

# THE ROUTLEDGE COMPANION TO THOUGHT EXPERIMENTS

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# HOW THOUGHT EXPERIMENTS INCREASE UNDERSTANDING

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Thought experiments can and do increase our understanding. In this chapter, I use resources from mainstream epistemology to help explain this feat. I present three main kinds of understanding identified in mainstream epistemology, and show how each of these may be created by thought experiments in different ways. I close with some epistemological discussion of those ways, and the cognitive activities that underpin them. While everything I say is meant to hold for the relation between thought experiments and understanding in general, my examples will come from the scientific domain.

## **1 Why talk about thought experiments in the context of understanding?**

It can be tempting to see the entire epistemological literature on thought experiments as focused on a single issue: whether the facts about thought experiments support rationalism, empiricism, or whether some naturalist middle ground is to be preferred. Rationalism, empiricism, and naturalism are views about the source of knowledge. Taken as an issue concerning knowledge, the epistemological question about thought experiments is: how do thought experiments produce new empirical knowledge without new experience? And indeed, many authors frame their accounts explicitly in answer to this question (e.g., Kuhn 1977, 241; Brown 2004, 34; Gendler 2004, 1152; Norton 2004, 44; Häggqvist 2009; Thagard 2010, 251; Davies, this volume; Goffi and Roux, this volume). But knowledge is not the only or even necessarily the most interesting epistemological desideratum. I think *understanding* gives it a run for its money, and many others do too (Kvanvig 2003, 2009; Elgin 2006; Pritchard 2009, 2010; Grimm 2012; Dellsén 2016).

To motivate the point, here are a few uses of thought experiments that seem to aim at understanding: thought experiments can illustrate a theory or theoretical claim (Brown 1991, 32; Peacock, this volume; Schabas, this volume), they can control extraneous variables and “invert ideals of natural order” (Sorensen 1992, 11–16), they can “exemplify”

properties and relations (Elgin 2014), they can provide “hypothetical explanations” (Schlaepfer and Weber, this volume), they can help us to see how rival theories lead to different results (Brun, this volume), and they can make certain intuitions accessible (Lenhard, this volume).

Thought experiments that play the above roles can improve the quality of our epistemological relationships with the world without necessarily (or merely) increasing our stock of justified true beliefs. For instance, illustrating a claim is not the same as justifying that claim or suggesting that it is true, since we can illustrate false claims. The same goes for attention-drawing. I do not deny that new knowledge can result from such thought experiments (e.g., we can always gain knowledge that we have just performed a thought experiment). I merely claim that there is more to the epistemological power of thought experiments than knowledge production.<sup>1</sup> We must not restrict our epistemologies of thought experiments therefore to whatever is reconstructible as a set of true propositions.<sup>2</sup>

Before we explore how thought experiments increase our understanding, we need to say something about understanding itself.

## 2 Kinds of understanding

Having recovered from philosophical banishment by the positivists (see De Regt 2009, 22–4) and behaviorists (see Barsalou 1999), understanding is again a respectable notion in epistemology. And there are many characterizations of what it could be. Wesley Salmon portrayed understanding as whatever a good explanation provides (Salmon 1984). According to Michael Friedman, understanding is what we get when we reduce the number of fundamental entities that we have to admit in a theory (1974). Phillip Kitcher modified this idea by portraying understanding as what happens when we find a way to explain different phenomena using the same patterns of argument (1981). Henk De Regt characterizes understanding in terms of intelligibility, which is “the value that scientists attribute to the cluster of virtues (of a theory in one or more of its representations) that facilitate the use of the theory for the construction of models” (2009, 31). Hasok Chang argues that understanding “is knowing how to perform an epistemic activity” (2009, 75). Catherine Elgin claims that

We understand rules and reasons, actions and passions, objectives and obstacles, techniques and tools, forms and functions and fictions as well as facts. We also understand pictures, words, equations, and diagrams ... Understanding need not be couched in sentences. It might equally be located in apt terminology, insightful questions, effective nonverbal symbols ... Even a scientist’s understanding of her subject typically outstrips her words. It is realized in her framing of problems, her design and execution of experiments, her response to research failures and successes, and so on.

(1993, 14–15)

It is implicit in this passage that we should not limit the objects of understanding to propositions: we can also understand e.g., actions, passions, etc. And Elgin points out that not all understanding is linguistically expressible, which further distances it from propositional

knowledge. Finally, Elgin hints where to find understanding: it is in the way we speak, work, wonder, and interact with the world. It is a matter of knowing where something fits in with our existing commitments and abilities.

The literature on understanding accommodates the above insights in classic analytic fashion by breaking up the concept of understanding into sub-types, each of which captures a different set of the properties we intuitively want to ascribe to understanding. Philosophers have therefore distinguished transitive from intransitive understanding; propositional from non-propositional understanding; interrogative (understanding what, where, and how) from non-interrogative understanding (see Baumberger 2011, 68–71; Carter and Gordon 2014, 3; and Baumberger, Beisbart, and Brun 2016); understanding as a *faculty* from understanding as a *process* from understanding as a *result* (Baumberger 2011, 69); and among moral, aesthetic, scientific, mathematical, and philosophical understandings (Hills 2015). Any distinction is as good as any other in principle: what matters is the philosophical work it allows us to do. In this chapter, I will focus primarily on a distinction found in the literature between three types of understanding, as follows.

