# Inconclusiveness in Scientific Thought Experiments

## or What can the Aristotelian say to Galileo?

John Norton claims that there is nothing miraculous about thought experiments; they are plain, old arguments dressed up in appealing garb[1]. More specifically, his claim is that thought experiments are arguments that:

(i) posit hypothetical or counterfactual states of affairs, and

(ii) invoke particulars irrelevant to the generality of the conclusion[2].

He also holds that a "good" thought experiment is "built from a template," or a deductive or inductive "logical schema", into which we can freely "insert *any* particulars" of our choosing[3]. Since the particulars are irrelevant, it should not matter which ones are used in a thought experiment. Against Norton, Gendler contends that "reasoning about *particular* entities" leads to conclusions that would not be "justifiable" by a straightforward argument. She claims that it is the "contemplation" of the particular scenario described in a thought experiment that leads us to "see" its conclusion. Despite her disagreements with Norton however, Gendler shares his conviction that the thought experiment establishes its conclusion in a manner that is "categorical and decisive"[4]. Notably, Gendler begins her paper by raising the issue of the "persuasiveness" of the thought experiment, but proceeds

1 John Norton, "On Thought Experiments: Is There More to the Argument?" Proceedings of the 2002 Biennial Meeting of the Philosophy of Science Association, Philosophy of Science 71:5 (2004). 1140.

2 John Norton, "Thought Experiments in Einstein's Work" Thought Experiments In Science and Philosophy. eds. T. Horowitz, G. J. Massey (Savage, MD: Rowman and Littlefield, 1991) 129.

3 Norton, "On Thought Experiment" 1143.

4 Gendler, "Galileo" 407.

to switch persuasiveness with "demonstrative force"[5]. Thus, Gendler sets herself the task of giving an account of the secure passage to the conclusion of the thought experiment without opting for Norton's solution, logic.

But in eschewing Norton's deflationary view of thought experiments, while retaining his assumptions about *what* the thought experiment achieves, Gendler does not go far enough. Both Norton and Gendler take the conclusion of a thought experiment, such as the one proposed by Galileo on falling bodies, to be firmly established and safe from contention and rational disagreement. And yet, Galileo himself is more modest about the achievements of his thought experiment, for in his text that is written in the form of a dialogue one of the interlocutors disputes the conclusion[6]. Simplico, to whom the thought experiment is addressed, claims that he does not "*see* how," a small stone added to a larger one fails to increase the speed at which the large one falls[7]. Not even Galileo's fictional characters unequivocally accept the conclusion of the thought experiment in the way that Norton and Gendler assume we do, barring irrationality or some imaginative blindness.

I shall argue that a thought experiment cannot be conclusive in the sense in which Norton and Gendler suppose and that it leaves room for legitimate and rational disagreement. I will do so by considering Galileo's thought experiment because it is

5 Gendler, "Galileo" 397-399.

6 Galileo Galilei. Dialogues Concerning Two New Sciences trans. Henry Crew and Alfonso de Salvio (New York: Macmillan, 1914) 63.

7 Ibid. Emphasis added

widely held as a successful *refutation* of an Aristotelian thesis and is also the thought experiment that both Gendler and Norton discuss. On the reading I propose, this thought experiment is very persuasive, yet essentially inconclusive, at the same time. In the first part of the paper, I will propose a positive account for understanding the Galileo thought experiment as "dialectical" in the Aristotelian sense. This means that it involves an essential "reference to another party,[8]" Simplico and us, the readers of Galileo, and is constructed with the aim of securing the acceptance of the conclusion by the other party. It also involves reasoning from premises that are not necessarily true or probabilistic, but plausible in nature[9]. I will discuss how Galileo's thought experiment uses plausible premises, and employs characteristically dialectical tactics, such as a specific ordering of theses leading up to the conclusion. The dialectical account will explain the persuasive aspects of the thought experiment. On the other hand, the thought experiment involves some non-deductive, defeasible reasoning and so it leaves room for objections to the conclusion, even when one grants the premises and accepts the inference from them, because the inference is not binding. I will discuss some ways in which the Aristotelian could contest Galileo's conclusion of the thought experiment, in the second part of the paper. Finally, I will provide an account that uses our present understanding of Newtonian science to explain why Aristotle's thesis *fails*, without being straightforwardly

8 Aristotle *Topics* 155b8-10. All references to the *Topics* are from Aristotle. "Topics." The Complete Works of Aristotle: The Revised Oxford Translation. Trans. W. A. Pickard-Cambridge. Ed. Jonathan Barnes. (Princeton, NJ: Princeton University Press, 1984.)

