions, consider the EPR-Bohm thought experiment. In this situation, the spin of a particle is completely determined by its local environment and the measurement over one particle has no influence on the other. A particle, therefore, has one and only one value for spin which will correspond to either T (up) or F (down) after a measurement. Suppose that we have three measuring apparatus A, B and C which are arbitrarily oriented at angles Π /2, 2 Π /3 and Π radians to the direction of motion of the particles. Suppose that we can randomly select the measuring apparatus and measure the spin of both the particles simultaneously. For measuring apparatus with the same orientation for both the particles they will show spin T or F, but the spin will be anti-correlated. Now, if there are hidden variables that determine the state of a particle and the measurement over one particle has no instantaneous influence on the other particle, the possible correlation in the experiment could be illustrated by the following table.

18 Here I am following a simple version of Bell's theorem explained by Leonard Susskind in his Standford lectures on quantum entanglement. For the full lecture follow http://www.youtube.com/watch?v=XlLsTaJn9AQ/10/10/2014. For a more simple version of the argument follow http://www.youtube.com/watch?v=sAXxSKifgtU/10/10 2014. For a detailed but introductory account of Bell's theorem see Abner Shimony, 2004, Bell's theorem.

A, B, C are apparatus for measuring the spin. T and F are the two possible measures of spin. + sign indicates the correlation where one result is T and other is F

Table 1. Table illustrating the correlation relation between different spin measurements.

A	B	C	A.~B	B.~C	A.~C	~A.B	~A.C
T	T	T					
T	T	F		+	+		
T	F	T	+				
T	F	F	+		+		
F	T	T				+	+
F	T	F		+		+	
F	F	T					+
F	F	F					

From the table it is evident that whenever A.~C occurs either A.~B or B.~C also occurs. But A.~B and B.~C can occur without the occurrence of A.~C. Therefore, we will get the following inequality:

N(A.~B)+N(B.~C) ≥ N(A.~C), where N stands for the number of outcomes of a particular combination. If we repeat the experiment several times and keep the count then

P(A.~B)+P(B.~C) ≥ P(A.~C).................................3

where P stands for the probability of a particular combination of measurement. It is also evident from the table that whenever B.~A occurs, either C.~A or B.~C also occurs. But C.~A and B.~C can occur without the occurrence of B.~A. Following the above reasoning, we could get

N(C.~A)+N(B.~C) ≥ N(B.~A). Hence,

P(C.~A)+P(B.~C) ≥ P(B.~A)..................................4

Similarly

P(A.~C)+P(B.~A) ≥ P(B.~C) …..............................5

The inequalities expressed in 3, 4 and 5 are called Bell's inequalities.

This is the prediction of the hidden variable interpretation of quantum mechanics. For statistical interpretation of quantum mechanics the prediction will be considerably different. Thus Bell's theorem paved the way for an experimental verification of the hidden variable interpretation of quantum mechanics. The experiment performed by Alain Aspect *et al.* later showed that the Bell's inequality is violated in real situation (Aspect *et al* 1982). But it should be noted that, Bell's inequality does not say anything about the completeness of quantum mechanics. It only suggests that no local hidden variable interpretation of quantum mechanics is consistent with the statistical interpretation of quantum mechanics (See Fine 1986 40-63).

The Evolution of EPR

Einstein *et al* published the EPR paper in Physical Review in 1935. Neils Bohr attempted a rebuttal of the EPR in the very next issue of Physical Review. Bohr argued that the definition of reality proposed by Einstein *et al* is ambiguous[19] (Bohr 1935, 697). According to Bohr, any act of measurement will produce irretrievable consequences in the system and hence there is no way to predict the value of a physical quantity without disturbing the system. Therefore, the description of the system by the wave function (introduced to describe it) before the measurement will not be a suitable description of the system after the measurement. The then scientific community accepted Bohr arguments.

Bohm has introduced significant changes in the EPR. The position and momentum are the non-commuting measurables employed in the original EPR. In Bohm's version different components of the spin of a particle are employed as the non-commuting operators. One could consider the EPR-Bohm as an adaptation as well as a retooling of the original EPR. The principal ideas in both the versions are the same. But the retooling made by Bohm, as we have already seen, helped Bell to come up with the inequality theorem. The retooling also helped people to suggest other EPR type thought experiments.

Einstein himself has opined that the original EPR thought experiment is 'smothered by formalism' (Home and Whitaker, 2007, 109). But Bohm's version, according to many scientists, "is a straightforward argument logically and physically, and it avoids the technical complexities and conceptual difficulties of EPR35 [the original EPR]" (Ibid, 120). A thought experiment which was seemingly complex at the time of its inception is made simple both logically and physically by retooling. The changes introduced to the EPR not only made it simple but also paved the way for transforming it into a form which allowed the transformed description to have a connection with experiment. Following Bell's theorem, Aspect *et al.* realized the EPR-Bohm in laboratory. They

19 Bohr's reply seems to have very little influence on the later developments of the EPR. In fact, those scientists who are dissatisfied with the Copenhagen interpretation and Bohr's reply contributed more to the development of the EPR and other interpretations of quantum mechanics. Since this paper focuses on the evolution of the EPR, Bohr's reply is not discussed in any detail. For a critical discussion of Bohr paper see Home and Whitaker 2007, 126-131.

considered polarization of photon, instead of spin, for experimental purposes. Polarization, like spin, do not commute for different orientations. This could be seen as another retooling of the EPR for the purpose of experimentation. From the initial EPR thought experiment by Einstein *et al.* to the experimental verification by Aspect *et al.* we could see a gradual evolution of the EPR thought experiment. These different steps could be summarized as follows:

1. EPR original 1935 by Einstein *et al.*
2. Niels Bohr's reply to EPR in 1935.
3. Adaptation and retooling by the introduction of spin by Bohm in 1951.
4. Bell's theorem in 1964.
5. The experiment by Aspect *et al* in 1982 by employing a further retooling. Spin which was introduced to the TE by Bohm is now replaced by polarization.

By employing Hacking's formulation, we could say that the EPR is a thought experiment with a life: maturing, evolving, adapting, being not only recycled but also, quite literally being retooled'. The EPR is not the only TE with a history of evolution. The above discussion shows that, contrary to Hackings contentions, thought experiments seem to have a life of their own surprisingly in the line of Hacking's own criteria for the life of real experiments.

In the next session I will discuss the history of evolution of Maxwell's demon, a thought experiment which Hacking was not ready to consider as a TE.

2.4.1.b Maxwell's Demon

This is a thought experiment proposed by James Clerk Maxwell. (Maxwell, 1908, 338). The thought experiment is as follows. Consider a box of gas. Let there be two chambers, A and B in the box and there is a window on the wall separating the chambers. The temperature of the gas in both the chambers (T_A and T_B respectively) is the same, $T_A^i = T_B^i =$ TK (K stands for temperature in

Kelvin scale). According to the kinetic theory of gases, any sample of gas is a collection of gas molecules with different kinetic energies. The temperature of a sample of gas is its average kinetic energy[20]. Now assume a demon who operates the window with a frictionless mechanism. When a molecule from the chamber A with a kinetic energy less than that of the average kinetic energy (corresponding to the temperature of the gas) approaches the window the demon opens it and lets the molecule to pass to the chamber B. If the kinetic energy of the molecule is greater than that of the average kinetic energy then the demon blocks its passage from A to B. The demon does the reverse for the camber B, i.e blocking the passage of the molecules with kinetic energy lower than that of the average kinetic energy (corresponding to the temperature of the gas) from B to A and letting those with higher kinetic energy to pass to the chamber A. By repeating this sorting process many times the demon creates a condition in which the average kinetic energy of the molecules in the chamber A increases. This will lead to the sample of gas in the chamber A having a temperature $T_A^f>T$. In the same way, the demon creates a condition where the average kinetic energy of the gas molecules in the chamber B decreases. This will lead to the sample of gas in the chamber B having a temperature $T_B^f<T$. The demon has not expended any energy in the sorting process mentioned above since it operated on a frictionless mechanism. Now in a closed system with the initial condition $T_A^i=T_B^i$, without expending energy the demon has created a situation where $T_A^f>T>T_B^f$. According to Maxwell, this is a violation of the second law of thermodynamics, which prohibits the flow of heat from a cold body to a hot body without consuming work[21].

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[20] According to the kinetic theory of gases, the temperature of a sample of gas $T=\frac{2}{3}\frac{K}{Nk}$ where K is the total kinetic energy of the gas molecules in the sample, $K=\sum_{i=1}^{n}\frac{m_i v_i^2}{2}$ where m_i is the mass of the i^{th} gas molecule and v_i is the velocity of the i^{th} gas molecule, N is the total number molecules in the sample of gas and k is the Boltzmann constant. (Sear and Salinger, 1975, 261)

[21] The second law of thermodynamics states that (Clausius formulation) "heat does not pass from a body at low temperature to a body at high temperature without an accompanying change elsewhere" (Atkins, 2010, 42). In other words if one wants to transfer heat from a cold body to a hot body, she has to expend energy and hence she has to do some work. In the thought experiment we begin with a condition $T_A^i=T_B^i=T$. Finally, without

I now briefly outline Hacking's interpretation of the above mentioned thought experiment. Hacking suggests that it is not a thought-experiment. To quote “I resist calling Maxwell's demon part of a thought experiment. It is part of a fantasy. Here I agree with Nersessian, who has remarked to me that it is hard to see what is experimental about the demon. Perhaps it is only a rhetorical device to reinforce Maxwell's statistical analysis. The demon does not, for me, prove even the possibility of anything....The problem with Maxwell's demon as an experiment is that you can't conduct it at all, no matter how much fantasy and idealization you allow yourself.”(Hacking, 1992, 302-03). In the above quote, Hacking offers us three distinct reasons as to why Maxwell's Demon is not to be characterized as a thought-experiment.

(a) There is nothing experimental about the demon. At least it is hard to see anything experimental about the demon. Maxwell's Demon, according to Hacking, is not experimental even in principle. One could understand this as an objection in principle, i.e. in principle there is nothing experimental about the demon.

(b) The demon narrative is a only a rhetorical device.

(c) The demon narrative does not prove the possibility of anything. Irrespective of the idealizations employed, the Maxwell's Demon as an experiment cannot be conducted in a laboratory. One could understand this as an objection regarding the implementation. i.e. it is practically impossible to realize the Maxwell's Demon thought experiment in a laboratory.

Reasons a and c together constitute a strong objection. Together these reasons suggest that Maxwell's Demon is non-experimental both in principle and in practice. Compared to a and c, b is not a strong objection.

Historically Maxwell did not use the term demon. According to Maxwell, “...if we conceive a

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expending any energy we arrive at a situation where $T_A^f > T > T_B^f$. This process is equivalent to a process where we transform heat from a cold body to a hot body without expending any energy. Therefore it is a violation of the the second law of thermodynamics.

being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us" (Maxwell 1908, 338) (emphasis added). Maxwell's formulation speaks about the conceivability of a being. Clearly, at this stage it is not assumed to be experimental. The conceivability is sufficient to make the point. If we can conceive a being of the sort mentioned in the thought-experiment then the rest of the thought experiment follows naturally. Since conceivability is not always supposed to be translatable into possibility, an objection of the type (a) might not stand. Also, the epistemological significance of the thought-experiment does not exclusively depend on its material realization. This is one of the important features of thought experiments (See Nersessian, 1992 296). This also makes the objection of the type (c) inappropriate.

The term demon was coined by William Thomson (Lord Kelvin) in 1874. Since Maxwell has not employed the term demon, the force of the objection (c) is lessened considerably. Interestingly in 1879 Thomson wrote, "[T]he conception of the "sorting demon" is merely mechanical, and is of great value in purely physical science. It was not invented to help us to deal with questions regarding the influence of life and of mind on the motions of matter, questions essentially beyond the range of mere dynamics." (Thomson 1879). At this stage, as Thomson clearly suggests, the demon is conceived as a mechanical concept. As a mechanical concept it is in principle experimental. In other words there is nothing non-experimental or demonic about the Maxwell's Demon[22]. This mitigates the thrust of the objection (a). In fact, in 2010 researchers have materialized a version of the thought experiment in laboratory. (Toyabe *et al* 2010). This completely neutralizes the objection (c).

Now consider the objection (c) that the demon narrative is only a rhetorical device. Maxwell has not employed the term demon. When Thomson coined the rhetorical phrase demon, he also

[22] A detailed description of the debates around the Maxwell's Demon is beyond the scope of this paper. See the two part papers by Earman and Norton 1998 for a good review of the birth and development of Maxwell's Demon and various attempts to exorcise it.

made it clear that the demon narrative is employed merely as a mechanical concept. It is true that the demon narrative has rhetorical elements in it which might have helped the thought experiment to attract the attention of a wider public. But, as it is evident from the above discussion the thought experiment as such is not a mere rhetorical device. Hence, dismissing Maxwell's Demon as a mere rhetorical device misses the point, especially in the context of a back to Bacon movement. .

The Maxwell's Demon is a good example of a thought-experiment that defies Hacking's characterization of thought experiments. This shows that some thought experiments which are neglected by philosophers are important to scientific practice and scientists do work on such thought-experiments. In a 'back to Bacon' movement[23] where we do focus on the scientific practice, we can see that the Maxwell's Demon is not an inappropriate example of thought experiments.

2.1.4.2 Thought Experiments and the Robustness of Results

Thought experiments are always performed under the rubric of some theory and therefore, the result of a TE is expected to change with respect to the changes in the theoretical understanding. The result of real experiments in contrast to that of TEs, according to Hacking, has the ability to remain unchanged even when the theoretical understanding of the experiments changes. One of the reasons for the robustness of the results of real experiments is the fact that the results of real experiments are the product of causal interactions which happen independent of the theoretical understanding of them. But, there are no real causal interactions in TEs and therefore the result of them may change with respect to the changes in the theoretical domain. In this section, I will try to show that the results of some TEs have the power to desist the changes in the theoretical understanding. I will employ Galileo's TE of Free Falling Bodies as a case to establish my point.

Galileo and the Free Fall

[23] It seems that this discussion about Maxwell's Demon is a good example showing the importance of the Back-to-Bacon movement. In that sense this discussion underscores the importance of Hacking's call to the investigation into scientific practice.

In the Aristotelean view, heavier bodies always fall faster than lighter ones when they are falling through the same medium. This is expressed as "...bodies of different weight ... move in one and the same medium with different speeds which stand to one another in the same ratio as the weights; so that, a body which is ten times as heavy as another will move ten times rapidly as the other" (Galileo 1954, p.61). Galileo proposes the following TE to show the incorrectness of the above Aristotelean view. Consider the following scenario. Consider the free fall of two bodies having weight W1 and W2 such that W1>W2. Let S1 and S2 respectively be the speed of these bodies in free fall. Let S3 be the speed of the system of the bodies united together in free fall. From the Aristotelean view, we can derive the following scenarios:

1. Since (W1+W2)>W1, S3>S1
2. Since W2 < W1 and S2 < S1, the lighter body retards the heavier body and thereby it retards the system of united bodies. So, S3 < S1

1 and 2 together suggest the following absurd conclusion that the heavier body moves both faster and slower than that of the system of combined bodies at the same time. This suggests that the Aristotelean understanding of the free fall is wrong. From this, according to Galileo, "we infer that large and small bodies move with the same speed provided they are of the same specific gravity" (*Ibid* 64).

I have presented a reconstructed form of Galileo's thought experiment. It should be noted that the point contested in the TE is about a phenomenological relation, the relation between the weight of a body and its speed in free fall. This point becomes clear when we pay attention to the following. In the beginning of the TE, Galileo writes that "[B]ut, even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that **a heavier body does not move more rapidly than a lighter one** provided both bodies are of the same material and in short such as those mentioned by Aristotle" (*Ibid* 62 emphasis added). The above quotation shows that the TE is aimed at disproving the Aristotelian understanding of the relation between the weight and speed of a body. In order to arrive at the conclusion, Galileo started with the following assumptions and idealizations some of which are part of the Aristotelian theory of motion.