The first type is *explanatory* understanding, which is discussed by, e.g., Duncan Pritchard (2010, 74), Carl Hempel (1965, 334), Philip Kitcher (1989, 419), Stephen Grimm (2008), De Regt (2009, 588), Kareem Khalifa (2012), Michael Strevens (2013), Alison Hills (2015), Michael Hannon (forthcoming), and many others. The second is *objectual* understanding, discussed by, e.g., Christoph Baumberger (2011), Baumberger and Georg Brun (2016), Elgin (2007), Jonathan Kvanvig (2003), Khalifa (2013), Daniel Wilkenfeld (2014), and Christoph Kelp (2015). Finally, there is *practical* understanding, which is mentioned by many but discussed in depth by few, at least in the main debate in epistemology. Let us look more closely at these types of understanding.

Explanatory understanding (EU) is having an explanation for why something is the case (De Regt 2009, 25; Khalifa 2011, 108). It can be propositional, though it need not be. For instance, Grimm (2006) and Hazlett (forthcoming) argue that explanations can be ostensive, as when my mechanic explains why my car won't start by pointing to the burnt-out ignition switches (Grimm 2006, 531).

Objectual understanding (OU) is understanding a thing, set of related things, or a subject matter. One popular way of characterizing this sort of understanding is as grasping the “coherence-making relationships” in a comprehensive body of information (Kvanvig 2003, 192), or as grasping and committing to a theory of something (Baumberger 2011, forthcoming). It relates to Elgin's claim (1993, 14–15) that “understanding a particular fact or finding, concept or value, technique or law is largely a matter of knowing where it fits and how it functions in the matrix of commitments that constitute the science.” Here is an example of OU from Baumberger,

Understanding global warming involves, for instance, understanding what effects (on natural and social systems) it will have, how it is linked to human activities (such as burning fossil fuels and deforestation) and related phenomena (such as the destruction of stratospheric ozone and global dimming), how far greenhouse gas emissions and, as a result, temperatures are likely to rise in the future, and how the changes will vary over the globe.

(Baumberger 2011, 77–8)

Finally, there is practical understanding (PU), as in, “Jimi understands how to play guitar,” which is “clearly not explanatory” (Khalifa 2013, 123). Elgin captures it this way:

Understanding physics is not merely or mainly a matter of knowing physical truths. It involves a feel for the subject, a capacity to operate successfully within the constraints the discipline dictates or to challenge those constraints effectively. And it involves an ability to profit from cognitive labors, to draw out the implications of findings, to integrate them into theory, to utilize them in practice.

(1993, 14–15)

PU may be phrased as knowledge-how or tacit knowledge, but in any case it is not standard propositional knowledge. For example, it does not appear to be susceptible to Gettier-style defeaters. Furthermore, it is not OU, as having that sort of understanding of guitars or playing guitars would not imply that Jimi could actually play the guitar, which is something that is necessary for PU. Likewise it is not EU, since Jimi arguably does not need to possess or be able to provide any explanations concerning guitar playing in order to play.

There is an on-going discussion in the literature about whether we can reduce some of the types of understanding mentioned to one or some of the others. For example, Khalifa (2013) tries to reduce OU to EU. Baumberger (2011) and Kvanvig (2009) argue that EU and OU cannot be reduced to one another. In my opinion, the most plausible scenario concerns the reduction of EU and OU to PU. Chang (2009), Hills (2010, 2015), Baumberger (2011) and Wilkenfeld (2013) make claims that are at least partially in line with this suggestion. Having PU is having certain abilities, one of which might be the ability to provide, grasp or assess explanations. Having EU could then be explicated in terms of having a specific sort of PU. We also have the ability to grasp and express the relations among events, objects, domains, etc. So having OU could again be explicable in terms of having a particular sort of PU.

However, even if EU and OU were reducible to PU (and much more would need to be said), the abilities to give and assess explanations, as well as to grasp and express internal relations among members of a set, are so important that they merit their own discussions anyway. For example, a lack of EU will be diagnosed and remedied in particular ways that we would not necessarily use to diagnose and remedy a lack of PU. For instance, we can lack PU of  $x$  because we have not had any practice with  $x$ , or because we cannot see how to apply  $x$  to a new case. But we usually lack the ability to give an explanation of  $x$  because we lack some relevant knowledge of  $x$  (whether causal or otherwise).

In other words, even if EU, OU and PU were mutually reducible, we would still want to keep them apart since there are different ways of obtaining each type of understanding and different ways of determining when each has been achieved. This is particularly clear in the scientific context (Stuart 2016). In any case, *until OU and PU are reduced to EU*, the current overwhelming focus in mainstream epistemology on EU is misplaced. Epistemologists should take OU and PU into account, especially if they want their accounts of understanding to include scientific understanding.

Now that we can talk about understanding more precisely, we can begin to see how thought experiments might produce it. The question: “How might a thought experiment increase  $S$ 's understanding of  $x$  (where  $S$  is an individual or community)?” must first be split into three questions.