9 Aristotle *Topics* 100a20-22. I have taken what Aristotle calls "reputable" premises to mean plausible. This is problematic in some respects because these are not equivalent concepts, but Aristotle's notion can be understood as a way of cashing out what is acceptable to most people and thereby to the interlocutor. This suffices for my purposes in his paper.

false and using this account, I will explain the success as well as the limitations of Galileo's thought experiment.

Before we begin the discussion a few remarks are in order. Firstly, my characterisation of Galileo's thought experiment may generalise for all thought experiments that attempt to persuade their reader of a particular conclusion[10]. I do not however imply that such a thought experiment reduces to dialectical reasoning, but only that they involve such reasoning. Secondly, I use "reasoning" in a broad, non-technical sense to refer to the process of coming to a conclusion, by "putting things together," without necessarily following a deductive or other logically structured inference schema[11]. The role of imagination is not ruled out or precluded by this account, and imagination may play a part in the psychological process of such reasoning. Lastly, my positive account is in many respects close to the one Gendler offers for thought experiments in philosophy. In her paper on this subject, Gendler calls philosophical thought experiments "devices of persuasion" that may or may not succeed in persuading[12]. Her account of Galileo's thought experiment is crucially different. While it is not uncommon for philosophers to hold that thought experiments in philosophy are different from thought experiments in science in the latter being conclusive, this position

10 This would not include thought experiments that only elicit intuitions, such as the trolley problem, rather than aim to persuade us.

11 The Greek verb, *syllogizesthai* is translated as "putting things together" or collecting. See Heda Segvic, "Deliberation and Choice in Aristotle," Moral Psychology and Human Action in Aristotle eds. Michael Pakaluk and Giles Pearson (Oxford University Press, 2011) 165.

12 Tamar Gendler, "Philosophical Thought Experiments, Intuitions and Cognitive Equilibrium," Midwest Studies in Philosophy: Philosophy and the Empirical XXXI (2007). 68-88.

often downplays the extent of disagreement over thought experiments in science, and misdescribes the nature of these disagreements. In this paper, I hope to offer a corrective, at least in so far as the Galileo thought experiment is concerned.

## I

A feature that often goes unnoticed in philosophical discussions of Galileo's thought experiment is that it is presented within a dialogue. Galileo chooses the dialogic format deliberately, partly because he wishes to persuade a general audience (not the academia) of the truth of the Copernican system[13]. Galileo, given his familiarity with Aristotle's works on dialectic and rhetoric, may also have known that dialectical reasoning is more useful when one faces a general audience, because of its informal character[14]. Moreover dialectic being a practice that involves engaging another person in reasoning bears a close relationship with dialogue or conversation in the everyday sense[15]. The Greek word for "dialectic" itself comes from the verb διαλέγω, which means holding a conversation. In Plato's dialogues, we see dialectical reasoning at work when Socrates engages one or more interlocutors, often attempting to refute the claims that they put forward. In

13 This is also the reason why Galileo chooses to write the entire work, *Dialogues Concerning Two New Sciences* in Italian rather than in Latin, which was the language of scholarly discourse in Galileo's time. See Nicholas Jardine "Demonstration, Dialectic and Rhetoric in Galileo's Dialogue," The Shapes of Knowledge from the Renaissance to the Enlightenment. eds. D.R. Kelley & R.H. Popkin (Dordrecht: Kluwer, 1991) 101.

14 In one of his letters, Galileo discusses the importance of Aristotelian logic and makes reference to dialectic and tells his friend that he is very well acquainted with these and uses them regularly. See Neal Gilbert, "Galileo and the School of Padua", Journal of the History of Philosophy I (1963) 229.