1. Every falling object has a different speed fixed by the nature and the speed cannot be altered without external force (*Ibid* 63). (This assumption is rejected after the TE.)
2. The speed of an object in free fall is inversely proportional to the resistance of the medium. In the later discussion, Galileo shows the incorrectness of this assumption (*Ibid* 66-67). Even though, the resistance of the medium has significant role in the speed of a free falling body, Galileo eliminates it as a part of idealization.
3. The figure of a body has only small influence on the motion of fall (*Ibid* 65). (Retains)
4. The influences of the medium which affect the single effect of gravity on the falling bodies need to be abstracted out. Galileo argues that in order to make a general claim about the free fall, one has to think about the situation where the only effect acting up on the falling body is gravity. This idealization, according to Galileo, was also held by Aristotle (See I*bid* 65). Galileo retains this idealization. Later he suggests that "in a medium **totally devoid of resistance** all bodies would fall with the same speed" (*Ibid* 72). (emphasis added.) Note the idealization (see point 2) by removing the impact of the resistance of medium.

Now reconsider the important results of the TE.

1. The TE rejects the general Aristotelian idea that every falling object acquires a definite speed which was fixed by the nature and that speed cannot be altered without employing external force.
2. It rejects the Aristotelean theory of free fall that the speed of an object in free fall is

proportional to the weight of the object.

3. More importantly, the TE proposes that in ideal situation, in a medium devoid of resistance, all bodies would fall with the same speed.

It should also be noted that the first two points are claims about a phenomenological relation, the relation between the weight and speed of a body in free fall. This relation was wrongly characterized by the Aristotelian theory. Galileo's TE not only rejects the Aristotelian characterization of the relation between the speed and weight of a body in free fall but also proposes the correct relation. Like any experimental result which rightly indicates a phenomenological relation, the speed-weight relation indicated by this TE can remain the same irrespective of any further changes in the theoretical domain. In other words, the result of this TE (in ideal situation all bodies would fall with the same speed) can endure the changes that may or may not happen in the theoretical domain. Hacking has shown the robustness of the results of real experiments. He has shown that irrespective of the changes in the theoretical understanding of microscopes, the results of experiments with microscopes remain the same. The reason is that the results of such experiments are produced by causal interactions. Also, such results are phenomenological which are determined by the contrived nature of the experiment and by the nature of the external world. Now consider Galileo's TE. Obviously there are no causal interactions in the TE. (It is possible to argue for the contrived nature of the TE by pointing to the different idealizations employed in the TE. But this is not important to make the point under consideration.) But the result of the TE is a phenomenological relation, a claim about the way the nature is. It appears that the result of this TE can remain the same unless and until there is a change in the external world. Since no change in the theoretical domain can cause a change in the speed of objects in free fall, no change in the theory of free fall can affect the the result of this TE.

The above discussion suggests that the results of some TEs can resist the changes in the theoretical domain. Robustness of the result is one of the important reasons for claiming a life of experiments. It appears that at least some TE do satisfy this criterion. Employing similar line of thought one could show that some TEs, especially those which discuss phenomenological relations, can claim the robustness of their result. Galileo's ship, a thought experiment by Galileo which shows the classical principle of relativity, is another example of a TE of the above sort.

2.1.4.3 Theory, Thought Experiments and the Order of Arrival

In this section, I will try to show that like real experiments there are some TEs that come before a theory and some TEs that come after a theory. I will employ two short TEs to argue out the point.

2.1.4.3.a Theory Preceding a Thought Experiment

Stevin's Inclined Plane: This was a thought experiment suggested by Thomas Stevin. Consider a prism like pair of inclined planes. Suppose that a chain is draped over the double inclined plane. Let there be no friction. How will the chain move? There are three possibilities. Depending upon the weight of the chain and steepness of a side, it may move left or right. Another possibility is that it may remain at rest. Stevin answered that the chain will remain in static equilibrium. If the chain moves we would get a perpetual motion which is impossible. The assumption of no perpetual motion machine is central to this thought experiment. This case could be considered as a TE in which the theory clearly precedes the thought experiment. (For a detailed account of Stevin's thought experiment, see Teun Koetsier 2010, 95-99)

2.1.4.3.b. A Thought Experiment that Precedes Theory

Galileo's Double Inclined Plane: Galileo designed a double inclined plane which demonstrates the law of equal heights. According to the law of equal heights, a pendulum's bob always recovers its original height as it swings from, say, top right to top left. Strictly speaking, for a swinging pendulum the distance from the mean position to the two extreme positions in a swing is the same. Like the bob of a swinging pendulum a ball rolled in a double inclined plane will also recover its original height. It was known to Galileo that due to the air resistance and friction of planes no ball in a double inclined plane recovers its original height in a real situation. Or the law of equal heights is directly applicable only to idealized situations. Galileo constructed a thought experiment of double inclined planes with idealizations. In the thought experiment, he supposed that one side of the plane is lengthened such that the ball has to travel further and further to regain its original height. If the side of the plane is infinitely lengthened then the ball can never return to its original height. According to the law of equal heights, the ball must continue its motion until it reaches its original height. From this it follows that in the thought experiment the ball will continue its motion in a straight line. (Sorensen 1992, 8-9)

According to Aristotle and common sense, it is natural for things to slow down and come to rest. Continuous motion therefore requires an explanation. But after Galileo's thought experiment it is not the continuous motion but the slowing down of moving bodies that needs an explanation. This illumination is captured in the first law of motion, i.e every body continues in its state of rest or uniform rectilinear motion unless it is compelled by an external force. The first law of motion is not a part of the thought experimentation rather it is the result of it. So, this thought experiment could be considered as the one which precedes the relevant part of the theory (Principle of Inertia).

The law of equal heights, friction etc are theory loaded terms. But, according to Hacking's notion of theory-ladenness, this will fall under the weak version of theory-ladenness. Therefore, the presence of such theories could not deny the life of this thought experiment. We could consider Galileo's Free Falling Bodies, Einstein's Chasing of Light and many more in this group of thought experiments.

We do not have an example, yet, of a thought experiment which has developed simultaneously but independent of a theory. But I do not consider this to be a serious mark against the view that TEs can and some do have a life. Hacking cites only one real experiment of this nature. One could always argue that the incident under consideration is a mere coincidence and it is a purely contingent issue whether such a coincidence will be repeated. But the other three typical cases, e.g. experiments preceding a theory, a theory preceding an experiment and a maturing experiment can be well identified within the class of thought experiments.

2.1.4.4 Different roles of Thought Experiments

According to Hacking, the only role of TEs is to expose the tension between two conceptual systems and they retreat after performing that role (Hacking 1992, 307). But Hacking affirmed this role of TEs in such a strong manner that finally he ended up suggesting two functions of TEs. Following Kuhn, Hacking suggests that "[T]he reason that people wrestle with thought experiments, use them for exposition and put-down argument, is **that they can reveal tensions between one vision of the world and another.** They can dislodge a person from a certain way of describing the world. **They can replace one picture by another.** That is their job, their once and future job" (*Ibid* 307. emphasis added). Clearly, revealing the tension between two conceptual systems and replacing one conceptual system (picture) are two different tasks. Not every thought experiment is intended to reveal the tension between two conceptual systems. Heisenberg's Microscope TE is a good example of a TE which was employed not to reveal the tension between two conceptual systems. Also, not every TE replaces (or can replace or attempts to replace) one conceptual system by another. For example, the EPR TE, which we have discussed earlier, does not suggest anything to resolve the problem it has revealed. Replacing a conceptual system is too hard and ambitious a job to be assigned to TEs. But a charitable reading of Hacking's notion of 'replacing picture' could suggest the following. Instead of replacing a conceptual system, TEs may suggest some ways to mitigate the tensions between two conceptual systems. For instance, Galileo's Free Falling Bodies TE not only reveals the incorrectness of Aristotelean picture of the world but also suggests a way to remove the tension. This discussion suggests that unlike Hacking's characterizations TE can and at times do perform different roles. Some of the different roles that are played by thought experiments are listed below.

1. Testing theories. I do not think that thought experiments can perform a litmus test which shows the validity or invalidity of a theory. But Robert Brown (1991) argues that some thought experiments can perform such a litmus test. According to Brown platonic thought-experiments can test a theory without looking into the world. He suggests Galileo's Free Falling as the best example.
2. Showing the incorrectness of accepted theories and the call for new theories. Hacking also agrees to this role of thought experiments. Galileo's Free Falling Bodies, The EPR, Galileo's Ship are some of the good examples of TEs which perform this role admirably.
3. Exhibit or create new phenomenon which needs explanation. The EPR thought experiment is the best example. The phenomena which was later known as quantum entanglement was first suggested by this thought experiment. Though quantum entanglement was not the target of the thought experiment, the thought-experiment was depending heavily on this counter intuitive phenomenon. Experimental verification of the phenomenon came much latter.
4. Provide Hints to the mathematical structure of a theory. Heisenberg's Gamma Ray Microscope performs this role. One could derive the uncertainty relation quite convincingly from this thought-experiment. (See Van Dyck, 2010)
5. Checking the internal consistency, external coherence, simplicity and explanatory power of theories. The EPR TE (1935) is the best example. It reveals that the two fundamental

assumptions of standard (Copenhagen interpretation of) quantum mechanics, the locality and completeness are inconsistent. (See Alisa Bokulich, 2001).

Conclusion

Hacking suggests that thought experiments are static icons that won't undergo evolution. The example of the EPR TE shows, however, that some TEs do evolve and seem to be dynamic icons. In fact some TEs, like the EPR, are too dynamic to be portrayed as a static icon. Robustness of the results is one of the main reasons for claiming a life of real experiments. The Galileo's Free Falling Body TE suggests that the result of some TE can indeed resist the changes in the theoretical domain. And contrary to Hacking's suggestions TEs perform different important roles. It could be also argued that like real experiments some TE even precede the appearance of well formulated theories. Hence, from the above discussion we could conclude that Hacking's characterization of thought experiments seems to be both incomplete and inadequate. A more charitable look, from the perspective of scientific practice, which also includes thought experiments, suggests that they too have a life of their own.

2.2 Why Computer Simulation cannot be an end of thought experimentation

Computer simulation (CS here after), when compared to thought experiments, is a recent development. But it is so effective and influential a tool such that some philosophers have argued for 'new techniques' in philosophy of science to make philosophical engagement with computer simulations effective (Humphreys 2009, 625). According them, computer simulation has brought novel epistemological, methodological and metaphysical problems which are beyond the scope of traditional approaches in philosophy of science (Humphreys 1991, 2009, Winsberg, 2001, 2003)[24]. The fact that both TE and CS rely on already accepted data and seem to produce new knowledge suggests comparison between the two methods. Di Paulo *et al* (2000) argues that computer simulations are opaque thought experiments. Taking clues from Norton's (2004) account of TEs as arguments, Claus Beisbart (2012) argues that computer simulations are arguments. Running a computer simulation in Beisbarts account is the execution of the argument that could be reconstructed from the simulation. But in a recently published paper Chandrasekharan *et al* (2013) argue that computer simulation is replacing thought experimentation in the contemporary science. According to the authors, it is computer simulation but not thought experimentation that suits the complex nature of contemporary science. They suggest limited roles as that of helping the designing of simulation to thought experiments.

In this second section I attempt to show that computer simulation cannot replace thought experiments with epistemic advantage. This section is further divided into three sub-sections. In the first sub-section, I will discuss the arguments of Chandrasekharan *et al*. In sub-section 2, I will try to show that many of the charges directed against TEs are either improper or unimportant in the context of TEs. In sub-section 3, I will employ the result that Kastner and Arnold (2011) arrive at to argue that a CS can never act as a crucial test in the case of a fundamental hypothesis. Since most of the TEs are employed in the context of evaluating a fundamental hypothesis in their respective domains, I will conclude that CS can never replace such TEs.

2.2.1. Is computer modeling the end of Thought experiments?

Sanjay Chandrasekharan, Nancy Nersessian, and Vrishali Subramanian argue that "computational modeling is replacing thought experiments in science and the latter will play only

[24]Contrary to the above mentioned view, Roman Frigg and Julian Reiss argue that computer simulations do not require radically different philosophical approaches. See Frigg and Reiss, 2009.

limited role in future practices of science especially in the sciences of complex nonlinear dynamical phenomena" (Chandrasekharan *et al.*, 2013, 239). They offer three reasons to support their claims.

1. "Thought experiments are a product of a more limited material and problem environment. The current material and problem environment is more suited to computational modeling.

2. Building computational models can provide deeper insights into problems than building thought experiments.

3. The central cognitive role played by thought experiments is a form of simulative model-based reasoning carried out with mental models. Computational models support this type of simulative model-based reasoning, but also allow more sophisticated simulation operations" (*Ibid* 239).

They suggest the following reasons in detail for preferring computational models in research in biosciences and engineering. And it seems that these reasons stand valid for any other field of science which uses computational models.

Complexity of Problem: The complex, non-linear and dynamic nature of problems studied in biology (and in many other fields) requires the assistance of computational models. Building the details of complex cellular and molecular interactions in head is almost impossible.

The nature of Data:

(a) Size of data: The experimental work in many areas of science produce massive amount of data. Computational models are good and easy aid to interpret these data.

(b) Contextuality of data: Data in biology are highly contextual and there is no theory that helps in structuring this scattered data. Computational models help to bring this data together in a structured manner. Also this data structure is dynamic and can be run with various inputs.

Easy availability of technology: Contemporary sciences employ different technologies which are easily available to support modeling. In the same line the authors argue that "the thought experiment method cannot generate and test the complex, dynamic and non-linear phenomena investigated by contemporary science" (*Ibid.* 241)

Another important point which the authors underscore is that TEs hardly give access to their building mechanism. So, one is forced to pay attention to the end product, the thought experimental narrative of the process. They call this phase as the interpretation phase which involves relating the TE to a theory or phenomena. In contrast to TEs, computational models do provide access to their own building mechanisms. This allows one to speak about the building process and so, according to the authors, focusing on the interpretation phase is not justified in the case of computational models. Hence, the authors shift their attention to what they called the process-oriented analysis of modeling and the roles models play in scientific practice.

Mental Simulation and TE

TEs, according to the authors, are constructed using concrete elements but models are built using variables. So, TEs do not naturally support simulation of counter factual scenarios beyond the particular scenario generated by a particular TE. This is because the mental simulation process is driven by the behavior of the concrete components of the TE. The authors have not discussed the details of the concrete components of a TE. But, it might be legitimate to assume that the initial conditions specified and the processes described in the TE narrative of a particular TE are the concrete components. Ian Hacking has also made a similar suggestion. According to Hacking, once executed into perfection, a TE does not allow changes in itself (Hacking 1992. See section 2.2 for a detailed version of Hackings arguments). A difficult and complex cognitive transformation is required to move away from the concrete case to the abstract and generic case. On the other hand the modeler works with abstract and generic cases and so, it is much easier to obtain the abstract cases. "Since models are made entirely of variables, they naturally support thinking about parameter spaces, possible variations to the design commonly seen in nature, and why this variation is commonly seen, instead of many others that are possible" (*Ibid* 256).

2.2.1.1 Two senses of the refutation theses

The theses that CS is replacing TEs as expressed by Chandrasekharan *et al* is ambiguous. It could be understood in a strong sense and a weak sense[25].

(a) In the strong sense, one could argue that TEs and CSs are functionally equivalent. In other words, both of them have exactly the same functions and hence, all the functions that are performed by thought experiments can be carried out in a better way by employing CSs. Therefore, TEs will be replaced by CS.

(b) In the weaker sense, TEs and CSs are not considered functionally equivalent. But the nature of problems addressed by contemporary sciences is too complex, especially with respect to the amount and complexity of data, to be handled by TEs. Therefore there is a historical process where the use of CS is thriving but that of TE is withering.

