4-15-2011

Galileo's Philosophy of Science

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A Thesis Submitted to The Graduate School at the University of Missouri – St. Louis in partial fulfillment of the requirements for the degree
Master of Arts in Philosophy

April 2011

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Abstract

The work of Galileo Galilei has, perhaps more than any other singular historical example, been used to support a huge variety of positions within philosophy of science. This simple fact immediately yields two questions: "what is it about the case of Galileo that lends itself to be so easily reinterpreted to fit such a wide variety of interpretations", and "what can we say with certainty about Galileo's philosophy of science?"

In this essay, I show that many interpretations of Galileo's thought suffer from very specific problems and fallacies. These in turn allow a distorted view of Galileo's work to be used to support widely disparate positions. Secondly, I argue that despite the wide variety of interpretations, there are identifiable trends in the works of Galileo that we can genuinely label as Galilean. None of these trends are unique in and of themselves to Galileo, but the particular synthesis they undergo in Galileo's work is unique and is Galileo's particular legacy.

The beginning student of philosophy of science can find in accounts of the thought and work of Galileo Galilei a maze of often contradictory interpretations. Certainly, this is true of many examples pulled from the history of science, but it has been said that there is no other single scientist, besides Galileo, in whose work even the most idiosyncratic philosopher can "with some semblance of plausibility find his own predilections or prejudices" (Finocchiaro 1976, 130). Yet for this very reason, the case of Galileo is instructional on many levels. It can function as a litmus test for burgeoning theories within the field, or as a foil for existing theories. Taken in a wider view, the Galileo case can teach us much about the use of historical example within the philosophy of science, as well as the dangers and limitations inherent in the use of such examples.

Galileo has been claimed by empiricists, rationalists, experimentalists, and even anarchists to name a few (131). What then is the aspiring historian or philosopher to think of the case of Galileo? What is it about this singular historical figure that allows for such a wide possibility of interpretation? In this paper I will argue for several distinct causes that lead to misinterpretations of Galilean thought. Partly these misinterpretations arise by confusing the historical Galileo with what has become Galileo-as-scientific-folklore, even for well known and otherwise astute thinkers.

Yet even after separating the historical figure from the Galileo of folklore, there remains considerable discrepancies in interpretations. These discrepancies also arise from misinterpretations that have identifiable causes separate from the issue of folklore. Specifically, I will examine four common problems in interpreting the work of Galileo; historical projection, confusion surrounding Galileo's relation to the traditions that came before him, a failure to take historical context sufficiently into account, and a failure to acknowledge the temporal progression of Galileo's work.

This brief list is surely not exhaustive of the ways in which Galileo can and has been misinterpreted, nor is it meant to be. Rather, I take these to be the most common fallacies, and in some cases the most insidious in that they are difficult to spot and intuitively appealing. In pointing these out, it is hoped that the reader will be better equipped to more readily distinguish viable interpretations of the work of Galileo from unsupportable claims.

Finally, there remains one final task. Once we have identified the most prevalent sources of error in the interpretation of the thought of Galileo, we are still left with an important historical question – "What, if anything, *can* we identify as being Galileo's philosophy of science?" I take it to be a fairly noncontroversial claim to state that there are clearly identifiable trends in the way in which Galileo approached science, trends for which he has received due credit. Despite the wide disparity of many interpretations, there are clearly hallmark themes in Galileo's approach toward science, and I will focus on three specifically: the role of mathematics, conceptual analysis, and experimentation. These three especially I take to be essential features of the historical Galileo in regards to philosophy of science.

None of these themes are in and of themselves unique to Galileo, and indeed, some interpreters have made the mistake of viewing Galileo as a completely radical innovator who shunned the authority of tradition.[1] This is a distortion at best. Rather, we can only avoid many of the misinterpretations discussed below if we view Galileo

[1] Such as Feyerabend, and to a lesser degree Koyre'

as an essentially progressive thinker working within a pre-classical framework. Indeed, many of his contributions were so progressive as to change the game for thinkers who came after him, and this is partially to blame for an exaggerated view of Galileo as the "father" of modern science. My central claim put forth in this essay is that what is most unique to Galileo's approach to science – and the legacy he imparted to successive generations, is not the historically inherited threads of mathematics, conceptual analysis, and experimentation, but the synthesis they undergo within his work.

This essay, then, can best be divided into four sections: first I will try to distinguish Galileo as scientific folklore from the historical Galileo. Second, I will examine four specific common mistakes in interpreting Galileo's thought that arise even when we are careful to relegate ourselves to a "folklore-free" Galileo. Third, I will outline the importance of mathematics, conceptual analysis, and experimentation for Galileo's philosophy of science. Finally, I will argue that the most important contribution Galileo made to the way science was conceived for his successors lies in the synthesis that the above three clearly identifiable trends undergo in his approach to science.

Galileo as Scientific Folklore

Surely the most common source of misinterpretation of the work of Galileo that a student of science will come across is mistaking Galileo the legend for the historical Galileo. One need not venture very far into introductory scientific literature to encounter Galileo the legend. Any introductory textbook in physics or astronomy will contain at least a cursory account of Galileo's confrontation with the Church that almost always contains some element of folklore mixed with it. The Galileo that emerges from these pages is rarely the historical Galileo. As Thomas Lessl writes, we might think of him instead as a "metonymic symbol of science's precarious position in the world, a reminder of the need for vigilant protection from unwarranted external influences" (Lessl 154).