15 See Jardine107-110. To be sure, dialectic, at least of the Socratic kind is used almost exclusively for negative purposes, refuting claims that the interlocutor may be committed to in advance and it is unclear if Galileo may be able to obtain positive results of establishing the truth of the Copernican system.

Galileo's treatise, *Dialogues Concerning Two New Sciences*, a character called Salviati, who plays a leading role, much like Socrates, is seen in conversation with two interlocutors[16]. Salviati engages a seemingly dimwitted man called Simplico who defends Aristotelian science, and Sagredo, an intelligent middleman who is much more sympathetic to the new Copernican system.

The famous thought experiment is presented within the context of a discussion of the possibility of vacuum. Before the scenario of the thought experiment is presented, however, Sagredo claims that he has "made a test" of the Aristotelian claim that a heavier body will fall more rapidly than a lighter one, of the same material, when dropped from the height of 100 cubits[17]. He claims that his results are contrary to those that Aristotle had claimed. We will discuss these test results in the next section of the paper, but in the context of the dialogue Salviati does not discuss empirical tests. He claims instead that without "further experiment, it is possible to show clearly, by means of a short and conclusive argument that the heavier object does not fall more rapidly than the lighter one," provided that they are of the same material and meet other constraints that Aristotle specifies[18]. Salviati proceeds to describe an imaginary scenario where a heavier stone is combined, somehow, with a lighter one to create a new object, and a contradiction seems to follow from applying the Aristotelian thesis to this new object. But before presenting this scenario, Salviati elicits an important concession from his interlocutor that proves

16 Naylor has a similar interpretation of the dialogic structure in Galileo. See Naylor, R.H. "Galileo's experimental discourse." The Uses of Experiment: Studies in Natural Science Eds. D. Gooding, T. Pinch, S. Schaffer. (London: Cambridge University Press, 1990) 124.

17 Galilei 62.

18 Ibid. 63

crucial for establishing the falsity of the Aristotelian claim. The relevant portion of the dialogue is as follows:

> Salviati: (1) If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. Do you not agree with me in this opinion?
>
> Simplico: You are unquestionably right.
>
> Salviati: (2) But if this is true, and if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight; (3) but the two stones when tied together make a stone larger than that which before moved with a speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition[19].

(1) is a claim about the natural speed of a composite body, made by combining two separate ones and it states how this speed relates to the individual speeds of each of its components. But note that at the outset (1) seems innocuous because its relevance to the refutation of the Aristotelian thesis is not obvious. Simplico unsuspectingly grants (1), though a more astute Aristotelian may not have done so. Following this admission, Salviati claims (2), which is an application of (1), a general claim, to a concrete instance. (3) is more straightforward. Here Salviati states that the weight of the combined object will be larger than that of either of the individual stones. Then, he points out that (2) and (3) result in a contradiction. By (2), the speed of the combined object is less than 8 and,

19 Galilei 63.

by (3), the speed is more than 8, given Aristotle's thesis that the heavier object falls more rapidly. Thus, a contradiction seems to result.

Salviati then claims that based on Simplico's "assumption" (the Aristotelian thesis) that a heavier object falls faster than the lighter one, he has "inferred" that the heavier body moves more slowly. Of course, Salviati does not directly "infer" the contradiction from the Aristotelian assumption (1), but he does so with a few further assumptions, and the *order* in which these are stated proves critical for the success of the thought experiment[20]. The ordering of points and the "framing" of the discussion is a unique requirement of dialectical reasoning, not shared by other forms of argumentation, in so far as it involves a reference to another party[21]. In this instance, as noted earlier, the relevance of (1) only becomes evident when (2) is presented, i.e. *after* Simplico has granted (1). This is a good tactic because, as Aristotle notes, the interlocutor is "on guard" against granting whatever his opponent's thesis requires and, leaving the relevance of the claim in doubt helps secure his opponent's acceptance more readily[22].

(1), in so far as it gets Salviati (2), turns out to be crucial for generating one arm of the contradiction. This tactic is also described in Aristotle's *Topics* as a way of securing the acceptance of relevant claims. Specifically, Aristotle states that one ought not to state the "necessary proposition" (in this case (2)) in so many words, lest the answerer

20 See Aristotle, *Topics* Book 8 Chapter 1 for a discussion of some of the tactics used in dialectical exchanges.

21 *Topics* 155b8-10.