Let us first consider the strong sense. The functional equivalence in the way articulated above is at least asymmetric. TEs are ineffective in handling huge amount of data or nonlinear dynamical equations. The authors have rightly identified this deficiency of thought experimentation. Clearly TEs cannot replace CSs in the above mentioned cases and hence TEs are not functionally[26] equivalent to CSs. This argument will eventually help one in holding (b). Can CSs perform all the functions that are performed by TEs? Making it more precise one could ask, can CSs perform all the epistemological functions performed by TEs? Epistemological roles of TEs need an explanation

[25]I am indebted to an anonymous referee for pointing out this distinction.

[26]Both TEs and CSs are employed in science teaching. Such pedagogical functions are not considered here.

here. Historically TEs have been successfully employed to perform the following epistemological functions.

Chandrasekharan *et al.* seem to hold the weak version. In their view the complex and dynamic nature of contemporary sciences do not permit one to employ a tool like TE to solve them. Hence, thought experimentation practice will wither away by giving way to CSs. This appears to be a correct suggestion. The employment of modeling practices and proliferation of modeling techniques in contemporary sciences are too obvious to be doubted. But the wider acceptance and applications of CS do not seem to suggest an obviation of thought experiments. Before showing the weakness of any such arguments, certain characteristics of both TE and CS requires elaboration. It appears that the authors have conflated certain roles of TEs and CS.

2.2.2. What TEs and CSs can and cannot do?

I this section I discuss some of the roles that are successfully performed by thought experimentation. This help us draw a stark contrast between what TEs and CS can achieve. This allows us to show the attempts that overburden TEs by comparing them with CSs.

Chandrasekharan *et al* comments that thought experimental method cannot test complex dynamic and nonlinear phenomena investigate by contemporary science (*Ibid* 241). They also comment that TEs are unlikely to settle a debate (*Ibid* 258). These claims are supposed to substantiate the larger claim regarding the withering away of TE in contemporary sciences. Consider the first claim. It should be noted that the claim is that TEs cannot test complex dynamic and non-linear phenomena. It is a curious claim because historically, TEs are never employed to test a phenomenon[27]. TEs are, at best considered as testing cases of theories. Some of the ways in which TEs test theories are listed as follows:

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[27] See chapter 3 for a detailed discussion on the role of phenomenon in the epistemology of TEs. TEs at best can help one conceiving a phenomenon. But testing in the sense of causal examination is not at all possible with a TE.

a) Showing the incompleteness of a theory- This may very well depend up on the meaning of completeness of a theory. Irrespective of the different understanding of 'completeness' let us grant that TEs can show the incompleteness of a physical theory. The famous EPR TE, according to Einstein *et al* (1935), is supposed to show the incompleteness of quantum mechanics.

b) Showing the inadequacy of a theory- If a theory fails to explain a phenomenon with in the domain of its application then the theory may be considered inadequate. Bohr atom model (for the sake of simplicity I am not considering the difference between a model and a theory) failed to explain the fine structure of hydrogen spectrum. It was also not applicable to atoms other that hydrogen and helium. Therefore we could consider the Bohr atom model an inadequate model of atom. TEs can show the inadequacy of theory by explicating the plausibility of a phenomenon that is unexplainable by the theory in focus.

c) Refuting a theory- The best way to refute a theory is to elicit a contradiction from the theory. But it is a well-known fact that laws *ceteris paribus* conditions are hard to refute in the above way and most of the high level theories are *ceteris paribus* laws. Galileo's Free Falling Body TE is the only TE that is generally considered as the TE that refuted a well-established theory (Aristotelian theory of free fall) at a single stroke. But this, at best, is a myth created most probably by James Brown (1991). There are many ways to save the Aristotelian theory of motion from Galileo's TE. (See Schrenk 2004 for the untenability of Galileo's arguments. McAlister has argued at length to show the different assumptions that make the evidential significance of Galileo's TE. (See Mc Allister 1996, 2002)

One of the important features of CS as a tool is that it enhances the mathematical talents of the epistemic agent's ability to a level which is beyond the natural psychological level of a human epistemic agent[28]. This, according to Humphreys, forces one to pay attention to the in-practice aspects of the resolvability of the problem than that of the in-principle resolvability. It seems that the idea of enhancement of epistemic abilities and the distinction between in-principle and in-practice solutions are crucial in the comparing CS and TE. TE as a tool of reasoning does not seem to enhance any natural modality of the epistemic agent. Historically, TEs have never employed to handle massive data. This at least suggests that TEs are not meant to do such a job. The comparison of the TE and CS as a tool in the context massive data arises from the unwarranted assumption that both TE and CS are functionally equivalent. At some points Chandrashekharan *et al.* seems to assume a similar notion of functional equivalence. For example, they comment that "[C]omputational models, particularly ones with visualizations, go beyond TEs, as these models can generate complex behavior similar to natural phenomena, provide explanations of why these phenomena exist and not others, and also allow interrogation and "drilling down" into the behavior for details. Such models thus enable the externalization of creative thinking in science, and thereby extend the cognitive capacity for mental simulation similar to the way telescopes have extended the perceptual capacity for seeing. **And just as no scientist studies the stars with the naked eye anymore, no one would use TEs to probe the complex phenomena studied by contemporary science**" (Chandrasekharan *et al.* 2013, 257 emphasis added). (See Chandrasekharan and Nersessian 2011 for a discussion of other cognitive roles played by external representations, particularly the process of building.)

[28]Humphreys suggests three types of epistemic enhancements as that of extrapolation, conversion and augmentation. CSs are best examples of augmentation. Also, CSs force one to focus more on executability and hence one has to think more about the in practice but not in principle solutions. According to Humpreys, CS requires radically novel approaches in philosophy of science. Though I accept epistemic enhancement theses and the distinction between in-principle and in-practice solution, I suspend my judgment regarding the novelty of the problems posed by CSs. See Humphreys 2004.

Though the meaning of "externalization of creative thinking[29]" is hardly clear the main point appears to be that of the enhancement of natural capacities of human agents. CSs, like telescopes, have enhanced the cognitive capacity of human agents. But they are correct in claiming that no one uses naked eye to study stars any more. But it seems inappropriate to claim that no one employs TEs to probe the complex phenomena. This is inappropriate because a) it borders on the unwarranted assumption that TEs, like CS, enhances human modality and both of them are functionally equivalent. b) The notion of complexity employed is fraught with ambiguities. Complexity can arise from different reasons. It seems that TEs can handle some versions of complexity. (**See section 2.2.3.2**). The points of this discussion can be summarized as follows:

1. TEs are tools not to test phenomenon but at best to test theories.
2. TEs do not augment any human modality. Therefore, considering them as a tool that enhances natural human modalities and attempting to employ them to handle large amount of data is unwarranted. Such attempts not only overburden TEs but also wrongly assume that TE and CS are functionally equivalent.
3. The notion of complexity associated with TE and CS are appears interrelated but different.

2.2.3 Why CS is not an End of TE

2.2.3.1. The nature of material and problem environment.

According to the authors "Thought experiments are a product of a more limited material and problem environment. The current material and problem environment is more suited to

[29] One of the ways to understand the externalization of thinking is as follows. Consider that human thinking follows some sort of algorithm. If so, the human thinking is a step by step process. Since a CS can execute an algorithm, the human thinking in an algorithmic form can be executed in a CS. Therefore, in this sense CS could be seen as an externalization of thinking. But this does not clarify 'the externalization of creative thinking'. If one can show that creative thinking is an algorithmic thinking, then CS can, act as an externalization of creative thinking. But I doubt the feasibility of an algorithmic reconstruction of creative thinking. I am indebted to friend Mohan, M.Phil. student, Department of Philosophy, University of Hyderabad for clarifying this point.

computational modeling." (Chandrasekharan *et al* 2010, 239). For a closer examination this claim could be contrasted into two interrelated but apparently distinct claims.

a) The claim about material environment

b) The claim about problem environment.

Consider (a). If we understand material environment as the status of technological progress then the claim that the current material environment is better than that of the past will turn to be a truism. At any point in the history of modern science, we could see that the technological status of the present always appears to be better than that of the past. In order to make this truism as a case for the withering of TEs in contemporary science one need to show:

1) A near absence of TEs in contemporary sciences.
2) One should entertain the claim that past science was full of successful TEs.
3) The epistemological significance TEs are closely related to the material environment.

Consider the first assumption that TE are nearly absent in contemporary science. The authors have rightly identified the fields were CSs are proliferating. It is the field of engineering and biological sciences. We have already seen that TEs were hardly employed to handle data. History of science tells that TEs were extensively used in the theoretical debates in physics. Hence, it will be worth if we consider contemporary theoretical physics. If contemporary physicists are employing TEs in their theoretical debates then the claim that TEs are withering way is not correct at least in the case of theoretical physics. I will provide a number of TEs discussed in contemporary physics to show that unlike what was argued by Chandrashekaran *et al.*, TEs are very much employed in contemporary theoretical physics.

1. Eric Hanna and Kenneth Eppley proposed a TE to show the necessity of quantizing gravitational fields. (Hanan and Eppley, 1977). Callender and Huggett (2001) criticized the TE by arguing that the TE won't stand if one assumes a different interpretation of quantum

mechanics than that is used in the TE. James Mattingly in 2006 argued that Hanna and Eplley's TE is fatally flawed. According to Mattingly, "[T[he device they propose, even if built, cannot establish their claims, nor is it plausible that it can be built with any materials compatible with the values of c, @, G. Finally the device, and any reasonable modification of it, would be so massive as to be within its own Schwarzschild radius—a fatal flaw for any thought experiment" (Mattingly 2006, 73). Mark Shumelda in 2013 defends Eppley and Hanna and proposes a' more nuanced' role for the TE. (Shumelds, 2013). The above sketch suggests that the TE by Eppley and Hanna is not yet discarded but very much discussed in contemporary theoretical physics.

2. Goffredo Chirco *et al.* suggest a TE to show the possibility of an extremal black hole without violating the third law of black hole thermodynamics. (Chirco *et al*, 2010)
3. Leonard Susskind and Larus Thorlacius employ a number of TEs to show the importance of black hole complementarity. (Susskind and Thorlacious 1994)
4. Holographic thought experiments by Donald Marolf. (Marolf 2009)
5. Experimental realization of a TE from Bohr-Einstein debates by L. Ph. H. Schmidt *et al.* (Schmidt 2013)
6. The quantum delayed choice experiment by proposed by Radu Ionicioiu and Daniel R (Ionicioiu and Terno 2013)
7. A micro-black hole thought experiment and the derivation of generalized uncertainty principle in quantum gravity by Fabio Scardigli.(Scardigli 1999)

(The list is not exhaustive.)

The above list shows that TEs are employed at least in contemporary physics. Therefore, the assumption that TEs are nearly absent in contemporary science is incorrect at least in the domain of theoretical physics.

Consider the second assumption that history of science was full of successful TEs. This is an already contested claim. According to Reiss, if one compares the wealth of concrete experiments to that of TEs in the past it is evident that TEs will lose in count. (Reiss 2002). This is not to suggest the insignificance of TEs in science but to show that the number of TEs that have critical evidential significance are comparatively low (when compared to that of real experiments) even in the past. One could see the proliferation of CSs in contemporary sciences and this might be taken as a case for arguing against TEs. But it was stated that even in the past TEs were comparatively less than the number of real experiments. This suggests that the relation of TEs with material environment of science is something different than that was envisaged by the authors.

One way to understand this problem is to examine the context of TEs. Many of them are the product of a problem environment were empirical data is neither available nor possible. Also the claims made in many of those TEs have less direct connections to the material environment. Consider Galileo's free falling body TE. In a sense the TE is a product of an underdeveloped material environment. Free fall of bodies in vacuum on the surface of earth will violate Aristotelian laws of motion. But an experimental arrangement in which two bodies under the influence of mere acceleration due to gravity was not possible at the time of Galileo. Therefore, one could argue that Galileo was forced to employ a TE. If we consider this as the objection, then CSs too could be of no help either. A CS of the free fall has to model the scenario either with the Aristotelian laws of motion or with the Galilean laws of motion. If the CS is based on the models of motion following the Aristotelian theory, then there won't be any difference in the speed of the bodies in the result of the CS. If the model is based on the Galilean view, then it could come up with a different result which is contradictory to the result of the Aristotelian view. But since the principle on which the two models (Aristotelian and Galilean) are built are mutually inconsistent and the CS has no empirical connections to the world, one could doubt the feasibility of the CS of Galilean model. In such situations both TE and CS are epistemically on par.

Now consider epistemological functions of TEs and its relation to the material environment. Generally TEs are not supposed to be executed in the laboratory and such an execution is impossible in many cases. This is because the epistemic relevance of TEs is independent of their execution in a laboratory. Nancy Nersessian (one among the authors) has pointed out this feature of TEs in her early writings. She argues that "[A] thought experiment is usually so compelling that even in those cases where it is possible to carry it out, the reader feels no need to do so. The constructed situation, itself, is apprehended as pertinent to the real world in several ways" (Nersessian 1992, 296). One of the important relations of an experiment or a TE with the material environment of its occurrence is the feasibility of its empirical realization. Since TEs generally do not require a realization in a laboratory the progress in technology does not affect thought experimentation practice. So, considering TEs as the product of a material environment which lacked the possibility of empirical realization is not an adequate characterization of thought experimentation practice. The authors are right in saying that many of the TEs are envisaged in a data less context but that doesn't act as a sufficient reason for claiming the withering away of TEs. The points discussed so far could be summarized as:

a) Epistemological significance of TE are not directly related to the material environment.

b) Even when the epistemological significance of TE are related to the material environment some fields of contemporary sciences are venturing in data less (almost data less) areas and scientists in such fields employ TEs. Quantum gravity, String theory, Cosmological investigations about black holes are some of the good examples for data less fields. Therefore, the limited material environment which makes the execution difficult is a charge which doesn't affect the thought experimentation in the way the authors have envisioned.

Another sense in which one could understand the material environment as the amount of data subjected to analysis. In this sense it is always true that contemporary science has more data to interpret than that of the past. Since anything and everything could be seen as data we need clarification here. In a strict sense we could say that in the practice of a particular case the amount of empirical records it handles is unimaginably huge in contemporary science. This is a correct claim. The complexity and size of data is rightly pointed out as a reason for the proliferation of CSs. One could not simply calculate or arrange such huge amount of data in her head. TEs are of no help here. Authors have rightly underscored this point. Three among the four extended reasons they have pointed out are related to the data which contemporary scientists are handling. **(See section 2.2.1 for the extended reasons**)

No one has claimed that TE are employable in the analysis of massive data. In fact TEs were never employed to manage data. Data mining, arranging and analysis are special techniques. TEs are of no use here. The example of logarithm-table might be of some help here. Logarithm-table was extensively used in calculations before the invention of scientific calculators. No one in the contemporary period prefers a logarithm-table over a scientific calculator for calculating big numbers and long complex equations. One could rightly say that logarithm-table is replaced successfully by scientific calculator. But the analogy breaks down when we realize the mismatch between the functions of TEs and logarithm-table. Logarithm-table as well as calculators were employed in the same process of calculation. So, one could say that former was replace by the later. But unlike CSs, TEs were neither employed nor supposed to be employed in data managing. So, as a technique one could not see a match between TEs and CSs in this particular case. Clearly CSs are well equipped to handle complex data just like calculators are well suited for complex calculations. But that is one of the purposes for which they are developed. Since TEs are not supposed to handle complex data it is not worth a charge to raise that they are unemployable in the cases of complex data. The advantage of CSs in this respect is not a disadvantage of TEs for they are different techniques developed for performing different functions even when applied to the same case.

The nature of problem environment

It is difficult to make a clear distinction between the nature of material environment and problem environment. We have already discussed the nature of material environment. The problem environment has close connection to the material environment. When we consider the nature of the problem environment in connection with context of material environment it will be clearer. One way to understand the nature of problem environment is to look into the context of discovery. Chandrasekharan *et al* have given very few clues here. Their main point seems to be that the nature and complexity of data which contemporary science is handling. We have already seen that the nature of data has very less significance with regard to the functioning of TEs.