First, if we mean *S*'s EU of *x*, then we can increase this with a thought experiment that contributes to a (good) explanation of *x*.

If we mean *S*'s OU of *x*, this is more complicated. OU consists in grasping relations between objects, events, and domains on the one hand, and other objects, experiences, background knowledge, and so on, on the other. What sorts of relations are there between say, the uncertainty principle and the rest of quantum mechanics? Or between chemistry and our experience of chemical substances? One important kind of relation that we might grasp between these elements is a *semantic* relation. With respect to the notion of a semantic relation, I want to be inclusive: it could be (a) the pairing or mapping of propositions, terms, concepts, variables, etc., to their referents; (b) the intensions or psychological "senses" of propositions, terms, concepts, variables, etc. (which might take the form of prototypes, proxytypes, theories, exemplars, definitions, etc.); (c) the location of a proposition, concept, etc., in a system of knowledge; (d) truth conditions; or (e) something else. In any case, building semantic connections or grasping semantic content is not the same thing as increasing knowledge since an increase in semantic understanding is either a *process* of establishing/grasping semantic connections, which cannot be identified with a set of justified true propositional beliefs because processes are not propositions. Or it will be a cognitive state which results from having established new semantic connections. This state could be reconstructed propositionally, but the proposition "*S* has grasped 'unmarried adult male' as the semantic content of 'bachelor'" is no more *S*'s actual cognitive state than the proposition "I have eaten" is my being full. I conclude therefore that *one* interesting way to increase *S*'s OU of *x* is by grasping the semantic content of *x*.

Finally, if we mean *S*'s PU of *x*, we have to increase (the quality of) *S*'s abilities that are relevant to *x*.

My task in the next section is to examine whether thought experiments can increase EU, OU and PU in these ways.<sup>3</sup>

### 3 Thought experiments increase understanding

#### 3.1 Thought experiments can contribute to explanations

First, if you simply ask people what their "favourite deep elegant or beautiful explanation" is, they sometimes answer with a thought experiment. In 2012 the website *edge.org* did exactly this, putting the above question to 192 people, including Daniel Dennett, Lawrence Kraus, Tania Lombrozo, Richard Nisbett, and Stephen Pinker.<sup>4</sup> Twenty-one of the replies were well-known thought experiments, and another 8 were imagination-based inferences that any broad-minded characterization of thought experiments should include. Almost a sixth of the participants therefore gave a thought experiment as their *favourite* example of a deep, elegant or beautiful explanation, which shows that at least some people naturally think that thought experiments can be (very) good explanations.

Second, a study of thought experiments in textbooks revealed that many thought experiments survive even when "superseded at the cutting edge of science" because they "may still be in use to explain particular phenomena economically" (Gilbert and Reiner 2000, 268). In other words, we continue to educate using outdated thought experiments because

they explain a given phenomenon particularly well. In another study, high school students, undergraduates and doctoral students were given hard problems in mechanics and dynamics and then observed to see what thought experiments they invented and why. The authors found that “the most frequently observed purpose of using a thought experiment is for ‘explanation’” (Köseme and Özdemir 2014, 882).

Finally, if we consider the main characterizations of explanation in the literature, we can find examples of thought experiments that fit into each of them. Perhaps the most famous account of explanation is Carl Hempel’s, according to which an explanation is the subsumption of a phenomenon under covering laws, that is, “exhibiting the phenomenon to be explained as a special case of some general regularity” (Hempel 1965, 257). Darwin’s eye thought experiment (described on page 532) helps us to explain the vertebrate eye since it provides a series of steps that show how the eye could be subsumed under the framework of evolution by natural selection.

For others, an explanation is what we get when we unify various disparate phenomena (see Friedman 1974; Kitcher 1989; Bangu 2016), for example, by subsuming such phenomena under a common vocabulary, a common cause, a common mechanism, or a common formalism. Isaac Newton unified projectile motion (such as throwing a ball on Earth) and orbital motion (such as the moon orbiting the Earth) in a “paradigmatic” case of unification (Woodward 2014). And Newton’s achievement at least partially relies on his use of a thought experiment, what we now call Newton’s cannonball.

Another account portrays explanation as whatever answers a why-question given a contrast class (e.g., van Fraassen 1980). That is, why does *x* happen as opposed to *y*? Many thought experiments fit into this account, including perhaps the most famous thought experiment in the literature, Galileo’s falling bodies thought experiment (see Brown 1991; McAllister 1996; Norton 1996; Gendler 1998; Palmieri 2003, this volume; Buzzoni 2008, 106–7), which tells us that bodies of different weights fall at the same speed *as opposed to* speeds that are proportional to their weights. It goes part of the way towards explaining why bodies fall this way (and not another way) by suggesting that there could be no other way for them to fall.

Finally, there are accounts of explanation that focus on the identification of causal chains, causal counterfactuals, or causal networks (see Salmon 1984, Woodward 2003, and Strevens 2009, 2013, respectively). Thought experiments will be important here since they are one of our main methods for investigating counterfactual dependence claims and answering “what if” questions. Häggqvist (2009) explicitly characterizes an important class of thought experiments as playing this role, and many others (including e.g., Williamson 2004) agree that thought experiments are needed to validate counterfactuals (see also Cohnitz and Häggqvist, this volume).