22 *Topics* 156b4.

"foresees" what follows from them[23]. Allowing for this possibility opens the space for an objection. (1) is a "dialectical proposition" in Aristotle's sense of the term in that it is a proposition that "holds in several cases" and, more importantly, "no objection is forthcoming" to it[24]. In other words, (1) is defeasible but it is also not easily countered. This is because it is not immediately obvious why and under what conditions it may be wrong. Aristotle explains that it is good dialectical practice to state such propositions for which no objection appears at all, or, at least, none appears "on the surface[25]". The reason is that "when people cannot see any case in which it is *not* so, they admit it for true[26]." Aristotle is indicating a feature of human rationality by which we would accept something as true just in case it is undefeated, rather than suspend judgment perhaps, and wait for certain, indubitable proof. Perhaps, (1) seems right to Simplico and to us because motion generally works in this way. Imagine two horses that tend to go at different speeds, one is much slower than the other, and the two are harnessed to the same carriage. It seems *prima facie* plausible that the speed of the carriage would lie somewhere between the speeds of the two horses. But on the other hand, it is much harder to think of cases where (1) is not true, or to think why it could be wrong. Salviati is thus well placed for securing his interlocutor's acceptance of (1). But once (1) is taken to be true, (2) follows necessarily. Salviati, like any good student of dialectic, has secured the necessary proposition by first securing a less objectionable one from which the necessary

23 *Topics* 155b14-15.

24 *Topics* 157b32-33.

25 *Topics* 158a3-5.

26 *Topics* 158a3-5.

proposition follows[27]. I submit that it is such an establishment of (1) that lends the sense of inevitability to Galileo's thought experiment[28].

On Gendler's account, what the Aristotelian does in carrying out Galileo's thought experiment is contemplate an imaginary body made up of two stones to draw the Galilean conclusion, for herself. Her account is compatible with the claim that the reasoning involved in the process of carrying out the thought experiment is dialectical (in the sense discussed above). The Aristotelian may be accepting (1) by some such psychological process of contemplation of a composite object. But even so, what helps her reach Galileo's conclusion, or that which is doing much of the persuasive work here, is the ordering of the steps and the way they have been put forth by Galileo. For instance, when Simplico contemplates the scenario, his having already acceded to Galileo's key assumption about natural speed ((1) above)) makes a lot of difference. This assumption can no longer come up for evaluation in the reasoning about the falsity of the Aristotelian thesis, because it has been granted in the immediate past. I am suggesting that the *framing* of the imaginative scenario by our interlocutor, Galileo, has consequences for the kinds of inferences we tend to make in our contemplation of the scenario.

27 Galileo himself was well trained in the art of rhetoric and was well acquainted with Aristotle's treatises on dialectic. We may also note that the scope and use of dialectic was much expanded in late sixteenth and seventeenth century Europe, partly as a result of humanist reforms. See Jardine 197-109.

28 Atkinson comes to a similar conclusion, although he is much more dismissive of the thought experiment as "largely polemic." See Atkinson David Atkinson, "Experiments and Thought Experiments in Natural Science." Observation and Experimentation in the Natural and Social Sciences ed. Maria C. Galavotti (Dordrecht: Kluwer, 2003) 209-25. Michael Stöltzner "The Dynamics of Thought Experiments - Comment to Atkinson" Observation and Experiment in the Natural and Social Sciences ed. by Maria C. Galavotti (Dordrecht: Kluwer, 2003) 210-215.

Another way of seeing the role of the dialectical aspects in the thought experiment is to consider a scenario where the order of the claims and questions is switched, (3) is followed by (2) and the dialectical premise is omitted. Suppose Salviati were to state the scenario as follows: "If a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then, when they are united, do you think the composite will move at a speed of twelve, or a speed of six?" In this case, whether or not the Aristotelian accepts Galileo's conclusion is an open question. He may agree with Galileo or not. He may even suspend judgment on this case. This openness will become more evident at the end of the next section.