2.2.3.2 Contextuality and Complexity

It seems that the authors have undermined or ignored a number of crucial differences between TE and computational models. Also, even when arguing for the contextuality of computational models they have paid less attention to the context of TE. These points can be explained as follows. The notion of complexity can be understood in many ways:

a. Computational complexity: If the equations that govern a problem situation is analytically unsolvable then it could be seen as a computationally complex problem situation. This may arose because of the nature of the equation itself (most of the second order differential equations are analytically unsolvable) or the number of variables involved is too large to keep track. CSs but not TEs are applicable to such situations.
b. The amount of data needs to be managed is too huge and therefore, the situation is complex. TEs cannot handle such situations.
c. The system is chaotic. TEs are not applicable here.
d. The problem environment is conceptually complex in the sense the scientists are facing a

theory change. In such situations, well-formed theories are not available to handle a problem situation. Historically, TEs are extensively employed in such theoretically or conceptually complex situations. TEs are not employed to interpret data in the same way computational models are used and the complexity associated with a TE is not that of data but that of the problem situation. This can be further elaborated by considering a few examples. Consider the complexity associated with the conceptual space of early quantum theory. For example, the determination of the complexity of the situation of the EPR cases is not an easy exercise. By examining them post hoc within the frame work of today's well developed quantum mechanics one might feel the EPR cases to be examples of easy problems and the situation less complex. But at the time of the discussions related to the EPR case the situation was complex enough to demand the interventions of scientists like Albert Einstein and Neils Bohr. Paul Humphrey's response to Karl Popper's comment on the Galileo's Free Falling Bodies thought experiment is worth quoting here. Karl Popper commented that "it [Galileo's Free falling body thought experiment] is one of the simplest and most ingenious arguments in the history of rational thought about our universe"(Karl Popper 1959 quoted in Humphreys 1993, 217) Humphreys responds that "Ingenious, yes; simple, no, for Galileo spends over twenty pages answering both obvious and subtle Aristotelian objections to the assumptions underlying his thought experiment, arguments that are essential for the thought experiment to conclusively establish that the Aristotelian theory is untenable" (Humphreys 1993, 217). This discussion clearly shows that caricaturing thought experiments as the product of a limited material and problem environment and thereby calling them less complex is an uncharitable way of portraying thought experimentation.

2.2.3.3 Computer Simulations, Real Experiments and Thought Experiments

In this section, I will argue that unlike thought experiments computer simulations cannot be employed to test fundamental hypothesis. I will employ Johannes Kastner and Eckhart Arnold's (2011) argument to make my point clear. Kastner and Arnold argue that despite their similarities to real experiments a CS can never test a fundamental hypothesis.

2.3.3.1 Computer Simulations and Real Experiments

According to Kastner and Arnold (2011), following are the conditions to be satisfied by a CS to be a substitute for an experiment. They have employed a case study from theoretical chemistry, which I will not discuss here, to draw the conditions.

Conditions

1) Back ground theories and Ruling theories:

Experimenters do rely on back ground theories that are well-accepted and uncontested within the range of application. In most of the cases the back ground theories are taken for granted and experimenters in general cases do not worry about such theories. Back ground theories may vary from experiment to experiment. For example, Newtonian mechanics may be the background theory for an experiment on the motion of a cricket ball but relativistic mechanics may be the background theory for an explanation of planetary motion. In this context the authors introduce the idea of ruling theories. Ruling theories are "theories that completely describe all causal connections within a well-defined range of phenomena. Or, in other words, everything that happens within this range of phenomena happens according to the theory". (Kastner and Arnold 2011, 7). A ruling theory must satisfy the following conditions.

a) "The theory has been empirically confirmed in many important cases.
b) The theory has not been disconfirmed in any instance. If any anomalies have occurred, then the sub range of phenomena for which anomalies can be expected can at least clearly be delineated.
c) Any alternative theory (i.e., a different theory that fully or partly covers the same range of

phenomena) has identical consequences as the ruling theory within the overlap region of their respective ranges of phenomena and within reasonable bounds of precision." (*Ibid* 8)

Quantum mechanics satisfies the above requirements to consider as a ruling theory for the description of a chemical reaction. The Schrödinger wave formulation and Heisenberg's Matrix mechanics can be regarded as alternative theories. (In strict sense of the term theory these are not alternative theories. They are equivalent but alternative formulation of quantum mechanics.) So, quantum mechanics can be considered as a ruling theory in the case of a chemical reaction. Being more precise, relativistic quantum mechanics or quantum electro dynamics (QED) is the ruling theory and quantum mechanics is the first approximation to QED. In an approximation, molecular dynamics can be considered as the ruling theory for the behavior of molecules. This is a case where the ruling theory is not the fundamental theory.

According to the authors, simulations which are based on ruling theories are the best candidates for substituting RE. The validity of a CS, which is based on a ruling theory is reduced to the questions whether the approximation and modeling techniques are passable. The authors claim that "in cases where these can sufficiently be justified theoretically, an empirical validation of the simulation is in principle not even necessary anymore."(*Ibid* 8). In the cases where we do not have a ruling theory but the approximation and simulation techniques are theoretically justified, we cannot do away without empirical validation. This is because of the fact that without an empirical validation of the CS we would not know whether our theoretical assumptions about the particular phenomena hold true for that particular application under our consideration or not.

2) Various approximations must have been taken adequately. This varies from simulation to simulation.

3) The CS can be replicated. "In the case of a computer simulation, replication means: reimplementing the same simulation under different conditions, for example, under a different

environment, with different but functionally equivalent software frame works and libraries with different but equally well motivated approximations or with different functionals that have comparable reliability for the problem at hand. This reassures the researcher that the obtained results are not an artifact of the idiosyncrasies of the particular set up."(Ibid 14)

The second and third conditions can be considered as necessary modeling techniques that must be followed in any case of model building. So, according to the authors, "a ruling theory and well approved modeling techniques jointly form a sufficient condition for a proper experiment surrogate." (*Ibid* 15)

The above discussion suggests that only those experiments that are conducted under ruling theories are replaceable by CSs. Now, suppose that we have a well-developed ruling theory. Suppose that an experiment is proposed to test a hitherto unenvisaged theoretical possibility (which falls under the ruling theory) or a new phenomenon. One can still doubt the replaceability of such experiments by CSs even though the proposed experiment falls under a ruling theory. This suggests the inability of a CS to test a fundamental theoretical hypothesis. This could be explained as follows. CSs generally employ mathematical models of the external world which are suggested by the theory under considerations. When the theoretical model and the subsequent mathematical model are too complex to be solved analytically, the experimenter will opt for a CS. But in such cases all the possible outcomes of the CS are nothing but the possible outcomes of the theory on which it is built. So, in principle, a CS does not provide anything entirely novel which is not possibly envisaged by the theory. Therefore testing a theory with a CS amounts to circularity. It is circular because the results of a CS are already envisaged by the theory and are built in to the model on which the CS is developed. The CS will solve the built in model and provide a result. If all the model assumptions are correct then it is very likely that there will be no errors. In such cases, the CS is almost like a numerical calculator which solves the complex equations.

This also suggests that a CS can never act as a crucial test. This can be explained by considering the following imaginary situation. Suppose the Classical Mechanics with ether hypotheses (Lorentz contraction is not considered here) and the Special Theory of Relativity as two competing theories and the Michelson-Morley experiment as the crucial test to decide between them. Suppose that we have a CS of the Michelson-Morley experiment[30]. Now, if the above discussion about CS is correct, then the result of our particular CS of Michelson-Morley experiment will depend up on the theoretical model on which the CS is built. If the CS is based on the Classical mechanics with ether theory it will provide a non-null result, as it was originally expected by Michelson when he had conducted the experiment. If the CS is based on the Special Theory of Relativity then it will provide a null result. This shows the incapability of CS to act as a crucial test.

Conclusion

Computer Simulation and Thought Experiments

The discussions above shows that it is not easy to employ a CS to play the role of a crucial experiment when confronted with the task of adjudicating between two fundamental theories. In other words a CS can never test a fundamental hypothesis. There are many TEs that are directed towards fundamental hypothesis in the respective field. The EPR cases, Photon Box and Niels Bohr's reply, Galileo's thought experiment of Free Falling Bodies, Maxwell's Demon are some among the many that can be enumerated. Since CSs cannot test such fundamental hypothesis one can convincingly argue that they cannot replace a TE of this nature. In other words, the CS of a TE

[30] By keeping the historical details aside, one can say that the Classical Mechanics with ether hypotheses or Special theory of Relativity are employed to explain the result of the Michelson-Morley experiment. Thinking in a different way one can assume that both these theories predicting certain results, related to the speed of light, and that result is tested in the Michelson-Morley experiment. In order to provide quantitative result a CS should incorporate a mathematical model of the phenomenon under consideration. But the Classical Mechanics with ether hypotheses and the Special Theory of Relativity will provide different mathematical models and thereby corresponding CSs will provide different result.

where the TE questions a fundamental hypothesis does not provide any epistemological advantage. More than that the additional effort required to build a CS is a disadvantage.

TEs are not always similar in characters. Some of these like Einstein's Elevators, Galileo's Double Inclined Plane, and Einstein Chasing the light beam do not consider measurement even in the qualitative aspect. But almost all the computer simulations do consider measurement. The two case studies which Chandrasekharan *et al* have provided make this point clear. Given this fact about thought experiments, the advantages computational modeling has in measuring as well as producing data seize to be an all-encompassing advantage over thought experiments. It seizes to be an advantage because many of the TEs do not and do not need to employ measurement process even in the qualitative sense. If this is the case then the simulation models, if produced of some thought experiments, say Galileo's Double inclined plane or Stevin's Inclined Plane, seem to have no epistemic advantage other than the visual appeal the simulation model may have. One will wonder whether such a modeling is better than that of the TE. And the additional effort and expertise required to develop a simulation (in the sense of developing a computational model which can mimic the real process) is much more than that is required in a thought experiment. So, in such cases, contrary to the arguments made by Chandrasekharan *et al* computational simulation becomes less advantageous than TEs. At least the simulation process is no more an easy process than that of a thought experimentation of the same phenomenon.

The nature of the argument the Chandrasekharan *et al* suggests is also important. This conclusion seems to be less warranted and one can wonder whether it can avoid the fallacy of hasty generalization. Unfortunately the authors have not applied both TE and CS to a specific problem. They have presented two case studies where CS is employed successfully. From the case studies, authors argue out the unemployability of TE in such cases. Later they qualify this position by allowing TEs some minor roles, as that of aiding an experimenter in her formulation of CSs. Apart from this TEs, according to the authors, are of little use. Authors are right in explaining the insignificance of TEs to the cases they have discussed. From this one could make the following two conclusions. (a) TEs are unemployable and hence insignificant in similar contemporary sciences which handle huge data and complex phenomena. (b) TE are unemployable and hence insignificant in contemporary sciences. Here (a) is a warranted conclusion. But (b) seems to be a farfetched generalization. We have already seen in **section 2.2.3.1** that TE are very much employed in contemporary theoretical physics. It should also be noted that the authors have not cited a CS that has been effectively employed to replace a TE[31]. At best the authors have shown the important of the method of CS. But the importance of CSs in scientific research is not a reason sufficient enough to prove the replaceability of all TEs by CSs. I have already discussed some cases of TEs where computer simulation might not be of any epistemological advantage. Of course, CSs may still help one in designing the empirical set up for executing TEs as well as real experiments in a laboratory. But this in no way appears to suggest a minor role to be accorded to TEs.

[31] I am indebted to **Dr. Joby Joseph,** Centre for Neural and Cognitive Sciences, University of Hyderabad, for suggesting this point.

CHAPTER 3

PHENOMENA, CONCEIVABILITY AND THOUGHT EXPERIMENTS

This chapter is divided into three sections. In the first section, I discuss the data-phenomena distinction introduced by Bogen and Woodward. Following Basu (2012) I argue that the above distinction is multilayered and context dependent. In the section two, I attempt to show the importance of data-phenomena distinction in the epistemology of TE. I discuss two TEs two show the centrality of the data-phenomena distinction in the epistemology of TE. Next section is a discussion on the notion of model dependent conceivability. With the help of two brief case studies from history of science, I argue that model dependent conceivability is a central notion in scientific reasoning. In the last section, I employ the motion of model dependent conceivability to account for an epistemology of TEs. I argue that TEs are models of phenomenon. The success of failure of TE depends on the conceivability or inconceivability of the phenomenon under discussion. I also attempt to show that this way of reasoning is a part of scientific practice.

3.1 Data-Phenomena distinction and Thought Experiments

Traditionally anything that is observable is considered as phenomenon. Well-formed scientific theories are supposed to "save the phenomena" and saving the phenomena is the catchword for scientific explanation. Pierre Duhem and Bas Van Fraassen are the two best-known philosophers vouching for 'saving the phenomena' project. Since an explanation is generally an answer to a why-question the above view allows one to think that anything (preferably observable) that could elicit a why-question as a phenomenon[32]. Pierre Duhem suggests that if a theory saves the appearances then it saves the phenomena (Duhem 1969). According to Van Fraassen, "if what it [theory] says about the observable things and events in this world is true then it saves the phenomena" (Van Fraassen 1980, 12). In this view, a phenomenon could be anything happening out there in the world. It could be the occurrence of day and night, thunder and lightning, magnetic attraction and repulsion, etc. However, not all phenomena will be considered a phenomenon in a particular domain. For example, solar eclipse might not be considered as a phenomenon to be accounted for by thermodynamics. This traditional view does not make a distinction between data and phenomenon. Bogen and Woodward argued out the distinction between data and phenomena in there classic paper Saving the Phenomena (1988). According to them, a phenomenon is not always equivalent to the observables. Observations when recorded amount to data but not to phenomena.

In this section, I discuss Bogen and Woodward's distinction of data and phenomena. Then I try to show that this distinction is central to understand the working of thought experiments (TE). I will discuss two paradigmatic cases of TEs to show the importance of the data-phenomena distinction in the context of TEs.

3.1.1 Data and Phenomena

Bogen and Woodward argue that scientific theories are attempts to account for phenomena but not for data. Data in its most elementary sense stands for the recorded observations in the

[32] Since the answer to a why-question is generally an explanation, anything that requires an explanation becomes a phenomenon. However, even a what-question can hint at a phenomenon. Consider the question, what is lightning? According to the ancient Indian myths, lightning happens when god Indra strikes with his weapon Vajrayudha. Therefore, for ancient Indians lightning is the effect produced by the weapon of god Indra. The modern science answers what is lightning differently. Thus, the same what-question may receive different answers. Finalizing an answer to the what-question itself becomes a scientific task here. In the above example, the correct characterization of lightning gives us a natural phenomenon. This suggests that even a what-question can hint at a phenomenon.

framework of an experiment. Thermometer readings, X-ray photographs, Geiger counter records Bubble chamber photographs etc. are good examples of data. Data for the most part could be observed straightforwardly. Observations mediated by instruments are also considered as straightforward observations. The importance of the notion of straightforwardness will be made clear later. Bogen and Woodward provide three important characteristics of data. These are:

1. Data act as evidence for the existence of phenomena.
2. Data could be observed straightforwardly.
3. Data is not amenable to any systematic explanation by theory. Also they are not predictable.

In contrast to data, phenomena have the following properties.

1. Phenomena are amenable to prediction and systematic explanation.
2. Phenomena are detected by the use of data.
3. Not all phenomena are straightforwardly observable. (This is a revised attitude taken in Woodward 2011)
4. Facts about phenomena are evidence (or potential evidence) for or against high-level theories.

Consider the infamous example of the phenomenon of melting point of the metal lead (Pb) which Bogen and Woodward discuss in *Saving the Phenomena*. Data here is the set of thermometer readings recorded in the course of the experiment. The phenomenon under consideration is the melting point of the metal lead (320 C$\pm$ k, where k is the margin of error). Bogen and Woodward employ this example to illustrate

a. The non-explainable nature of data by any theory.
b. The non-straightforward character of phenomenon.