In sum, if any of these accounts of explanation are on the right track, thought experiments can play an important role in explanations.

According to the recent literature on understanding, this means that thought experiments can help to increase understanding since coming to possess a good explanation is either identical to or very strongly correlated with increased EU (see Hempel 1965; Friedman 1974; Achinstein 1983; Kim 1994, 1996; De Regt and Dieks 2005; Keil 2006; Lombrozo 2006, 2011; De Regt 2009; Riggs 2009; Khalifa 2011, 2012; Strevens 2013; Greco 2014; Kelp 2014; Wilkenfeld 2014; Hills 2015; Hannon forthcoming).

To conclude, while there might be good reasons to be skeptical about inter-defining understanding and explanation *in general* (Lipton 2009; Gijsbers 2013), it is nevertheless the case that since having an explanation provides EU, then, since thought experiments can play an important role in generating explanations, they can help to provide EU.

### 3.2 Thought experiments increase meaningfulness

Existing pedagogical methods test for the semantic form of OU. To see this we need only consider written tests of any kind. The sort of question that asks a test-taker to put something into his or her own words, define a term, or fill in a blank, are testing precisely for OU (Stuart 2016). When we pass this sort of test, it is only because at some previous point in time we made semantic connections between the idea in question and our other beliefs, concepts or abilities in a way that made it meaningful for us. Can thought experiments aid us in this regard?

In Stuart (2016) I gave three examples of thought experiments that seem to have been designed explicitly for this purpose. I will quickly mention two.

The first is Darwin's vertebrate eye. By the time we get to this thought experiment in Chapter 5 of the *Origin*, Darwin has already introduced and argued for natural selection. Now he wants to forestall some possible objections. Perhaps the most famous is the eye, which appears too complicated to have been the result of chance mutations. Darwin answers with a thought experiment that takes us through a possible course of evolution from a single nerve sensitive to light, to a patch of nerves, the addition of muscles to focus the light, to the organ you are using right now to read this. The eye thought experiment helps us understand what it *means* for an organ like the eye to be a product of evolution. We do not learn how eyes actually evolved; that is something fossil evidence is unlikely ever to reveal. Instead, on completing the thought experiment, we come to appreciate what it means for eyes to have evolved.

Another example is Maxwell's demon. Briefly, Maxwell found himself in the following situation by the end of *A Theory of Heat*: He knew his version of the second law of thermodynamics could be violated in principle, but not in practice. And he knew that it would not be quite clear what this meant. That is, if we could violate the second law in principle, why can't we violate it in practice? And if we could *never* violate it in practice, there must be some reason for this which would make our inability to violate the second law a matter of principle. Maxwell answers with the demon thought experiment (see Peacock, this volume, 212–15). By performing it we come to appreciate why we will not witness any actual violations of the law in nature but *that* such violations are not forbidden. We do this by seeing that if we were the demon, we could violate the second law. Meanwhile we recognize that there is probably nothing in nature that could actually do what the demon does on a time scale relevant to human interests. This way, we come to understand the meaning or semantic content (including modal strength) of Maxwell's statistical second law.

The idea that thought experiments can increase the meaningfulness of a scientific idea, concept, event, etc., crops up again and again in the history of science, especially in the history of physics (Beller 1999, 107; Norton, unpublished, ch. 29). Alexander Koyré noted that thought experiments take a concept and make it meaningful by connecting it to our experience. In his words, thought experiments "help scientists to bridge the gap between

empirical facts and theoretical concepts” (Koyré 1968). In other words, they provide empirical semantic content for parts of theory. Athanasios Velentzas and Krystallia Halkia argue that thought experiments are used “both for clarifying the consequences of physics theories and for bridging the gap between the abstract concepts inherent in the theories and everyday life experiences” (Velentzas and Halkia 2013a, 3027). And in a similar vein, Lynn Stephens and John Clement argue that thought experiments “appear to have considerable value as a sense-making strategy” (Stephens and Clement 2006).

Thought experiments have therefore been recognized as helping us to create semantic connections between new ideas, concepts, models, etc., on the one hand, and experiences that we have already had, experiences we might have, existing knowledge, abilities, concepts, etc., on the other. In other words, through them we can schematize difficult theoretical entities (in Kant’s sense; see Buzzoni, this volume, 336; Stuart 2017).<sup>5</sup>

But is this the same as increasing OU? Many philosophers argue that learning what something means is an instance of increased understanding (e.g., Davies 1981; Elgin 2000; Pettit 2002; Longworth 2008). And as with explanations and EU, we can be quite hesitant to identify meaning-making with understanding *in general*, and still happy to identify it as a means to or type of OU, since semantic relations do seem to be one sort of “coherence-making” relation that we can grasp. Thus, since we can increase meaningfulness using thought experiments, we can increase OU using thought experiments.