## III

Now I turn to consider the responses open to the Aristotelian that may allow him to deny or contest the Galilean conclusion. There are two types of responses open to her. The first are the kind that are available to anyone faced with a deductive argument and they consist in either denying the premises or questioning the inference to the conclusion, if the argument is invalid. Note that these reasons are sufficient for showing that Galileo thought experiment is not conclusive, if we think of it as an argument in Norton's sense. The second sort is available to someone confronted with defeasible reasoning of the kind we see in dialectical encounters. Here one can object to the conclusion on further grounds, even if the premises have already been granted as true and the inference to the

conclusion is accepted. This is because the inference to the conclusion is not binding in defeasible reasoning. I shall argue that such a response is available to the Aristotelian. The availability of such a response also goes to show that the dialectical account that I am proposing is more adequate for Galileo's thought experiment, than the ones proposed by Norton and Gendler.

As for the first type of response, the Aristotelian presented with Galileo's thought experiment can respond by denying (3)[29], the inference from the Aristotelian thesis about natural speed, to the case of a composite body. She can do so by denying that a composite body falls under the scope of the Aristotelian thesis. This way no contradiction results from granting (1). There are, at least, two ways that the Aristotelian can justify her denial of (3). She can do so by appealing to the idea that the composite body does not count as a single entity. This is because it is an artificially unified body, and like a statue it lacks the kind of unity a natural object has. Aristotelian metaphysics allows for degrees of unity, which can support the claim here[30]. Alternatively, she may claim that the notion of natural speed does not apply to composite objects[31]. Galileo defines the Aristotelian notion of

29 *Pace* Gendler, the Aristotelian does not need to come up with an "alternative hypothesis" in order to refuse (1). This is because, in Aristotle's description of dialectical reasoning, the burden lies with the questioner to secure the acceptance of the interlocutor. Aristotle states that an answerer may even deny a true premise, just because he "forsees" that an unfavorable conclusion would follow from it (*Topics*. 155b10-13). Gendler "Galileo" 404.

30 Sally Haslanger, "Parts, Compounds, and Substantial Unity," Unity, Identity, and Explanation in Aristotle's Metaphyisics eds. Scaltas et al (Oxford: Oxford University Press, 1994) 128-131.

31 As Vickers notes, there is also no evidence for the fact that "the Aristotelians even *considered* how 'combined bodies' would fall." Peter Vickers. Understanding Inconsistent Science. (Oxford: Oxford University Press,) 195.

"natural speed" at the outset of the thought experiment as follows, "each body falling acquires a definite speed *fixed by nature*, a velocity which cannot be increased or diminished, except by use of force or resistance[32]". It is unlikely that composite objects were included among the objects having speeds fixed by nature, given that Aristotle does not even conceive of manmade objects such as statues as having "natures," in the strict sense[33]. Using one of these considerations, the Aristotelian might claim that no contradiction results for her thesis, because (3) does not follow from the Aristotelian thesis.

On Gendler's reading, such ways out of the argument are "precluded" by the thought experiment. She claims that the thought experiment involves "contemplation" of an "imaginary" body made up of two stones, as described by Galileo, and that this "brings him [i.e. the Aristotelian] to see" that certain tacit, defeasible assumptions about objects are "not defeated in this particular case[34]". The tacit assumptions are that,

(A) For *any* body "there is a determinate fact concerning its weight and natural speed"
(B) "There is no determinate fact" about whether or not a combined object is one body or more.

32 Galillei 63.

33 The Aristotelian may also deny the inference from (1) to (2), the inference from the Gailean assumption (or dialectical proposition) to the particular case (2). The inference here seems to necessary but (1) only states that in a composite the speed of one stone is retarded and that of the other is increased. This does not imply that the two stones will *move* as one entity and have a single final speed. But a composite object could also experience discontinuous motion where the stones may move at different speeds while falling. As we shall see later on, this kind of phenomenon is actually possible with falling bodies. But this response relies on a Newtonian understanding of speed and acceleration, and this may not be available to the Aristotelian.