Any particular data point, say 318.5 ˚C, is the result of the causal interaction between the thermometer and the sample of lead. However, the data point (318.5˚C) so observed is not just the result of the real melting point of lead alone. Rather, it is infected by various controllable and uncontrollable factors like the observational error, purity of the sample, efficiency of the thermometer and even the efficiency of the observer. According to Bogen and Woodward, no theory can systematically account for all such factors. Therefore, a theory of the melting point of lead cannot explain the occurrence of a particular data point. This suggests that the data is not amenable to systematic explanation or prediction[33].

The phenomenon, according to Bogen and Woodward, is reasoned out from the data by the employment of suitable data processing methods[34]. For example, in the above case, the melting point of lead is reasoned out from the scattered data points by employing suitable statistical methods. The melting point of lead obtained by the application of statistical methods (the mean of the individual data points in this particular case) on the set of data may not correspond to any particular data point the data set. In other words, the phenomenon reasoned out from the data might not be seen directly in the data set[35]. This suggests that what is uncontroversially and directly observable is data but not phenomena. The phenomenon of interest needs to be inferred from the data. In this particular example, we employ statistical methods to infer the phenomenon. The

[33] This particular feature of data might not be true in every case. Consider the case of astronomical observations where the possibility of intervention from the part of the observer is limited. Consider the trajectory of a planet as the phenomenon. The trajectory is gathered from a set of observation. In this case, not only the trajectory of the planet but also the data points (the position of the planet at a particular time) is amenable to systematic explanation. Predicting the position of a planet is an important part of astronomical research. This also suggests the contextuality of the data-phenomena distinction. See Basu 2003 for a detailed discussion of the contextuality of the data-phenomena distinction.

[34] Apel (2011) calls this as the pattern view phenomena. Pattern view of phenomena was not unanimously accepted. For criticism of pattern view, see, McAllister 1997, Glymour 2000. Apel offers a context dependent account of phenomenon, which according him, will account the scientific practice in a better manner than that of the pattern view. See Apel 2011.

[35] There is nothing peculiar about this. Consider the following case. Let 3,2,4,4,6,6,7,8,9,9, are the marks of students in a class test. Let 10 be the total number of students in the class. The average mark of a student in that particular test is 5.8 and it is not present in the data set.

phenomenon, which is inferred from the data, is amenable to systematic explanation and prediction. In fact, higher order theories predict and explain only phenomena. The melting point of lead could be explained by employing the theories of chemical bonding of atoms and in molecules in a solid.

The following features of data will help us make a sharp contrast between data and phenomena.

1. Data must be accessible to our senses. By this, we do not mean the accessibility of data to unaided senses. In almost all cases, we employ instruments to gather data. What is required of the data is the accessibility of it to different data managing techniques, including the computer-assisted techniques.
2. Data must occur frequently and sufficiently large.
3. Data must be amenable to demand for data-reduction and statistical analysis.

Unlike data, phenomena might not be always accessible to senses. For example, the trajectory of a planet is not accessible to our senses but we can derive it from the observation data. One of the reasons which make this derivation possible is the 'stable and repeatable' feature of the phenomenon (trajectory of the planet). Unlike phenomena, the characteristics of data are idiosyncratic to the procedures of the experiment. This happens because the same phenomenon can appear in various experimental situations and the nature of the data gathered in each experiment is pertinent to the particular experimental set up.

3.1.2 Contextuality and Evidential significance of the Data-Phenomena Distinction

Two features of the data-phenomena distinction in the above discussion require further consideration. It was argued that what is uncontroversially and directly observable is data and data is not amenable to systematic explanation or prediction by high-level theories. In contrast to these features of data, phenomena are amenable to systematic explanation and prediction but they are not uncontroversially and directly observable. However, these two features of data and phenomenon are not as distinct and clear as it appears. Rather the data-phenomena distinction could be context dependent and it may include many layers.

Consider the motion of a planet around a star. The position of the planet in the sky is the only observation record. Orbit of a planet, which is the trajectory of its motion around a star, is derived from the set of observations on the motion of the planet over a long period. The orbit (trajectory of the planet) is not accessible to the senses of an observer[36]. This is a good example for an unobservable phenomenon, which is amenable to explanation and prediction by theory. Now consider the position of a planet at a particular time. This is an observation record and it belongs to the data set. But, the position of a planet at a particular time is also amenable to systematic explanation and prediction. Knowing not only the orbit but also the position of planets is very important in astronomy. For example, knowing the position of planets is very important in deciding the time of execution of interplanetary missions. This suggests that both the position as well as the orbit of a planet can act as a phenomenon. Also, depending up on the nature of the project, the position of a planet- observation record of the position of a planet- can play the role of both phenomenon and data. This indicates the contextual dimension of the data-phenomena distinction[37].

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[36] The trajectory figured out from the observation data may accord well with more than one geometrical figure. For example, both the Ptolemic and the Copernican astronomical systems employ different geometrical figures to explain the motion of planets in the solar system. Issues related to this are not considered in this thesis. See Duhem 1969 for a detailed account of such problems.

[37] Basu argues out similar point by employing an interesting case study from history of chemistry. According to Basu, "the data-theory relation or the data-phenomena relation is a multi-layered relation. What counts as "same" data needs to be contextualized and is contingent upon the particular case in hand". Since the nuances of the contextuality of the data phenomena distinction is not important for the present theses I will not discuss it any further. See Basu 2003, 354-56. By employing a case study from astronomy, Apel also argues out similar point. See Apel 2011.

One of the important features of phenomena is its potentiality to act as evidence for or against a theory. The contextual nature of the data-phenomena distinction has repercussions on the evidential significance of phenomenon. Basu employs the contextual and multi-layered nature of data-phenomena distinction to argue out the theory-ladenness of evidence. He suggests that "a piece of evidence for (or against) a theory is a construction in the context of that theory from (raw) data. In this construction, a set of auxiliary assumptions is employed. These auxiliaries may themselves be theoretical in character. From the same (raw) data it is possible to construct different evidence for (or against) different theories since the auxiliaries employed in connection with different theories can be different. Finally, although the (raw) data are expressed in a language which is acceptable to partisans of competing theories, the evidence constructed from the same (raw) data is often expressed in the partisans' differing theoretical languages" (Basu 2003, 357). The mains points could be summarized as follows:

a. What is uncontroversially accepted is raw-data, which is the primary observation record.
b. The phenomenon, which is often constructed from the raw- data may differ for different partisans[38]depending up on the nature of theories and auxiliary theories they have employed in the construction of phenomena.
c. Even when there is agreement about the raw-data, the evidence and phenomenon constructed from the raw-data might not call for an agreement among the partisans.

3.2 Thought Experiments and Phenomena

In this section, I argue that TEs are models employed to reason out features of external world. They achieve this goal by carefully constructing phenomenon within the thought experimental model. I will discuss two paradigmatic cases of TEs to elucidate this point.

[38] This is a very important point in the case of TEs. This will be clearer when we discuss TE –anti-TE scenarios.

3.2.1 Galileo and the Free Fall

Galileo in the first day of his *Discoursi* presents an ingenious TE to counter the Aristotelian view of free fall. According to the Aristotelian view and common sense, heavier bodies always fall faster than lighter ones when they are falling through the same medium. This is expressed as "...bodies of different weight ... move in one and the same medium with different speeds which stand to one another in the same ratio as the weights; so that, a body which is ten times as heavy as another will move ten times rapidly as the other"(Galileo 1954, 61). Galileo proposes the following TE to show the incorrectness of the above Aristotelian view. Consider the following scenario. Consider the free fall of two bodies having weight W_1 and W_2 such that $W_1>W_2$. Let S_1 and S_2 respectively are the speed of these bodies in free fall. Let S_3 be the speed of the system of the bodies united together in free fall. From the Aristotelian view, we can derive the following scenarios:

C_1) Since $(W_1+W_2)>W_1$, $S_3>S_1$

C_2) Since $W_2<W1$ and $S_2<S_1$, the lighter body retards the heavier body and thereby it retards the system of united bodies. So, $S_3<S_1$

C_1 and C_2 together suggest the following absurd conclusion that the heavier body moves both faster and slower than that of the system of combined bodies at the same time. This implies that the Aristotelian understanding of the free fall is wrong. From this, Galileo suggests, "we infer that large and small bodies move with the same speed provided they are of the same specific gravity" (*Ibid* 64).

3.2.1.1 Modeling Phenomenon

3.2.1.1a Idealizations and Abstractions

I have presented a reconstructed form of Galileo's thought experiment. It should be noted that the point contested in the TE is about a phenomenological relation, the relation between the weight of a body and its speed in free fall. This point becomes clear when we pay attention to the following. Galileo writes that "[B]ut, even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that **a heavier body does not move more rapidly than a lighter one** provided both bodies are of the same material and in short such as those mentioned by Aristotle" (*Ibid*, 62 emphasis added). The above quotation shows that the TE is intended to disprove the Aristotelian understanding of the relation between the weight and speed of a body. In order to arrive at the conclusion, Galileo started with the following assumptions and idealizations some of which are part of the Aristotelian theory of motion.

1. Every falling object has a different speed fixed by the nature and the speed cannot be altered without external force (*Ibid* 63). (This assumption is rejected after the TE.)
2. The speed of an object in free fall is inversely proportional to the resistance of the medium. In the later discussion, Galileo shows the incorrectness of this assumption (*Ibid* 66-67). Even though, the resistance of the medium has a significant role in the speed of a free falling body, Galileo eliminates it as a part of idealization.
3. The figure of a body has only small influence on the motion of fall (ibid 65). (Retains)
4. Galileo argues that in order to make a general claim about the free fall, one has to think about the situation where the only effect acting on the falling body is gravity. Therefore, the influences of the medium, which affect the single effect of gravity on the falling bodies, need to be abstracted out. This idealization, according to Galileo, was also held by Aristotle (See ibid 65). Galileo retains this idealization. Later he suggests, "In a medium totally **devoid of resistance** all bodies would fall with the same speed" (*Ibid* 72). (Emphasis added.) Note the idealization invoked (see point 2) by removing the impact of the resistance of medium.

3.2.1.1b The nature of measurement and phenomenon

Data in an experiment is produced by observation and measurement. Let us consider the nature of measurement in the TE. There are four instances of measurement in the TE. In each case, the experimenter has to determine the speed of a moving object.

1. Measuring the speed of W_1. We get S_1

2. Measuring the speed of W_2. We get S_2 and $S_1>S_2$

3. Measuring the speed of the system W_1+W_2. We get S_3 and $S_3>S_1$ because $W_1+W_2>W_1$

3.1. Measuring the speed of the system W_1+W_2 with the added assumption or information that W_2 retards W_1. Here we get $S_3<S_1$

In any of the four cases, we are not interested in quantification in the way of determination of the exact magnitude of weights and speeds of bodies. Measurement, in the sense of attaching numbers to values of properties, is not explicit in any of these cases. Instances 3 and 3.1 require a closer examination. They enable the thought experimenter to conceive of a scenario in which she is forced to attribute two different speeds ($S_3>S_1$ and $S_3<S_1$) to the system (W_1+W_2) at the same time. In a concrete experiment, there is only one measurement at a time (Case 3) and we get S_3. Case 3.1 is only a different visualization of Case3 and this allows one to conceive a different value for S_3. In a real measurement, S_3 may or may not be greater than S_1. Case 3.1 can be seen as a different possible interpretation of the Case 3 based on the Aristotelian understanding of free fall. Note that, here also, we are not in a need of quantification. Rather what makes the two scenarios (3 and 3.1) different from each other is the incorporation of the additional information that W_2 retards the system W_1+W_2. This added constraint on the motion of the system of bodies allows one to reason out that $S_3<S_1$. Accuracy and precision, the two important conceptions regarding measurement seem to play

no important role here. One can say that measurement is not used quantitatively but only qualitatively.

Let us pay attention to the particularities of this TE. No new data is produced in the TE. But more than once, we pay attention to measurements. For example, in order to get the result S3>S1 in $C_{1,}$ an experimenter in a concrete case has to measure the speed of the objects W_1 and W_2 in free fall. In the case of an actual experiment, we repeat this measurement several times to get a good result. In such an experiment, there will be a set of values for both S_1 and $S_{2.}$ But in the TE, we hardly pay attention to this data gathering part, which is crucial in the case of concrete experiments. The information that both S_1 and S_2 have specific magnitudes (x and y units respectively) is sufficient in the TE scenario to reason out its conclusion. This is made possible by focusing only on the phenomenon, which is the speed of an object in free fall. It should be noted that Galileo has employed various idealizations and abstractions (See points 1-4 listed in the above section) to make the TE a feasible one. Simplicio, the Aristotelian in the dialogue, sanctions all this points. This, like the raw-data in a concrete experiment, is the uncontroversial part of the TE. If we challenge the underlying assumptions and idealizations, the TE becomes untenable. By employing non-contestable idealizations, Galileo modeled the free fall of an object under the influence of gravity alone. The motion (Free in the case the TE) of an object under the influence of gravity alone is the phenomena here. It should be noted that such a situation is not available in the external world[39]. By focusing attention on this phenomenon Galileo was able to draw a contradiction from the Aristotelian theory of free fall. In this way, Galileo was able to show that a phenomenon, which could be legitimately modeled from the Aristotelian theory of motion, is untenable within the Aristotelian theory. The TE makes this possible by focusing attention only on the phenomenon but not on data. The

[39] This in a sense resembles the contrived nature of a concrete experiment. Laboratory situations are created for the purpose of interventions too. This too adds to the contrived nature of experiments. Many of the laboratory situations as well as phenomenon do not occur in the world outside the laboratory.

phenomenon modeled in the TE satisfies the general characteristics of phenomena listed in the session 3.1

1. The phenomenon (Free fall) in the way modeled in the TE is stable and repeatable. The nature and characteristics of free fall, for example the relation between speed and weight of an object in free fall, does not change with respect to different experiments.
2. The phenomenon is not directly observable. It is modeled from the data by employing a theory[40]. The measured values of S_1, S_2 and S_3 are the only directly observable data. At the time of Galileo, no such experiment was empirically feasible. Therefore, no new data is produced or employed in the TE and the phenomenon is reasoned out from the available data by the theory.
3. The phenomenon is not idiosyncratic to any particular experimental procedure.
4. The phenomenon is amenable to explanation and prediction.
5. The phenomenon acts as evidence against the Aristotelian theory of motion and it acts as evidence in favor of Galileo's theory of motion.

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[40] After elucidating the contradiction from the Aristotelian theory of free fall, Galileo proposes his theory of free fall. One could argue that the phenomenon of free fall was already constructed by employing the various abstractions and Galileo's new theory of free fall is an explanation of the phenomenon. However, the Aristotelian theory is committed only to the explanation of appearances and it is not intended to explain anything that is not observable. The phenomenon of free fall under the influence of gravity alone is not something observable at the time of Galileo and hence, the Aristotelians are not committed to such a phenomenon and its explanation. What Galileo has performed in the TE is the construction of a phenomenon based on the Aristotelian theory of motion with the help of non-objectionable idealizations and abstractions. Whether the phenomenon is constructed from the Aristotelian theory or the Galilean theory is an interesting question in itself. It appears that the phenomenon is constructed from the Aristotelian theory. If not, the TE may fail to gain credible evidential significance against the Aristotelian theory of motion. Though the phenomenon appears to be constructible from both the theories, answer to the above question seems to have little bearing on my argument. The phenomenon is constructed from one of the theories and the TE depends heavily on the nature of this phenomenon. This is sufficient to show the importance of the notion of phenomena in the case of this TE.

3.2.2 Einstein, Bohr and the Photon Box Thought Experiment

Weighing the atom is an interesting episode from the famous Bohr Einstein debates in the history of quantum mechanics. This episode has two TEs, a TE and a counter TE. Einstein proposes a TE to show the violation of Heisenberg's uncertainty principle. Bohr counters Einstein's TE with an improved and improvised version of Einstein's own TE. In this section, I will discuss the nature of phenomena in this TE-counter TE episode.