### 3.3 *Thought experiments increase fruitfulness*

Again focusing on pedagogical orthodoxy, we already test for fruitfulness when we have test-takers derive, explain, extrapolate, or otherwise evince that they can *use* an idea to do something they could not before. And we take this to be evidence that a test-taker understands that idea. This can be applied to the case of thought experiments in the following way: a thought experiment increases *S*’s understanding of *x* if after performing the thought experiment *S* can do something that *S* could not before, for example, manipulate a model, make a successful prediction, produce a good explanation for a phenomenon, derive a particular conclusion, etc. Even if the new abilities are accompanied by an increase in our stock of justified true beliefs, we would still want to deny that they just *are* justified true beliefs.

There are reasons to think that thought experiments can increase fruitfulness. Consider thought experiments that are used in therapy to give participants power over themselves to, for example, overcome a fear of heights or face an abusive partner (see Gendler 2004). Examples can be found in the scientific context as well. Velentzas and Halkia (2013b) took a group of high school students who could not make correct inferences about the relation between orbital and projectile motion. They presented the students with Newton’s cannonball thought experiment and the students could then pass their tests, even with questions that required a good deal of extrapolation. They repeated this study using Einstein’s elevator and train with the same results (2013a).

The case can also be made historically. After performing Darwin’s eye thought experiment the scientific community gained (and continues to profit from) the ability to investigate complicated traits by imagining a string of possible mutations, each of which is adaptive given its environment for the organism that possesses it. This has been a useful

strategy in addressing objections to evolution as well as providing new hypotheses for traits and organs of interest.

To summarize the last few sections: thought experiments can increase EU of  $x$  by helping to explain  $x$ , OU of  $x$  by increasing the meaningfulness of  $x$ , and PU of  $x$  by increasing the fruitfulness of  $x$ .<sup>6</sup> Now, let's see what the literature on understanding can contribute to the epistemology of thought experiments.

## 4 How do thought experiments increase understanding?

### 4.1 How thought experiments increase explanatory understanding (EU)

To say precisely how thought experiments contribute to EU, we would first need to choose or defend a characterization of explanation (or if we are pluralists, several). Given a particular characterization, we can then ask what sorts of explanations thought experiments take part in and how, whether thought experiment-based explanations have special qualities that make them better or worse than other kinds of explanations (for example, their experimental, narrative, or dialogical features), whether thought experiment-based explanations work by testimony, and how thought experiments justify modal claims (when that is their role in an explanation). It would require more space than I have to enter into the long-standing debates surrounding these questions. Instead, I will focus on OU and PU.

### 4.2 How thought experiments increase objectual understanding (OU)

There is no direct discussion of OU in the literature on thought experiments, but there are a number of resources in epistemology (not to mention aesthetics, hermeneutics, phenomenology, and philosophy of language) that can be brought to bear. In the space I have, I will highlight the work of Elizabeth Camp (2003, 2006, 2007, 2008, 2009, unpublished), which turns on the notions of *perspectives*, *characterizations*, and *frames*. The basic idea of a perspective is that when we read a narrative from a certain point of view, we learn to see the world *as if it were* the way the narrative presents it. We pay attention to different features of the world, and we are directed to experience those features as having specific relevance and intensities. We may evaluate these features differently, too, making moral, aesthetic or other value judgments in a way we would not otherwise. While watching a Saturday morning cartoon, we think it is morally acceptable for characters to smash one another over the head with mallets. And we feel uncomfortable reading *Lolita* because we are supposed to take up Humbert's perspective, and we don't want to.

When we *apply* a perspective (even our own) to something particular, we have a *characterization*. Because we are taking up Humbert's perspective when we read *Lolita*, we (are supposed to) characterize Dolores as an object of sexual desire. And on Saturday mornings we (are supposed to) characterize Daffy Duck as occasionally deserving a good mallet-smashing.

More recently, Camp has introduced the notion of a *frame*. A frame is a representational vehicle that crystalizes a perspective by suggesting a characterization. For example, Romeo regards ("characterizes") Juliet as so much "above" everyone else that you cannot

even look at her without being “blinded” by her charm. Romeo encourages us to share in this characterization with the utterance (frame): “Juliet is the sun.” Likewise, I might want you to enter into a characterization that portrays our friend Jane as someone who always expects everything to go wrong, thinks everything is her fault, and demurs to any authority. To do this I present the frame: “It’s as if Jane had a puppy who died when she was little and she’s still convinced it was her fault” (Camp 2009, 110). It is easy to see how models in science may serve as frames. For example, Bohr’s model of the atom is a frame which prompts us to characterize features of atoms in certain ways.

Perspectives, characterizations and frames are non-propositional. They are not thoughts but tools for thinking. We can express frames and characterizations using propositions, but these expressions are not the frames or characterizations themselves. This is because any characterization or perspective will outstrip its propositional reconstruction since the characterization can always be applied to new situations which were not included in the propositional reconstruction. To actually have a characterization, one must have the appropriate dispositions to evaluate, focus on, interpret, and relate together the features of a subject in a certain way.

OU-oriented thought experiments can be understood as frames which are meant to snap us into certain characterizations.<sup>7</sup> Some of Darwin’s opponents characterized the eye as a watch. Even if we saw a watch on a deserted island, we would nevertheless assume the watch was created because of its complexity and obvious purposefulness. This frame suggests a characterization of the eye as being like a watch, which is complex, purposeful and the product of intentional creation. That is how the frame casts doubt on the idea that eyes are the result of a series of chance mutations. Darwin, on the other hand, presents a competing characterization using his thought experiment, which narrates a series of mutations that could plausibly result in a fully functioning eye beginning with a single nerve. This characterization makes it easy to see the eye as having evolved.