34 Gendler, "Galileo" 408.

If as Gendler argues, the Aristotelian holds both these assumptions, the possibilities the Aristotelian may have for denying 3, such as those stated above are foreclosed. (B) for instance, blocks the move based on the claim that the composite object has a different kind of unity. Gendler's claim is that the thought experiment evokes said tacit assumptions, which act as "background support" for accepting Galileo's assumption (1) above[35]. This way the assumptions help establish the conclusion of the thought experiment.

But given his metaphysical commitments, the Aristotelian seems not to have these tacit assumptions. In her account, Gendler does not tell us how the Aristotelian may have come to have these assumptions but her explanation of their reliability suggests that they are somehow obtained through experience of the world. She appeals to Mach's account of "unarticulated knowledge" of the world gained through experiences to say that the Aristotelian already has the relevant beliefs about falling bodies, although they are hitherto unarticulated[36]. But Mach's account is based on empirical knowledge of the world, while the two tacit assumptions are neither observable facts nor are they derivable from such facts of nature. Nothing in the world tells us *that* there is no determinate fact about how many entities make up a composite object. More importantly, the assumptions (A) and (B) themselves presuppose philosophical (and scientific) claims such as those about the scope of physical laws of nature, and what an entity is. The Aristotelian, given his philosophical commitments, may very well not share these presuppositions. And not

35 Ibid.

36 Ibid 415.

having the necessary presuppositions, the Aristotelian would also not hold the tacit assumptions that block ways out of the argument for Gendler. It seems that, contrary to Gendler's claim, the Aristotelian is in a position to deny the relevant premises of the argument (assumption (3)) after all.[37] Admittedly, there is something unsatisfactory about the line of response I am proposing for the Aristotelian here. The concern here may be that by these moves, Aristotelian science does not have anything to say about the speed of a composite body and this makes it explanatorily deficient in a problematic way. We will return to this worry shortly.

There is a second kind of response available to the Aristotelian. She can cite other evidence for the Aristotelian claim and such evidence may include empirical findings. For instance, the Aristotelian can claim that the Aristotelian thesis can be verified by the test that Sagredo claims to have performed at the start of the thought experiment. If we were to carry out the test for Aristotle's thesis that Galileo describes in his text, and drop a 100-pound iron ball and a 1- pound iron ball from a height of 100 cubits, we would observe that the heavier ball hits the ground much before the lighter one[38]. Such a result supports Aristotle's thesis. These kinds of empirical findings offer the Aristotelian

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38 Carl J. Adler and Byron L. Coulter, "Galileo and the Tower of Pisa experiment," American Journal of Physics Vol. 46 (1979): 200. Izabella Nowakowa and Leszek Nowak also argue that Aristotle's thesis held up empirically. "Galileo-Newton's Model of Free Fall." The Richness of Idealization (Amsterdam: Rodopi, 2000) 48-50 and 54. See also, Carl J.Adler and Byron L.Coulter, "Aristotle. Villain or Victim?" Physics Teacher Vol. 13 (1975): n.12.

rational grounds for denying the conclusion. It is also noteworthy that as a matter of historical fact, Aristotelians responded to Galileo in precisely this manner, by citing empirical observations that vindicated the Aristotelian thesis[39]. In so far as Galileo's text is concerned, Sagredo's claim that he has empirically tested and found the Aristotelian claim to be false, is itself a dialectical ploy that serves to throw suspicion on the Aristotelian claim, even though the claim is in fact untrue[40].

However, the suggestion that there is empirical evidence for the Aristotelian claim should seem surprising. After all, from our modern perspective, we take it that Galileo was right in claiming that the Aristotelian thesis is false. The explanation for these puzzling empirical claims is that the Aristotelian thesis is not straightforwardly false. This requires some explanation. Aristotle's claim concerns falling bodies in a medium where the medium resists the motion of the body. This is to say that the body is subject to drag or the force that a medium such as air exerts, by which the motion of a body is impeded in a way similar to friction[41]. But when Galileo claims that two objects of different weights "falling" together, end up arriving at the same time, he seems to be describing "free fall" or the motion of a falling body in the *absence* of drag, and under further constraints such as a uniform gravitational field[42]. Aristotle, presumably, was not inquiring about falling

39 James McAllister. "The Evidential Significance of Thought Experiment in Science," Studies in History and Philosophy of Science 27 (1996): 243.