3.2.2a Einstein's Photon Box

According to Heisenberg's uncertainty principle, it is impossible to measure the position and momentum of a particle simultaneously with any arbitrary degree of accuracy. The indeterminacies in the simultaneous measurement of position and momentum of the particle are of the order of Plank's constant divided by 2ʌ. Let Δp and Δx are the indeterminacies in the simultaneous determination of the position and momentum of a particle; then according to the uncertainty principle Δp.Δx ≥ h/ 2ʌ, h is Plank's constant. This is called the position-momentum uncertainty. Uncertainty principle in its general form states that no canonically conjugate pair of physical quantities can be measured simultaneously with any arbitrary degree of accuracy. Let ∂p and ∂x be the uncertainties in the simultaneous measurement of a pair of conjugate physical quantities then ∂p.∂x ≥ h/ 2ʌ. (h is Plank's constant). Uncertainty principle holds valid to the measurement of the variables energy (E) and time (t). Let ΔE and Δt are the uncertainties in the simultaneous measurement of energy and time of emission of a particle then ΔE.Δt ≥ h/ 2ʌ.

During the 1930 Solvay conference on Magnetism, Einstein came up with a thought experiment to counter the uncertainty principle. He proposed a device consisting of a box with a hole in its wall. The hole can be controlled by a shutter moved by the mechanism of a clock in the box. The box contains a certain amount of radiation. Now the apparatus is arranged in such a way that a single photon is emitted through the hole at a particular moment. The time of the emission can be noted with any arbitrary degree of accuracy. The mass of the photon can be calculated by weighing the box before and after the emission of the photon. From the $E=mc^2$ relation the energy of the photon can also be calculated. Thus, both the energy and the time of passage of the photon can be measured with any arbitrary degree of accuracy. From this, Einstein concluded that the uncertainty principle is undermined.

3.2.2b Neils Bohr's Reply

Niels Bohr made his reply by focusing on the possible instruments one needed to perform this TE and subsequent difficulties. In his own words, "[O]ur discussion concentrated on the possible application of an apparatus incorporating Einstein's device..." (Bohr, 1985, 268). In Bohr's account of the TE, the box is suspended in a spring balance and furnished with a pointer to read its position on a scale fixed to the balance support. The weighing of the box can be done with any given amount of accuracy by adjusting the pointer to zero position with the use of adequate loads. Now to weigh the box it should be moved in the gravitational field. The movement of the clock in the gravitational field will make a change in the clock reading by Δt. The change of time in its measurement is a consequence of the General Theory of Relativity proposed by Einstein. By incorporating the change of time in its measurement (indeterminacy in the time measurement) Bohr successfully derived the uncertainly relation ($\Delta t. \Delta E \approx h$, where h is the Planks constant). Einstein accepted Bohr's conclusion.

The derivation can be shown as follows. Let Δp and Δq are the change in position and momentum of a particle respectively. According to the Uncertainty relations, if Δ t is the change in time and ΔE is the change in energy of the emitted particle, then $\Delta t \Delta E \geq \frac{h}{2\pi}$. Consider the TE. Let change in the momentum of the particle $\Delta q = \Delta(v \times m)$, where v is the velocity and m is the mass of the particle.

Let the total change in the momentum $I = T \times g \times \Delta m$, where T is the duration of weighing, g is the acceleration due to gravity.

$$\Delta p \cong h/\Delta q < T \times g \times \Delta m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

But, according to General Theory of Relativity,

$$\Delta t = T \times g \times \frac{\Delta q}{c^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$\Delta t \times c^2 = T \times \Delta q \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

$$T = \frac{\Delta t\, c^2}{g\, \Delta q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

From 1 and 4

$$\frac{\Delta t\, c^2}{g\, \Delta q} \times g \times T = \frac{\Delta t\, c^2}{g\, \Delta q} m \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

$$\Delta t \Delta m c^2 > ▯ \ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

But, according to Special Theory of Relativity, $E = mc^2$ therefore,

$$\Delta t \Delta E > ▯$$

3.2.2.1. Data-Phenomena Distinction and Evidential Significance

It is obvious that no data is produced in the TE. Even though in the TE there are references to measurements, nothing quantitative is recorded in any interesting sense. Therefore, the TE produces no (raw) data. The uncertainty relation between energy and time ($\Delta E.\Delta t \geq h/ 2\Lambda$) is the phenomenon in these TEs. This is not a directly observable phenomenon. Einstein suggests that the uncertainty relation is violated in his TE. It means that the phenomenon is an untenable one in the context of the TE. Bohr counters that, the proper modeling of the data will not allow the violation of uncertainty relation. Let us list the raw-data on which both the participants agree.

1. Some amount of radiation (m) is emitted from the atom in the box
2. The mass of the radioactive substance, before and after the emission of the radiation (M_1 and M_2 respectively).
3. Time (T) of emission of the radiation.

Both the partisans, Einstein and Bohr, accept the raw-data listed above. However, Bohr differs from Einstein on the value of T. According to Bohr, one has to consider the consequences of General Theory of Relativity in the measurement of time. If one does so, she will obtain a value for T which is different from the value of T measured in the Einstein's version of the TE. This additional theoretical consideration changes the evidential credential of the raw-data. Without considering the General Theory relativity, Einstein was able to model the raw-data in such a way that it could act as evidence against the uncertainty relation. But when we introduce the additional theoretical consideration, the general theory of relativity, the evidential credentials of the raw-data changes completely and it no more acts against the uncertainly principle.

When Einstein argues that the Uncertainty principle is undermined; he bases his reasoning not on the raw-data but on a modeled data (evidence). Einstein employs the Newtonian conception of time and mass, which are absolute and independent of the observer, to model the raw-data. This improper modeling of the raw-data suggested the untenability of the phenomenon, the uncertainty relation. No direct claim to the raw-data is made. The appeal here is to the plausible modeled data (evidence). Bohr's reply is based on a different modeling of the same raw-data. He transforms the raw-data into evidence favorable to the tenability of the phenomenon by employing a theory, which was not a part of Einstein's TE. Since the credentials of the new theory, the General theory of Relativity, is beyond contention, the evidential significance of the raw-data modeled in Bohr's version of the TE is also beyond contention[41].

3.3 Model, Conceivability and Thought Experiments

In this section I introduce the notion of model dependent conceivability. I argue, with the help of two brief case studies, that model dependent conceivability is a central notion in scientific theorizing.

3.3.1 Model Dependent Conceivability

Like possibility, notions of conceivability abound[42]. The relations between the two are discussed at length in the philosophical literature. In this section I introduce the notion of model[43] dependent conceivability, which falls under the rubric of nomological conceivability. The model dependent conceivability is defined in the following way. If the dynamical laws of a model do not prohibit the occurrence of a phenomenon, then that phenomenon is conceivable within that particular model. Occurrence of the phenomenon within a model requires an elaboration here. Given the initial conditions and dynamical laws if the model could assume a state which could correspond with the target phenomenon then that state of the model could be considered as an occurrence of the phenomenon in the model.

Consider the following cases.

(a) Cooling of a cup of hot tea.

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[41] Though Einstein has accepted Bohr's victory, people later have challenged Bohr's introduction of the General theory of Relativity in the TE. For a detailed discussion of this See Max Jammer, 1974, 137-156

[42] See **Appendix 1** for a brief discussion on the different notions of conceivability and possibility.

[43] For details about models and scientific theories See **Appendix 2**

This is conceivable within in the models of thermodynamics and hence the phenomenon is conceivable within the model of thermodynamics.

(b) A cup of cold tea getting hotter spontaneously.

This is not conceivable within the models of thermodynamics. The phenomenon under consideration is prohibited because it violates the second law of thermodynamics, the law of entropy. Hence, even when the particular phenomenon under consideration is an actual phenomenon (in this case it is not) if it is inconceivable within the particular model then the model fails to save the phenomena.

The two examples listed above help us understand the difference between conceivability and imaginability. Nothing stops an agent from imagining both (a) and (b). One could imagine a situation where a cup of cold tea getting hotter spontaneously[44]. But the same is not conceivable within the models of thermodynamics. The notion of conceivability employed above is nomologcally bound but imaginability is not. Also, conceivability within a model is assumed to be a good guide to possibility but imaginability is not.[45] It is already explained that not everything imaginable is conceivable. Also, not everything conceivable within a model might be imaginable. This is because some states which a model can assume without violating the dynamical laws of the model might not be immediately available to the agent. This is because, in some cases, one has to solve complicated dynamical equations to reach a result. Such solutions generally do not appear trivially to the reasoner and hence such states of the system, which are conceivable in the above sense might not be imaginable. This marks the difference between conceivability as a psychological capacity and as a

[44] Think about the world described in the Harry Potter novels penned by J.K. Rowling. In that world, with the help of her magic wand a witch can change a cup of cold tea into a boiling one in a moment. In that imaginary world, one can even transform a cup of tea into red wine. All these are conceivable as well as possible in the world of Harry Potter. In fact, transforming a substance into a different one is an ordinary event in the Harry Potter world. The technical name for such transformation is transfigurations. "**Transfiguration** is a branch of magic that focuses on the alteration of the form or appearance of an object, via the alteration of the object's molecular structure". For details follow http://harrypotter.wikia.com/wiki/Transfiguration 4/6/2015

logical ability. The notion of conceivability employed here is the ability of an agent to follow the derivation of a conclusion from the initial conditions employing the rules. Therefore, a state of a model or the conclusion of a long derivation process is conceivable. This also suggests that a computer assisted modeling process and the results of it are conceivable within the model. None of these might be imaginable for the obvious reason that the mathematical or logical ability of a human agent is limited and hence the result of a lengthy derivation or calculation which is assisted by computers might not be imaginable for an agent.

In this account, conceivability is always a guide to possibility. In fact there is not much difference between conceivability and possibility here. Everything that is conceivable is in-principle possible. This suggests that the long debated relation between conceivability and possibility plays very little role here. Unless the word possibility is employed in a sense of empirically available or experimentable, there is no difference between conceivability and possibility. I will stick with the notion of conceivability because possibility has a much closer relation to the experimentable but the word conceivability does not. Whether something is experimentable or empirically feasible is a highly on the technological status. For example, the motion of an object under the influence of gravity alone was a phenomenon conceivable for Galileo, but it was not possible (experimentable or empirically feasible) at the time of Galileo.

The relation between actual and conceivable is more complex than that of the relation between conceivable and possible. Model dependent conceivability is not a good guide to actuality. Also, actual might not always seem the best conceivable and therefore actual might not always seem the best possible. These could be explained further by paying attention to two actual phenomena and their conceivability within different scientific models.

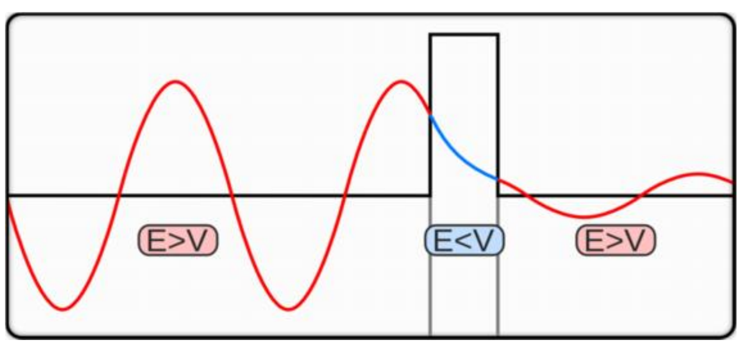
3.3.2 Actual vs Conceivable: Cases from the History of Science

a. Quantum Tunneling

It was suggested that conceivability is a model dependent notion and hence not every actual phenomenon seems conceivable. This can be explained further by considering the phenomenon of quantum tunneling. Quantum tunneling is a peculiar phenomenon in which of a particle with lower kinetic energy passes through a region with higher potential energy. This is a classically impossible phenomenon but observed among the atomic and subatomic particles.

Consider the movement of an atomic particle with energy E. Let V be the potential of the region through which the particle is moving and assume that V is not constant. Classically, the particle can move only through those part of the region where E>V. This region is called as classical region. But it is observed that the particle with energy E moves through the region where E<V. This phenomenon, the motion of a particle from a region where E>V to a region where E<V is called quantum tunneling.

A diagram[46] showing quantum tunneling.



In the diagram the regions where E>V is called the classical region. The particle surmounts this region. The region, where E<V is the non-classical region. According to the classical mechanics, it is impossible for the particle to surmount the non-classical region where energy of the particle

[46] This diagram is not of actual scale. It is employed to make the concept of tunneling clear. The picture is by Felix Kling and is taken form https://commons.wikimedia.org/wiki/File:TunnelEffektKling1.png#

$E<V$. But it is observed that the particle with energy E moves through the region where $E<V$. This phenomenon, the motion of a particle from a region where $E>V$ to a region where $E<V$ is called quantum tunneling.

Tunneling is an actual phenomenon confirmed by experimental results. However, classical models of the motion of a particle through a region of potential V do not suggest quantum tunneling. In fact, classical mechanics in no way suggests or permits the motion of a particle over a potential barrier where the potential $V > E$. In short, classically the tunneling is an inconceivable phenomenon. This suggests that not everything actual appears conceivable and hence possible. But quantum mechanically tunneling is a conceivable and hence a possible phenomenon. When we quantum mechanically express the equations of motion of a particle through a potential V, the dynamical laws of motion of the particle and the subsequent mathematical description of motion do not prohibit the motion of the particle in a region where $E<V$. In fact, the quantum mechanical models suggest some probability for the particle to surmount the potential barrier and move through the region where $E<V$. Therefore, tunneling is conceivable and hence possible within the models of quantum mechanics[47].

b. The Perihelion of Mercury

The precision of perihelion of mercury is one among the earliest classic tests of General theory of Relativity. According to the Newtonian Mechanics, a planet orbiting around the sun describes an elliptical orbit with the sun as one of the foci. The perihelion is the point closest to the sun the in

[47]Physicist Leonard Susskind explains this peculiarity with the following Slogan. According to Susskind, "[E]verything not forbidden is compulsory". He further explains that there are many events that are not just possible in classical mechanics. But in quantum mechanics, they are not impossible but only improbable. It means that the probability of an event, quantum tunneling, though very small is not ruled out by the theory (quantum mechanics). Hence, if one waits for a long period the improbable events will turn out. If such an event turns out then the theory which rules the domain of that event, according to Susskind, is bound to explain such a phenomenon. The theory makes this explanation by showing at least the probability of the phenomenon in accordance with the dynamical laws. Therefore, everything that is not forbidden by the theory is compulsory. See Susskind 2008, 121-122. For a detailed and technical description of quantum tunneling, see Griffiths, 2005, 320-322

the orbit of a planet. If, the sun is spherically symmetric and the planet is an isolated one then the perihelion must remain the same. But the perihelion of mercury does not satisfy that condition. It was observed that with every completed orbit the perihelion of mercury changes slightly. This amounts to saying that the orbit of the mercury slightly changes its orientation every time it completes its orbit. This is generally called as the precision of the perihelion. The change in the position of the perihelion can be accounted for by the Newtonian mechanics. The change in the position of perihelion can be accounted for by appealing to various forces other than that of the gravitational attraction between the sun and mercury. Due to the presence of more than one planet and other astronomical objects, the solar system is not a perfect two-body system. Therefore, the mutual influence of various astronomical bodies within the solar system must be taken into account while describing the motion of a planet. Interestingly, the irregularities in the motion of the planet Uranus prompted astronomers the prediction of planet Neptune. The confirmation of this prediction was a startling evidence for the Newtonian mechanics. Later it was noticed that the planet Neptune was observed many times even before the actual recognition of the object as a planet. But, the explanation of the precision of the perihelion of mercury evaded the well confirmed Newtonian Mechanics. Even after employing various ad hoc[48] assumptions to account for the precision of the perihelion of mercury, it was observed that there is a significant residual change in the perihelion of mercury amounting to 43 seconds of arc per century. In 1915, Einstein employed his General Theory of Relativity to account for the precision of the perihelion of mercury. This result was one of the first classic tests of General Theory of Relativity.