Darwin’s frame succeeded because it allowed us to associate with the eye (and other complicated organs) a whole new set of semantic and explanatory relationships, possible causal histories, relations to other organs, evaluations, and so on, in a way that accords with the values of science (explanatory power, simplicity, predictive accuracy, etc.). Since possessing such a characterization is not possessing any specific propositions but rather certain dispositions, it is clear how the right frame could enable someone to pass the relevant tests of meaningfulness mentioned above.

How exactly do we gain OU by using frames? Camp writes “I might, for instance, gain a more intimate appreciation for the anguish of orphanhood, or for the attractions of gambling or being a bully, by empathizing with characters who undergo those emotions” (2009, 116). Such imaginative exercises help us understand orphanhood, gambling addiction or bullying by grasping what these mean from a first-person perspective. And, as Elgin (2014) argues, thought experiments can exemplify properties. That is, they can provide (perceptual or cognitive) access to an instance of a property, while also referring to that property, allowing us to make new inferences about the class of things that possess that property. This extends our semantic reach; not only do we grasp the meaning of, e.g., a specific gambling addiction by imagining ourselves as a specific gambling addict, we now begin to understand gambling addicts of all sorts, and even perhaps addicts in general. This is how thought experiments increase semantic OU in an epistemologically interesting way: they give us direct access to properties and indirect (inferential) access to the class of

objects that possess those properties (by exemplification) *while also* providing new tools for thinking about those objects (by the characterization).<sup>8</sup>

Furthermore, thought experiments will be particularly helpful as frames since they do not simply suggest a characterization; they prompt us to experiment with that characterization, filling it in ourselves as we go. More on this below.

I conclude that one way for an OU-oriented thought experiment to be successful is to be a good frame. That is, a good OU-oriented thought experiment will prompt in an efficient manner an epistemically and semantically valuable characterization or perspective. This allows us to appeal to a normative theory of perspectives in order to work out a normative theory of thought experiments, which I think is an attractive prospect.

### 4.3 *How thought experiments increase practical understanding (PU)*

Portraying thought experiments as frames allows us to explain some of their potential to create PU. For example, Camp notes that in Shakespeare's sonnet 73, Shakespeare likens his own dying to fall becoming winter, twilight becoming night, and fire becoming ash. These frames help us characterize DEATH. But they also provide a way to *cope* with death. We realize that death is "a natural and inevitable moment following on from more abundant, energetic ones." We may not like the cold and lonely images of winter and night, but we may be comforted by "acceptance and awareness of what lies ahead" (2009, 118). Likewise, it is only because we can see Newton's cannonball as the projectile which fills the gap between projectile and orbital motion that we can learn to apply our knowledge of one context to the other.

Besides this plausible option, there are other ways to explain the ability of thought experiments to increase PU. Again, space constrains me to consider only one. In this case, I will look briefly at the work of Alison Hills (2010, 2015).

Hills discusses understanding in terms of "grasp," which she explicates as an increase of "cognitive control."

The best way of thinking of [understanding] is by an analogy with grasping a ball or cup of tea or similar. If you grasp a ball, you have it under your control. You can manipulate it, move it, turn it round, and so on, that is you (normally) have a set of practical abilities or practical know how, which you can exercise if you choose.  
(2015, 3)

More formally, you understand  $p$  when you can follow an explanation for why  $p$ , explain why  $p$  in your own words, draw the conclusion that  $p$  from  $q$ , make analogical inferences from  $q'$  to the relevantly similar  $p'$ , use  $p$  to explain other related propositions, and finally, use  $p'$  analogically to explain related propositions,  $q'$ .

Those are Hills's conditions, which she uses to explicate understanding-why (the sort of understanding we have when we understand that  $q$  is why  $p$ ). This might seem like a departure from PU, but it is only a particular case. Hills claims that "guidance from an expert can certainly help, but that help does not necessarily take the form of assertions passing on standard propositional knowledge; or even if it does, that only works if it is combined with practice," and, "I don't think that it is very plausible to identify cognitive control with extra propositional knowledge. For no particular extra number of pieces of propositional

knowledge guarantees that you have the grasp required of understanding, the ability to draw conclusions yourself in a new case” (2015, 11).

Having cognitive control is a matter of having a certain set of abilities concerning propositions, for Hills, and that set of abilities, though often expressible in propositions, is not propositional itself. Hills’s account can be extended to PU by removing the requirement that the object of understanding be a proposition. Jimi understands how to play the guitar because he has a set of abilities towards a musical instrument instead of a proposition. Likewise, a student may be said to understand a signalling pathway in biochemistry when she can create a computer simulation that captures its behaviour accurately and robustly.