40 Commentators have argued that Galileo could not have empirically tested the falsity of Aristotelian thesis. See Adler and Coulter, "Galileo and the Tower of Pisa experiment"

41 Adler and Coulter, "Aristotle" 36.

42 Stöltzner 252. See also Izabella Nowakowa and Leszek Nowak 54.

objects under such a description, or we might also say that his notion of falling objects does not have the same constraints in place. The drag force depends on the weight of the object but also its shape and some properties of the medium that the object is moving through[43]. But in everyday cases where drag is significant the velocity of a falling object is significantly affected by its weight. Heavier ones will move much slower than lighter ones, as Aristotle claims, even though he is wrong about that the way that speed varies in relation to weight. Another way to see the differences between Galileo and Aristotle is to note that Galileo's thesis that all objects fall with the same speed is true if we understand "natural speed" as acceleration. But Aristotle on the other hand, seems to have observed, what we now understand as "terminal velocity" or the maximum velocity reached by a falling object when the influence of gravity is counter-acted by the drag force, the resistance offered by a medium such as air. This is why certain empirical tests done ordinary conditions, where drag is present and significant, will support Aristotle's claim.

Nonetheless, Aristotle's account of falling bodies *fails* in an important respect. It fails to distinguish the two forces (gravitational force and drag) that both act on a body falling through a medium, and thereby fails to come to the conclusion that only one of these forces acts on a body in vacuum[44]. The point is that Aristotle's theory is not straightforwardly false; rather it fails in some crucial respects[45]. In part because of such

43 To be sure, Aristotle does not recognise many of these dependencies and only sees the motion of falling bodies as affected by the weight and density of the medium.

44 Aristotle also disbelieved in the possibility of vaccum, which also prevented him from considering the possibility of free fall as such.

45 But on the other hand, Galileo too was misled in claiming that he could show Aristotle to be wrong in the test described here because he underestimated the effects of drag when dropping objects from said heights. Adler and Coulter, "Galileo" 200. As Nowakowa and Nowak argue, that Galileo's claim depended on idealtization and that it was Newton who provides the theoretical underpinnings for his

failings, Aristotle did not isolate all the factors that would affect the drag force, such as the viscosity of the medium. For our present discussion, this explains why the Aristotelian thesis seems to be explanatorily deficient. To see why, we may first note that, on the one hand, the Aristotelian thesis is true under certain, specifiable empirical conditions, in particular for terminal velocity under conditions of laminar flow of the medium. Laminar flow defines the condition in which the layers of air (or any other medium) glide smoothly past one another in straight lines. On the other hand, the Aristotelian thesis is unreliable under all other conditions. In particular it is often false for motion under other conditions of flow, such as turbulent conditions where there is chaotic movement in the medium and eddies (or small currents of fluid) move in different directions[46].

Even under laminar flow conditions, combining objects may change the shape and surface area of the resulting object such that it changes the drag force on the object and it thus changes the object's terminal velocity. We may for instance, imagine the two stones of Galileo's scenario being joined back to back such that it results in a bulkier large stone. This is similar to the dumbbell shaped object that Blackburn imagines in his explanation of the Galileo thought experiment[47]. In this case the drag would be significantly larger and the resulting speed of the object would be reduced. In such cases, Aristotelian thesis does not accurately predict the terminal velocity of the composite object. If we imagine

claim and the reason why Aristotle's theory turns out to be more accurate empirically. See Nowakowa and Nowak 49-51.

46 Motion under turbulent flow is notoriously hard to model.

47 Simon Blackburn, The Oxford Dictionary of Philosophy (Oxford: Oxford University Press, 1996) 365.

the scenario in the way described above, we will infer that the speed of the composite would not be much greater than that of both of its components. We will then agree with Galileo's conclusion. Thus, Galileo's clever scenario can succeed in bringing out the limitations of the Aristotelian claim in that it fails to account for such cases.