3.3.2.1 Some Features of model dependent conceivability

The above discussion on the two instances from the history of science suggests the following

[48] For a good discussion on the various ad-hoc theories employed to explain the precision of perihelion of mercury and its repercussions on theory testing, see U Gahde, 1997, *Anomalies and the revision of theory-elements: notes on the advance of Mercury's perihelion*

features of model bound conceivability.

1. An actual phenomenon might not always be conceivable. But one of the important aims of scientific theorizing is to make the actual conceivable within the models of science. Quantum tunneling shows this feature of the model dependent conceivability. Once a phenomenon is made conceivable and if the model and its assumptions are right, then the phenomenon must be actual. If a phenomenon which is conceivable within a model could not match the observed data or data models[49], it will eventually result either in the correction of the model or in a radical change of the model. Consider the perihelion of mercury. This phenomenon is conceivable within the Newtonian Mechanics. With the help of various ad-hoc assumptions the dynamical laws of Newtonian Mechanics can even predict the variation in the trajectory of the Mercury. But the prediction of Newtonian Mechanics (43 seconds of arc per century) varied considerably from the observed data. But General Theory of Relativity made prediction (36 seconds of arc per century) which is closer to the observed data than that of the Newtonian Mechanics. Therefore, the General Theory of Relativity replaced Newtonian Mechanics in explaining the perihelion of Mercury.
2. A phenomenon may be made conceivable within more than one model. In such cases if the models are radically different, the adjudication between them is suggested by the fit or

[49] From observations or measurements what we get data. Generally recorded observations are considered as data. This we call raw-data. Generally one has to perform a lot of operations to make the raw-data ready for further scientific purposes. This is because the data we just gathered might contain a lot of errors. Therefore, one has to first correct the data. Then it may be rectified and regimented for the particular use. In many cases after correction and regimentation what remain will be an idealized version of the raw-data. This modified or arranged data is generally called as data-model. In the case of astronomy, we may first remove the errors (if an observation, among the number of samples, is far deviant from the observed ones, then in most of the cases it is an error) data point and try to present them through a set of smooth points in a curve. These attempts are generally called data reduction and curve fitting. For example, if we are investigating the orbit of a planet, we eliminate the points that are fallacious from the observations and then draw a smooth curve. If the fallacious points repeats over a period of time in our observation of the trajectory of the planet then we might consider it as a phenomenon and try to explain it. Constructing data models is an extremely difficult job. It requires a lot of statistical techniques. Generally, it is to the data models that we check our theories. In many cases, the raw-data which is too complex might not be of any help. See Suppes 1962. See Frigg 2012 for a succinct discussion of data-models.

degree of fit between the theoretical model and the data model. This suggests that the conceivability of phenomena alone does not guarantee the truth[50] of a model. But the inconceivability of an actual phenomenon within a model suggests the incorrectness of that model.

3. Conceivability can be achieved by the employment of successful ad-hoc theories. Many ad-hoc hypotheses were proposed to account for the precision of the perihelion of mercury within the models of the Newtonian Mechanics. This shows that the conceivability of a phenomenon in a model might not be a result of straight forward derivation from the dynamical laws governing the model. Consider the perihelion of mercury in the light of Newtonian Mechanics. In a perfect two body system where the only force acting on the bodies are gravity, a phenomenon like the perihelion of mercury does not arise. The bodies will observe a perfect parabolic orbit. But solar system is not a perfect two body system. In order to explain the perihelion of Mercury, many ad-hoc considerations including the presence of a minor planet between the sun and the Mercury were proposed. Only with the help of these ad-hoc assumptions the perihelion of mercury was conceivable within Newtonian Mechanics. The dynamical laws of Newtonian Mechanics (Universal law of Gravitation) do not directly suggest the perihelion of mercury.
4. When two models successfully account for a phenomenon or make a phenomenon conceivable, one of the best ways to adjudicate between the models is to check the fit or degree of fit of the prediction of the models and the empirical data. The prediction by the General Theory of Relativity was closer to the observed data than the prediction of the Newtonian model. This was one of the prime reasons to choose the General Theory of

[50] Generally, truth and falsity are not assumed to be the features of models. This is one of the important features of a semantic account of scientific theories. It is always better to speak about the correctness of the model. Here I employed the term truth to indicate that the conceivability of a phenomenon does not guarantee a realist commitment. It suggests that model dependent conceivability is not a good guide to metaphysical possibility.

Relativity over the Newtonian Mechanics to account for the precision of perihelion of mercury.

5. Conceivability is not always a direct consequence of the dynamical laws of a theoretical model. It also suggests that the conceivability of a phenomenon within a model is not a direct deduction from the initial conditions by employing the dynamical rules. Various ad-hoc hypotheses and idealizations are employed at different levels to make a phenomenon conceivable.

From the above discussion, it is evident that transforming an actual phenomenon into a conceivable one or a conceivable one into an actual one are two important parts of scientific activity. The first part clearly lies in the theoretical domain and the second part falls into the experimental realm. Also, as it was clearly noted, there is a trade-off between the two activities. For example, scientists are forced to make changes to their well confirmed theoretical models because of the mismatch between the theoretical model and the experimental result. Similarly, experimental models are modified by taking theoretical inputs into considerations[51]. The intention of the above discussion is meager. The lessons I want to carry over are:

1. Employment of model dependent conceivability is a part of regular scientific activity.
2. Showing that a particular phenomenon is conceivable is necessary, if not sufficient, for at least a partial theoretical understanding of some aspect of the external world.

3.4 Model Dependent Conceivability and Thought Experiments

In this section, I discuss the relation between the model dependent conceivability and TE. It was already argued that the notion of phenomenon is crucial in the working of TEs. Here I argue

[51] The complexities of these two activities are very much noted in philosophy of science. For a detailed discussion on the relation between theory and experiments, see Hacking 1983, Franklin 1989, Weinert 1995, Franklin and Perovic, 2015. See Nersessian 2008 for a good account of the creation of theoretical models. For a recent account of the creation of models even in the absence of well formulated theoretical accounts, see Miles Maclleord and Nancy Nersessian, 2013.

that TEs work by showing either the conceivability or the inconceivability of the phenomenon modeled.

3.4.1a Reconsidering Galileo's Falling Bodies

According to the Aristotelian understanding, there are four general kinds of changes in the terrestrial realm of objects. These are: change in the position, change in the quantity, change in quality and change in the substance. All the four changes depend up on the nature of the object. In other words it is the natural constitution of an object that determines the nature of the change of an object. Objects in the terrestrial plane, according to the Aristotelian understanding, are composed of four elements: earth, water air and fire. The nature of motion of an object is determined by the constitution of the object. For example, the upward or downward motion of an object depends up on the nature, the heaviness of its constituents. The heaviness of the elements are in the following descending order earth>water>air>fire. Therefore, all elements that are composed by air will move upward but those that are composed by earth will move downwards. For instance, smoke or fire always tends to move upwards but a stone which is composed of earth does not. From day to day observation, Aristotle classified terrestrial motion into natural and violent. Natural motion is the motion according to the nature of an object and violent motion is the motion of an object against its nature under the influence of force. Therefore, the upward motion of a stone is an example for violent motion but the downward motion of it is a natural motion. From observation, it was concluded that every heavy or earthy object, when unimpeded, tends to move towards the center of earth in a straight line because the center of earth or the geometrical center of the universe is the natural place for all heavy or earthy objects.

Given this background let us first model the free fall in the Aristotelian way. According to Simplicio, the Aristotelian in the dialogue "…bodies of different weight ... move in one and the same medium with different speeds which stand to one another in the same ratio as the weights; so that, a body which is ten times as heavy as another will move ten times rapidly as the other. The speeds of one and the same body moving in different media are in inverse ratio to the densities of the media; thus, for instance, if the density of water were ten times that of air, the speed in air would be ten times greater than in water" (Galileo [1954] 2013, 61). This suggests that the speed of a body in a medium depends up on the weight of the body and the density of the medium. Then the speed S of an object having weight W in a medium of density D can be expressed as S $\propto \frac{W}{D}$. This Aristotelian model accords well with daily experiences where a heavy object, a stone, moves faster than a light object, feather, in free fall.

Let us now consider the TE. We are considering the free fall of two objects of different weights strapped together. Since various accidental properties like resistance of the medium, shape of the object etc. which affect the speed of the object are abstracted way we are focusing only on the relation between the weight and speed of the object. We consider that the same medium offers the same resistance to the motion of the two objects under consideration. This allows us to neglect the influence of resistance of the medium on the motion of bodies. This allows us to undermine the influence of density of the medium on the speed of the object. Therefore, the equation that governs the motion of the object in the TE can be expressed as$S \propto W$. If the speed is a natural property and weight is additive, then the description of motion of the system of objects strapped together leads to a contradiction: the system moves both faster and slower than the heavier object.

In terms of the notion of model dependent conceivability, we could suggest that the dynamical laws of the model lead to a situation that is inconceivable. The state of the models is inconceivable because it is a contradiction. It is a widely accepted notion that a model that leads to contradiction is an untenable model of a physical phenomenon. In order to save the model Galileo suggests a radical modification that the speed of an object in free fall has no relation to its weight. It should be noted that by showing the inconceivability of the motion of an object in the Aristotelian model, Galileo tacitly suggests that the speed of an object is not a natural property depending on the composition of the object. It should also be noted that the inconceivability is not a straight forward derivation from the Aristotelian model. Galileo has employed different idealizations and abstraction. Without these the TE would not work. This calls close parallel to the case of concrete experiments. Conceivability or inconceivability of a phenomenon even on the description of concrete experiments is not a straightforward derivation. The features of the inconceivability shown in the models are:

1. The inconceivability shown is model dependent. Only in Galileo's thought experimental model we find the description of free fall inconceivable. The Aristotelian model neither shows any inconceivability nor disagrees with experience. The mismatch between Galileo's model and experience is explained by appeal to accidents[52] and phenomena. The Aristotelian model is intended to explain only the appearances or natural occurrences in the external world. But Galileo's model intends to explain the stable universal phenomenon underlying all the natural occurrences. In that way Galileo's model is a model of phenomenon but the Aristotelian model is a model of occurrences.

[52] The notion of accidents has an important role in Galileo's physics. We reach the genuine phenomena by abstracting out the accidents. The laws of natural world express in the form of mathematical equations are about the phenomenon alone. Therefore there will always be a slight mismatch between the experimental result and the mathematical result. Galileo writes "[N]o firm science can be given of such accidents of heaviness, speed, and shape, which are variable in infinitely many ways. Hence to deal with such matters scientifically, it is necessary to abstract from them. We must find and demonstrate conclusions abstracted from the impediments, in order to make use of them in practice under those limitations that experience will teach us" (Quoted in Koertge, 1977, 407). For a detailed discussion of the notion of accidents in Galileo, see Koertge 1977.

2. The notion of phenomena is central in deriving the inconceivability[53]. The Aristotelian model has obvious advantages in explaining the occurrence. A model centered on phenomena cancels out the above advantage by showing the occurrences as the appearance of the phenomenon under the influences of accidents. This also shows the importance of the data-phenomena distinction discussed in Section 3.1.
3. The inconceivability is overcome by introducing radical departure from the Aristotelian science. This is not at all a surprising move. As we have already discussed in the (section) such departure and modeling are common practice in science.
4. The inconceivability is not a straightforward derivation from the dynamical laws of the models. Various assumptions are involved in deriving the inconceivability. (See section). This is also common in scientific practice.

The above discussion shows the working of thought experiments on the basis of model dependent conceivability. In the next section I discuss the virtues as well as plausible objection to this account.

3.5 Virtues of Model dependent conceivability account

Following Clatterbuck (2013), it was already argued that any account of the epistemology of TE has to satisfy the following three criteria: Modeling Criterion, Parsimony modeling criterion, Unification Criterion. Modeling criterion suggests that the account should capture the actual reasoning happening within the TE. According to the parsimony criterion, an epistemological account of TEs does not make ontological commitments which are beyond necessary for explanation. The unification criterion suggests that the epistemological accounts of TE should be an instance of more general and well supported kind of process. (**See Chaper 1.1**).

[53] McAllister argues in a similar line. According to McAllister, it is the move from occurrences to phenomenon that makes the Galileo's TE interesting and important. He suggests this move as a fundamental departure from the entire Aristotelian physics. See McAllister 2004

The model based conceivability account satisfies all the above three criterion. It is evident from the discussion of the two TEs (Galileo's Falling Bodies and Einstein's Photon Box) that a TE is not a simple argument and the model based account captures the working of TE. I will elaborate this point later when comparing this account with that of Norton. The model dependent conceivability account makes no ontological commitment other than that is committed by the theoretical models. It was also evident from the discussion **(See section 3.2**) that the reasoning based on model based conceivability is a part of larger scientific practice. This suggests that the model dependent conceivability account is not an account of reasoning tailor made for TEs.

3.6 Differences between Model dependent Conceivability account and Norton's argument account.

Limitations of Norton's argument view of TEs have already been discussed in the first chapter. The argument view fails to satisfy the three desiderata mentioned above. The argument view, as it was already pointed out, considers the evidential significance of TEs as intrinsic one. Following McAllister (1993) it may be argued that TEs do not attain an intrinsic evidential significance. The evidential significance has bearings on the underlying metaphysical assumptions. Model dependent conceivability account does not face this difficulty. In this account, the evidential significance relies on many features such as the validity of the dynamical laws, validity of modeling assumptions, validity of the auxiliary assumptions. Hence it does not consider the evidential significance of a TE in isolation. This account has close similarity to the argument view in explaining the failure of TEs. Like the argument view, the model dependent conceivability account also suggests that a TE becomes a failure when the underlying dynamical laws are incorrect. This calls for similarity to that of argument view where a TE fails when the underlying argument fails to substantiate its conclusion. But the model dependent conceivability account suggests other reason for the failure of a TE. For example, if the phenomenon under consideration is modeled by an incorrect theory then it becomes a failure. Einstein's Photon Box TE is a good example. In this TE, Einstein models the phenomenon (emission of a photon) and its subsequent features without considering the effect of relativity. Later Bohr explains the inadequacy of Einstein's TE by incorporating the effects of General Theory of Relativity into the TE. Here the problem lies not with the argument underlying the TE but with the inadequate modeling of the phenomenon. Similar is the case with Galileo's TE of free falling bodies. Simplicio, the Aristotelian has a good argument that accords well even from the point of view of daily experiences. In Galileo's TE, we find the untenability of Simplicio version because the phenomenon is modeled in a different way. The move from occurrences to phenomena is central and crucial to the Galileo's TE and his science. Argument view could not capture this difference.

3.6 Plausible Objections

1. Deductive Character of the model dependent conceivability

The model dependent conceivability appears deductive in character. If the conceivability is deductive in nature then an explanation based on such a notion of conceivability appears like the D-N models of explanation. Such an account has to face various challenges leveled against the D-N model.

The model dependent conceivability is not a direct logical derivation from premises to conclusion. In most of the cases, the conceivability of a model is dependent up on various auxiliary assumptions. Most of the times, the auxiliary assumptions are tailor made to the particular model under consideration and the same assumption might not hold true to a different model or the application of the same model for a different case. The prediction of the planet Neptune is a good example for the above nature of auxiliary assumption. The presence of a new planet was suggested as an auxiliary assumption to explain the irregularities in the orbit of the planet Uranus. But the same strategy failed in the case of the perihelion of Mercury. In both cases the model was governed by the laws of Newtonian Mechanics (laws of motion and universal law of gravitation). This suggests that the legitimacy of the auxiliaries is context dependant. Also, the permissibility of the auxiliaries is not always determined within the models. Considerations like simplicity of the models, empirical feasibility etc. are considered in the selection of both the models and auxiliaries.

The model dependent conceivability is invoked at best as a necessary condition for the successful application of TEs. The success or failure of a TE has bearing on the various modeling assumptions employed. Therefore, even if one considers it as deductive, it does not have to face the challenges posed to a D-N model. Maxwell's Demon TE describes this feature correctly. **(See chapter 2 Section 2.3.2**) The flow of heat from a cold body to a hot body was made conceivable within the TE. This was enough, according to Maxwell, to describe the statistical nature of the second law of thermo dynamics. It should be noted that Maxwell did not invoke the possibility of heat flow from a cold body to a hot body. It shows that the conceivability of the phenomenon under discussion suffices, when the modeling assumptions are met, for the working of a TE.