With Hills’s notion of understanding extended to PU, we can focus on how thought experiments might produce it. I will be drawing on some recent remarks made by Hills, concerning how understanding comes from analogies and questions.<sup>9</sup>

First, consider knowledge, which can be gained through the testimony of others. A trusted expert asserts a true proposition, and we justifiably believe it and thereby gain knowledge. However, this will not work for PU, which requires the development of a set of abilities and not merely believing the right propositions. Instead, when we gain understanding with the help of others we are like Meno’s slave boy, who is led to understanding by a series of actions that he performs in response to leading questions. Besides leading questions, we can also use analogies. Hills provides the example of treating light as a wave to understand the interference pattern in a double slit experiment. Since knowing requires believing true propositions, questions and analogies will not typically be able to transmit knowledge by testimony because questions do not assert propositions, and analogies are (often) literally false. What is common to understanding gained through questioning and analogy is that questions and analogies require us to *work on our own*. We are not given the answer to the question nor the key to interpreting the analogy, though we are encouraged to try to find them. And this exercise helps us develop new abilities or link existing abilities to new situations, until we can properly be said to have the relevant PU. For example, a computer scientist might ask a student, “Why do you think you are getting this error message?” as a way of helping her understand where she has gone wrong, and thereby increase her PU of a particular computer model. A driving instructor might tell a student to think of driving as a video game to increase the student’s PU of driving. If you have a fear of airline travel, a therapist might ask you to visualize getting on a plane, flying, and landing, over and over, until you have the ability to fly and are no longer afraid (Gendler 2004).

The key is the open-endedness of the prompt, which forces the agent to work things out for herself. In so doing, she lays the groundwork for the new abilities which constitute PU. A good PU-oriented thought experiment must therefore present a problem, along with enough information to work it out, without being prohibitively difficult. There will be enough information to set the agent on the right track, but not so much that the information can be accepted without developing any of the desired cognitive control.

Of course it is not just questions, metaphors and analogies that spur us into (cognitive) action. A thought experiment could be open-ended in this sense by employing a diagram, as these can be approached in many different ways (see Meynell 2014, this volume). There are also riddles and puzzles, which are regularly employed by logicians to get logic students to learn certain styles of reasoning.<sup>10</sup> A well-timed exclamation can also do the job.

Thought experiments can be exemplary prompts. First, they can combine several of the above prompt-types in one. Einstein and Galileo's thought experiments were often presented in the form of a paradox or puzzle and accompanied by a diagram. Second, their (at least semi-) experimental nature ensures their open-endedness. Thought experiments begin with a scenario or the statement of a problem, which causes us to create an imaginary world to explore the scenario or problem. We "set up" or "design" a thought experiment in this imaginary world, which we then "run" and "observe." John Gilbert and Miriam Reiner (2000) argue that thought experiments in science textbooks are typically sub-optimal precisely because they do not require students to run the thought experiment and then observe what happens in their own minds. In too many cases, the conclusion of the thought experiment is given first, and then the imagined scenario is introduced, which is supposed to lend credence to the conclusion. In this case, students do not vary variables in their minds; they simply follow along a text. This is better than simply reading the conclusion, but is not as good as having the student work through the problem on their own. The most successful thought experiments require our mental effort.<sup>11</sup> Einstein asks, "What would light look like if you were riding on a lightwave?" and Maxwell asks, "Could a demon in a closed system decrease the system's entropy?" To answer these questions, the scientific community required time and effort, which is exactly what was needed to increase the relevant PU.

## 5 Concluding thoughts

Much more needs to be said about how thought experiments increase understanding. For instance, we need to identify how thought experiments can mislead us, and if there are any kinds of understanding that thought experiments cannot provide. Relevant to the discussion of EU, Brown (2014) points out that thought experiments seem to provide "top-down" (or formal) explanations more easily or more often than "bottom-up" or mechanistic explanations. Is this necessarily the case, and if so, why?

And there are many more ways the literature on understanding can interact with the literature on thought experiments. There is agreement in the epistemological literature that understanding comes in grades (Kvanvig 2003; Elgin 2007; Baumberger 2011, forthcoming; Grimm 2014; Hills 2015; Hannon forthcoming). We will therefore have grades of EU, OU and PU. The tests we give to others and to ourselves in academic contexts are graded, and so, as graders of tests, we already have an idea of what counts as less than perfect understanding, and how much a thought experiment can help to increase the degree of someone's understanding. Perhaps one way epistemologists can therefore investigate degrees of EU, OU and PU is to look at the tests we give our students (and ourselves) and ask how thought experiments aid us in passing them.

Also, grades can be measures of breadth or depth (Elgin 2007; Strevens 2013; Greco 2014). This is helpful for increasing the precision with which we classify good understanding-oriented thought experiments. Can thought experiments provide both broad and deep EU, OU and PU? If not, why not?

Finally, understanding is a success term (Baumberger 2011). This is clearly true in science, where a student is judged to understand a model, system, method, or concept only when she or he can pass certain tests of understanding, which will be contextual

(depending on the domain and problem type) and conventional (like the 5-sigma confidence level in physics). These tests can amount to operationalizations of the success conditions for understanding (Stuart 2016). But much more needs to be said about the aptness of any given test as a means for evaluating the state of someone's understanding relative to the success conditions and also about the success conditions themselves, e.g., must they track whether our understanding "latches on" to the world? If so, how can they do this? How "objective" can the tests be?