We can also use the above account of falling bodies to grasp the limitations of the particular scenario of the composite body that Galileo uses. This will show why Galileo's assumption (1) is plausible at best and the thought experiment non-conclusive. We may begin my understanding Aristotle's thesis as a claim about terminal velocity, and modify the scope of the claim to only cover cases where the object moves through a fluid in laminar flow conditions. With these constraints, these are some instances where a composite object is likely to have a terminal velocity that is along the lines of what the Aristotelian thesis predicts. In other words, the terminal velocity of the composite body may have a speed that it is proportional to its final weight. This can occur if we imagined attaching the stones end to end and resulting in an elongated object. Such an object will move faster through air than any either of its components because of its shape. This is similar to the way in which an airplane or a sports car is helped by its shape The Aristotelian might even use such cases to turn Galileo's reasoning on its head, as Atkinson proposes[48]:

48 Atkinson 224.

(1') Terminal velocities of bodies are additive (not mediative, [i.e. lies in between the terminal velocity of the combined body is less than that of one of its components and more than that of another as (1) states])

(2') Weights are additive

(3') Therefore, terminal velocities of falling bodies are proportional to their weights.

Yet, there may also be scenarios in which neither (1) nor (1') is true, i.e *both* are false. This is to say that in some cases the terminal velocities of composite objects may be neither additive or meditative. The point is that no *universally true* statement, or even a probabilistic one, can be made about how the terminal velocity of a composite object relates to the terminal velocities of its components. This means that Galileo's key assumption (1) is not true or probabilistic and it will vary on a case-by-case basis[49]. It is at best plausible for reasons discussed in the first section of the paper. We have note here that there are actual cases of composite objects where the Aristotelian thesis predicts well and such cases can be conceived. When this occurs, the Aristotelian will deny the Galilean claim. Now we can see why the modified thought experiment presented at the end of the first section remains open and does not provide one definite conclusion. For the same reasons, Galileo's thought experiment cannot be conclusive as well.

In this section I have considered some ways available for the Aristotelian to deny the

49 Part of the reason for this is that the composite case is under-determined, as stated in Galileo's text. With a qualification that tells the Aristotelian to make up a composite where the stones are tied together back to back, the Aristotelian will reach the Galilean conclusion. But he may still be able to respond in the ways I have suggested.

result of the thought experiment. I have also explained the way in which the Aristotelian thesis turns out true for some, albeit limited range of cases, and is unreliable elsewhere. By explaining the failings of Aristotle's thesis, I have also offered a suggestion for how Galileo's thought experiment succeeds and how it suffers from inherent limitations. This account further supports the dialectical account proposed earlier in that Galileo's thought experiment turns out to be non-conclusive and open to objection, while also providing reasons for thinking that the Aristotelian thesis is not true without qualification.

## IV

In this paper, I have argued that the Galileo thought experiment is essentially inconclusive and yet also persuasive. I have offered an alternate account that explains the persuasive power of the thought experiment based on its dialectical aspects. I have suggested that these aspects explain how Galileo is able to elicit the acceptance of his interlocutors, including us, even though his reasoning is defeasible. Specifically, the ordering of the claims as well as a seemingly innocent, less objectionable assumption, help persuade the reluctant Aristotelian. This account is borne out by an explanation from a modern, Newtonian perspective, that explains the way in which Aristotle did get something right about objects falling in a medium and how Galileo's thought experiment may succeed in showing that there are many cases that Aristotle cannot account for.

As a closing note, I present a part of the letter that Galileo wrote where he attests to the relevance of Aristotelian logic and dialectic for his practice. It tells us that Galileo knew more nuanced forms of reasoning than he is often given credit for, and that he himself recognises his debt to Aristotle on this count,

> "I think that being a true Peripatetic or Aristotelian philosopher consists principally in philosophizing according to the Aristotelian teaching, proceeding with those methods and with those true presuppositions and principles on which scientific discourse must be based, presupposing those general notions from which it would be a serious fault to depart. Among these suppositions is everything that Aristotle teaches in his Dialectic concerning the avoidance of fallacies in reasoning, guiding and leading one to syllogize
> well and to deduce from the premisses conceded the necessary conclusion; and such doctrine concerns itself [purely] with the form of correct reasoning…Up to this point, then, I am a Peripatetic.[50]"

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