Conclusion

Thought experimentation is one among the earliest and effectively employed tools of scientific reasoning. More than once, they have played important roles in theory construction and theory change in science. I have taken up the epistemological roles of thought experiments in this thesis. The first epistemic problem of thought experimentation, as it is expressed in the literature, is as follows. Thought experiments do not produce new data. They are attempts to know about the external world by thinking through imaginary situations. Thought experiments, often produce knowledge about the external world. If so, how thoughts on mere imaginary scenario produces knowledge about the external world? This questions appears as rejuvenation of the debate between empiricism and rationalism in contemporary philosophy of science. Early debates on the epistemology of TEs took this path. This way of presenting, extended the problem by suggesting that if TEs produce knowledge about external world then, for an empiricist it is an epistemic magic. Any account of an epistemology of TE, therefore, has to explain away the above epistemic magic. Therefore, an epistemological account of TE has to do two jobs. One, it has to show that there is no epistemic magic in the case of TEs. Second, it has to show the actual working of TEs.

In order to answer the epistemological problem of TE, detailed historical analyses of some TEs are taken up in the thesis. Many TEs (Galileo's TE of Free Falling Bodies, The EPR and Maxwell's Demon) are discussed in details. The discussion of the evolution of TEs in science also helped to answer a related challenge to thought experimentation practice raised by Ian Hacking. Hacking contended that TEs do not have a life of their own. But the detailed historical account of TEs, their different roles in scientific practice and the evolution of a single TE (the EPR and Maxwell's Demon are taken as examples) suggested that Hacking's denial of a life to TEs is uncharitable to the scientific practice.

Historical analysis also helped to answer another challenge by Chandrasekharan *et al.* They argued that TEs will eventually be replaced by CSs in contemporary science. But a detailed analysis shows that any such arguments are based on less than convincing premises. It is clear that the number of TEs with critical evidential bearings when compared to that of concrete experiments were not large in the history of science. Therefore, conclusions like withering away of TEs by suggesting the limited number of TE in contemporary science is a far fetched generalization. The epistemic importance of TEs are not related to the number of TEs. Even if there is only one TE with evidential credentials, as a tool of reasoning it will raise the epistemic problems which have been discussed already. Therefore, philosophers of science with their focus on scientific practice have to look into TEs seriously.

In order to answer the epistemic questions of TEs, the data-phenomena distinction introduced by Bogen and Woodward (1988) is called for. It was argued that, the data-phenomena distinction is crucial in explaining epistemology of TEs. Two TEs are discussed in details to show the tenability of the above view. After this, a notion of model-dependent conceivability is invoked in the theses to answer the epistemic puzzle of TEs. The importance of the notion of model-dependent conceivability in scientific practice is explained with help of two case studies (Quantum tunneling and Perihelion of Mercury) from the history of science. These case studies suggest that model dependent conceivability arguments are part of scientific practice. It suggests that if model-dependent conceivability can account for the epistemology of TEs then thought experimentation does not require a different epistemic account than that of the routine scientific practice. Two TEs are further discussed in details to show the tenability of model-dependent conceivability account in explaining the epistemology of TEs.

The thesis attempts to argue for the following points:

1. The mystery of gathering knowledge about the external world employing mere thought, associated with thought experiments, in natural sciences is misconceived. An epistemological account of thought experiments, which accord well with empiricism, is possible. These points are argued in the first chapter.

2. Thought experiments do have a life of their own. A detailed historical analysis of the development and evolution of TEs proves this point. A lack of detailed historical accounts of TEs ay have been one of the main reasons for the arguments denying a life to TEs. These points are discussed in the first part of the second chapter.

3. TEs and CSs have some similarities in their epistemologies. But arguments favoring the replacement of TEs by CSs are inconclusive. A closer examination of the contemporary theoretical physics illuminates this point. The irreplaceability of TEs by CSs is argued in the second part of the second chapter.

4. The data-phenomena distinction, introduced by Bogen and Woodward, is important in the analysis of epistemology of TEs. This point is elaborated further by analyses of two thought experiments. Model-dependent conceivability is introduced to account for the epistemology of TEs. It is argued that reasoning based on model-dependent conceivability is a common practice in natural sciences. Hence, the account of epistemology of TEs based on the model-dependent conceivability is an empiricist epistemological account of TEs, which may be the basis for a robust demystified epistemology of thought experiments.

Limitations of the Study

1. The study is limited to the analysis of TEs employed only in natural in sciences.
2. The model-dependent conceivability and its role in scientific practice is not built up on detailed analysis of case studies from history of science.

3. The model-dependent conceivability account of epistemology of TE appears to face some problems that are common to any deductive of D-N model like explanatory accounts.

Plausible further studies

1. TE are common in several disciplines other than natural sciences and philosophy. The applicability of the model-dependent conceivability account to TEs outside the domain of natural sciences will be an interesting project.
2. The notion of model-dependent conceivability seems to have roles in concept formulation and conceptual reorientation. If this is true, then this account might be of some help to account for theory changes in science.

Appendix 1
Conceivability and Possibility

The relation between conceivability and possibility is much discussed in philosophical literature. Conceivability is generally but not always considered as a guide to possibility. To make this relation clear let us start with a general characterization of possibility. Possibility could be understood in different epistemic senses. In one sense, something, P, is epistemically possible if the possibility of P is defined in relation to a body of knowledge available to the agent (Gendler and Hathron, 2002, 3). In a permissible sense of epistemic possibility, P is possible for an agent S, if S does not know that not-p or in a strict account P is epistemically possible if P is consistent with everything that S knows (Ibid). There are some important differences between the two senses of epistemic conceivability. One of the important differences is that the strict account of epistemic possibility entails metaphysical possibility but the permissibility account does not. Generally, conceivability is not a good guide to epistemic possibility. If an agent knows that the rose in the flower vase is red then it is not possible that it is green. But a green rose in the same flower vase is very much conceivable for the agent. Therefore, conceivability is not a good guide to epistemic possibility. Some argue that conceivability, if not a good guide to epistemic possibility, is a guide to non-epistemic possibilities. Generally, there are three types of non-epistemic possibility. They are,

1. Logical (narrow)
2. Nomological
3. Metaphysical.

If P is non contradictory or no contradiction is derivable from P then it is possible in the logical sense. In other words, if the assertion of P is non contradictory according to laws of logic then P is conceivable. For instance, instead of New Delhi, Kolkata could have been the capital of India. There is nothing logically contradictory about this. But it is impossible that New Delhi is both the capital and non-capital of India. P is nomologically possible, if P is consistent with a set of norms.

For example, a vehicle travelling faster than the speed of light was nomologically possible even before the invention of supersonic airplanes. This is so because; the laws or norms of physics do not forbid such a possibility. In other words, an artificial object moving faster than sound is consistent with the laws of physics. Metaphysical possibility is generally considered as primitive (Ibid 4). The above characterizations of possibility engender the following problems to the conceivability possibility relation. For example, conceivability of P might not be suffice to call for the logical possibility of P. This is because, whether P is derivable and hence, P is non-contradictory, is a matter of logical proof. If the proof of P is considerably long, then P might not be conceivable for an agent. Similar is the problem with nomological possibility. Since an agent can easily conceive scenarios or objects that do not accord with the nomos, conceivability may fail to be a good guide to nomological possibility. Conceivability seems to have a good guide to metaphysical possibility.

Appendix 2
Models and scientific theories

In the logical positivist conception, scientific theories are considered as sentences which can be true or false in an axiomatic system. In the semantic conception, theories are not considered as set of statements in an axiomatic system. Rather, theories are considered as models or cluster of models which are made possible by certain axiomatic system. I am using the term model in the sense it was employed by Ronald Giere.

The hierarchical view of scientific models

Models are usually constructed according to explicitly formulated principles in science. (Here by principles Giere means the scientific laws.) Newton's principle of mechanics, the principles of thermodynamics and so on are good examples for such principles. Scientists create models using principles and specific conditions. "This attempt to apply models to the world generates hypothesis about the fit of specific models to particular thing in the world..." (Giere,). The principles according to Giere, can be taken to be true of or refers to some highly abstract object. It is an object which by definition has all the characteristics as specified by the principles. The principle's function is to act as "general templates" for the construction of models which are specific abstract objects. So, the additions of specific conditions to the general principles result in the construction of models. These models are also abstract objects but are more specific than general principles. For example adding the condition $f= -kx$ (x-displacement from the mean position) will give a general model of a simple harmonic oscillator. This model is applicable to a simple pendulous, a hanging spring with a mass at its one end, or to a diatomic molecule. Specifying x as the displacement of a mass in a spring does not give an empirical application. It is still an abstract model of a mass on a spring. For an empirical claim one needs to designate a particular mass of a particular spring. Then, one can determine whether the model agrees with the real (target system) or not. Giere (2010) argues for an intentional conception of scientific models. He presents a hierarchy of models to argue out his point. The following diagram shows the hierarchy of scientific models.

Principled Models

↓

Representational Models

↓

Specific Hypotheses and Generalizations

↑

Models of Experiments and Data

↑

The World, Experiments, and Data

Fig. A principle-centered picture of hierarchical relationships among models and the world.

In Giere's schema, the statements that are conventionally held to constitute theories function to characterize the principled models. For example, what are called Newton's laws of motions are "principles that characterize a class of highly abstract models (principled models) and thus characterize a particular mechanical perspective on the world" (Giere 2010, 270). These laws are not laws of nature as universal generalizations. They, by themselves, cannot be used to make direct claims about the world. According to Giere, these principled models represent nothing. This is because the principled models always deal with abstract entities such that they are not a part of the real world at all. The concept of point mass in Newton's laws is the best example. One can never find anything that corresponds exactly to such things (point mass) in the real world. Giere suggests that things in the world are represented using representational models which are prepared after applying 'conditions and constraints' to the principled model. For example, by adding

Gravitational law to the laws of motion one can prepare a representational model of a two body interactions in the three dimensional space. By adding further details, one will get specific model of some particular real system, say that of Earth and Moon.

It should be noted that in Giere's account only the three laws of motions are considered as the core of Newton's theory. The universal law of gravitation is taken as a specification for representational models. So, the addition of specifications to the principled models will produce representational models. How to relate abstract model to the specific physical system is the next question. This, according to Giere, is carried out through two processes called 'interpretation' and 'identification'. "For interpretation, elements of an abstract principled model are provided with general physical interpretations such as mass, position, and velocity. Such interpretations are already present in the statements that characterize the principled models. Scientists do not begin with an uninterpreted formalism and then add interpretations. For identification, elements of a representational model are identified (or coordinated) with elements of a real system" (Giere, 2010, 271).

A hypothesis is a claim that a fully interpreted representational model fits to a particular real system. An interpreted representational model of two-body system under gravitational force can be fully specified by designating one body as Earth and other as Moon. The fully specified representational models are tested with models of data but not to data themselves. So, the comparison is between two models but not between a model and a part of the world. This move from data to models of date requires assistance from many additional elements like experiments models, statistical and data processing techniques, empirical information from other sources etc.

Now, the next problem is the desired relationship between the representational model and the external world. This might not be of perfect fit because even for a relatively complex model there is a margin of error, which is an unavoidable part of any experimental set up. Also a model that perfectly fits the world is the one that perfectly fits everything out there. Truth too cannot be considered as a desired relationship between model and the world. Models are non-linguistic entities. Assuming truth as property of linguistic entities alone, models themselves are not candidate of truth and falsity. But hypotheses, the claims about models are linguistic entities and so, they can be true or false. For example, the relative fit of the claims about a model, say the period of Moon's orbit around earth can be true or false.

Intentional conception of scientific Representation

According to Giere, because of two reasons representation with models cannot be a matter of similarities. 1. Since there are vacuous similarities, we need to be specific about the similarities that matter. 2. Similarity is a symmetrical relation but representation is not. Giere suggests that these two difficulties could be dissolved by the addition of intentions of agent. "The formula is: Agents (1) intend; (2) to use model, M; (3) to represent a part of the world, W; (4) for some purpose, P. So agents specify which similarities are intended, and for what purpose" (Giere, 2010, 74). This conception eliminates the problem of multiple similarities because the agent specifies the relevant similarities between the model and the target system. It also introduces the necessary asymmetry. Giere calls this as Intentional 'Conception of Scientific Representation'.

Among the intentional acts of representation, one cannot make a sharp distinction between successful and unsuccessful representations. Experiments can reveal the extent of fit a model has to its intended target. The extent of fit depends on the individual or communal understanding of the current standards of particular scientific disciplines.

Some Strictures on representational Account

As it was discussed in the last session, models are representation of target system. The similarity between the model and the target system is invoked to explain the representation relation between the model and its target system. The agents who employ the model for a particular purpose specify the similarity externally. Giere's account of scientific representation explains the working of science with a minimum commitment to scientific realism. The realist commitment is limited because the representation relation between the model and target system is applicable only from the level of representational models. The principled models, according to Giere, represent nothing[54]. Principled models, prepare the perspective or template with which an agent approach the external world.

Though the account appears to accord well with the models of classical mechanics it does not enjoy the same success when employed in the cases of quantum mechanics. The intentional account seems to be fraught with the following difficulties. The agent is supposed to specify the representational aspects of the models. In order to specify the similarities one has to have some ideas about the target system and theoretical model. Our knowledge about the atomic or subatomic world is produced by the successful employment of quantum mechanics. In other words, the entire knowledge about the quantum world is mediated by quantum mechanics and hence, no vantage point outside the quantum mechanics (in Giere's terminology, no perspective other than that of quantum mechanics) is available to an agent. Also, no other successful model of the atomic world is available to make a comparative account of similarity. If the above considerations are true, then the representation account has two main problems:

1. The similarity aspect is highly theory dependent and is circular. The similarity aspect is theory dependant because the only model of quantum world one has is the theoretical model. Consider the case of Bohr atom model. It is a theoretical model of the structure of atom, which was constructed on the basis of the then available empirical data. The similarity relations an agent can specify here are those between the structure of atom proposed by the theoretical model and the structure of the data modeled. But in this specific case, the theoretical model is constructed to fit the data and therefore, speaking similarity between a model constructed to fit the data and the possible models of data doesn't make any sense.
2. No agent can specify the desired similarity aspects because no two models are available out there to make a similarity account. In the case of atomic phenomena, we have access to the following
    a. Our theoretical models
    b. Empirical data.

[54] See Nancy Cartwright 1983, *How the laws of Physics lie*. According to Cartwright, the higher order laws of physics do not represent anything. However, phenomenological laws, like Charles law, do have representational character.

It is possible to find a similarity relation between models of data and theoretical model in the case of theoretical prediction[55]. However, in such situations, instead of similarity one could employ the notion of fit. This is because similarity of a theoretical model and models of data is a matter of structural similarity. If similarity is considered as a structural relation then we are forced to assume that the structure of the theory somehow maps to the external world. Though this seems to be a plausible assumption, it engenders unwanted metaphysical commitments like the commitment that successful theory is true about the external world. History of science warns one from making such metaphysical commitments because many theories that have been successful at one point of time were discarded later as incorrect. It is very much possible to model the same data with different structures. Mutually incompatible theoretical models may be successful in modeling the same data. For example, the planetary motion can be structured in both in the Ptolemic way and in the Copernican way with considerable amount of structural similarity. Only one among the above two system is correct because a planet will not follow two structures at the same time. Therefore, the structural similarity of a theoretical model with that of the data does not guarantee the correctness of the theoretical model.

[55] The similarity aspect or fit is always specified by the theory itself. For example, one cannot specify a fit or similarity of a quantum particle in a way that surpasses the uncertainty principle. Giere suggests two distinct relationships that can be characterized on the basis of fit.

1. The relation between a prediction from a theoretical model and a data model

2. The overall relationship between a theoretical model and the system of which it is intended to be a model. Giere, personal email communications, 27-08-2014, 31-08-2014

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