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In this chapter, I drew attention to the potential for mutual illumination between the literature on thought experiments and the literature on understanding. We saw that thought experiments can increase explanatory, objectual and practical understanding, and also that what counts as a good understanding-oriented thought experiment will depend on the sort of understanding we want. A good explanatory thought experiment will participate in a good explanation. One way to be a good objectual thought experiment is to create a good frame to get us into the right characterization or perspective. And one way to be a good practical thought experiment is to be an open-ended, goal-directed prompt that entreats us to perform certain cognitive actions, which can then be repeated and reinforced to build new abilities.

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### Notes

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- 1 The suggestion that thought experiments increase understanding is not new. Brown made a similar point much earlier (1992, 274), although principally as a criticism of Norton. He has recently turned back to the issue, looking at thought experiments and understanding more directly (Brown 2014). Other philosophers of science have focused on understanding in thought experiments as well (e.g., Nersessian 1992, 2007; Humphreys 1993; Gooding 1992, 1994; Gendler 1998, 2000; Arthur 1999; Lipton 2009; Camilleri 2014), but none (save Catherine Elgin) have taken advantage of the recent work on understanding in mainstream epistemology. That is my aim in this chapter.
  - 2 Whether all forms of understanding can be reconstructed exclusively in terms of knowledge is the subject of a large debate (see, e.g., Hetherington 2001; Zagzebski 2001; Kvanvig 2003; Grimm 2006; Pritchard 2009; Hills 2015; Riaz 2015; Hannon forthcoming). I do not want to commit myself to a position here. Perhaps some forms of understanding can be reduced to ordinary propositional knowledge, and others to non-propositional knowledge (such as knowledge-how). I claim below that several forms of understanding are not reducible to propositional knowledge, and this is sufficient to distance these forms of understanding from knowledge, standardly conceived.

- 3 One reason I chose this tripartite distinction is because it subsumes most of the ways thought experiments lead to understanding that were mentioned at the beginning. For example, to illustrate a theory or idea is often to explain it (EU) or help us grasp its coherence-making relations (OU). Controlling for extraneous variables and inverting ideals of natural order enable us to do things we could not do before, which is a way of increasing PU. To exemplify a property is to provide direct access to that property (which is a way of drawing new semantic or explanatory relations to it) and also to refer to the property, which allows us to make inferences about all items with that property, which is to increase its PU. And so on.
- 4 [www.edge.org/responses/what-is-your-favorite-deep-elegant-or-beautiful-explanation](http://www.edge.org/responses/what-is-your-favorite-deep-elegant-or-beautiful-explanation).
- 5 This is not a trivial accomplishment. Determining the semantic content of theoretical entities is the general case of a solution to what Bas van Fraassen has called the “problem of coordination” (van Fraassen 2008). I discuss the idea that thought experiments are used in science to solve it in Stuart (2017).
- 6 The same thought experiment might do more than one of these, even at the same time; see (Stuart 2016) for examples.
- 7 Portraying thought experiments as frames would make them tools to increase understanding rather than knowledge, not just for me, but for Camp as well. She writes,

Insofar as philosophy seeks understanding, we need to do more than just identify a set of justified true propositions. We need to know which propositions we should pay attention to, what explanatory structures to impose upon them, and (in the moral case at least) even how we should feel about them.

(2009, 128)

I am merely emphasizing the power that frames and characterizations have for exploring and evaluating the semantic content of entities, terms, events or domains, and showing how this can lead specifically to OU.

- 8 Camp hints at thought experiments having such dual powers herself when she writes,

Philosophers also use thought experiments ... to present a supposedly common phenomenon in especially stark and vivid terms, thereby helping us to focus our attention on its structurally relevant features ... But such thought experiments can also operate ... by describing counterfactual situations in concrete detail, they can trigger a kind of experiential acquaintance that an abstract description misses.

(2009, 124)

- 9 This discussion draws on a presentation given by Hills at Fordham University, New York, June 20, 2016.
- 10 Philosophical discussions of riddles, and riddles as metaphors, can be found at least as far back as William of Conches (c. 1090 – 1154 CE), who (to some extent) equated the two. William believed that riddles and metaphors were important for appealing to our cognition, which was a faculty of the soul, using speech (a faculty of the body). According to William, riddles, metaphors, allegories, and fables were “labyrinths of imagery” that enclosed truth in darkness. Peter Dronke summarizes “The initiate can enter that darkness and there find the truth. Yet it is not only a dark place, but a passage in which [s/]he must walk: what [s/]he finds in the labyrinth, we might say to paraphrase, is not a truth ready-made, but a challenge ...” (1974, 49–50). Another interesting anticipation of this discussion is in pseudo-Dionysius, who says that “incongruous symbols” (*per dissimilia symbola*) are sometimes best for teaching people about difficult subjects, because they are not so similar to their targets that they could be confused for the object of study itself (Roques, Heil, and de Gandillac 1970, 74ff.). Thanks to Maximilian Wick for discussion and references on this point.
- 11 This will be true for laboratory experiments as well. As regards PU, being told the conclusion of an experiment is less helpful than watching that experiment performed, which is less helpful than being guided through the experiment step-by-step, which is less helpful than running the experiment yourself.

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