Luckily, Galileo as scientific folklore generally falls within the parameters of certain key themes, making it a fairly easy mistake to spot. Lessl, for example, cites five common and distinct features that are identifiable as themes in the Galileo legend. These include (1) the scientist as martyr, (2) Galileo as the founder of modern science, (3) Galileo against the Church, (4) disinterested science - interested religion, and (5) the Church as anthropocentric (Lessl, 1999).[2] Finocchiaro's *The Galileo Affair* (1989) contains an excellent discussion of the last three of the above list, but for the purposes of the philosophy of science, I regard number two as the most problematic, and as having the widest repercussions in terms of a cause for misinterpretation.

That Galileo's scientific achievements marked a huge advance for what we would today consider modern science can hardly be disputed. Certainly he can even

[2] Lessl's last point being that the Church was primarily motivated by a religiously inspired anthropocentrism that sought to retain the place of importance mankind held in a geocentric universe. Of course, the truth of the matter was more complicated. Politically, the Galileo affair took part during the Protestant Reformation, and Pope Urban VIII had been seen for sometime prior to the final outcome of the Galileo affair to have been "weak" toward the protestant movement. Thus the Pope could not afford politically at this time to ignore a doctrine which countered church tradition, despite the fact that he had been a great admirer of Galileo prior to becoming pope.

be considered a turning point in the development of science. However, the relatively common claim that Galileo's innovations signify the "discovery" of modern science cannot be supported on historical or philosophical grounds. Yet it is alarming how wide spread this misconception is. While Galileo certainly initiated drastic and lasting changes to the scientific endeavor, it would be inaccurate to see him as issuing forth from an intellectual vacuum. Instead, Galileo is best viewed as being rationally progressive (Pitt 88), but still working within the context of his time.

The most surprising part of this aspect of the Galileo legend is its pervasiveness. Here are two examples from thinkers no one can accuse of an intellectual lack of precision:

> Galileo, perhaps more than any other single person, was responsible for the birth of modern science. His renowned conflict with the Catholic Church was central to his philosophy, for Galileo was one of the first to argue that man could hope to understand how the world works, and, moreover, that we could do this by observing the real world.

The above is taken from Stephen Hawking's *A Brief History of Time* (179). Likewise, the following is a quote from Bertrand Russell regarding Galileo:

> He is, therefore the father of modern times. Whatever we may like or dislike about the age in which we live, its increase in population, its improvement in health, its trains, motor-cars, radio, politics, and advertisements of soap – all emanate from Galileo (34).

In the terms of philosophy of science, this mistake can lead to both an overdependence on the Galilean case when constructing a philosophy of science, and a disregard for the historical context in which Galileo worked and of which he was a part of. Both of these mistakes can lead to distorted treatments of Galileo's contribution to scientific thought.

Yet, there is nothing preventing us from separating the fundamental elements of Galileo's thought from the scientific legend of Galileo, and many careful scholars have done so to great results. However, this is only one common source of misinterpretation. Even when we have extricated Galileo-the-legend from Galileo the man, there are still significant sources of confusion. These arise from a variety of causes, such as differences in the evidence examined, or emphasizing certain aspects of Galileo's work over others.[3] Yet there are four particular mistakes easily made in interpretation, and it is these four I want to turn to in the next section.

Problems in Interpretation

Interpretations of the historical Galileo range from emphasizing the role Galileo had in the implementation and integration of experiment and observation (Machado, Silva 2007) to claims that "to the extent that Galileo's case was successful it did not involve appealing to the results of observation and experiment, at his own admittance" (Chalmers 153). Thus, before I turn to the question of what are identifiable features of Galilean thought, I will address four fairly common sources of misinterpretation of the historical Galileo's approach to science.

The first mistake is the kind of historical projection that involves imposing upon the time and work of Galileo a modern sense of science. What we tend to think of as "science" in modern terms is very different from the "natural philosophy" of

[3] See, for example Finocchiaro 1976, 131.

Galileo's time. Confusion can arise when we try to hold Galileo to criteria that were not yet in place (such as can happen in taking as fact the Galilean folklore "father of modern science" claim).

The method of scientific observation for which Galileo would become duly famous was a work in progress during his career.[4] Yet we should not under estimate the stringency of Galileo's requirements for evidence. I think that Finocchiaro, for example, is mistaken in claiming that Galileo did not really have a philosophy of science in the conventional sense (1976, 137). Finocchiaro holds Galileo to be more aptly characterized as an "unsystematic philosopher", but surely this is at odds with Galileo's consistent application of mathematics, conceptual analysis, and experimentation, not to mention the systematic thought experiments and arguments found in his works (For example, *On Motion* or *Mechanics*).

A second mistake is the "historical context" fallacy. This essentially is a failure to take into account an accurate description of the historical context of a given case. The fallacy of misinterpreting Galileo's relation to authority recounted below can be considered an off-shoot of this problem. Thomason calls this problem part of the "missing history of science," and believes there is a strong tendency among historians and philosophers of science toward "psychological predictivism", or "the tendency to believe when presented with a hypothesis that if a phenomenon is good evidence for the hypothesis, then that hypothesis (plus unproblematic auxiliary hypothesis) predicts the phenomenon" (Thomason 323).

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4 An example of how this can distort interpretation can be seen in the interpretations of Galileo's discovery of the phases of Venus example provided below.

Consider, for example, historical interpretations of Galileo's discovery of the phases of the planet Venus. Typically this discovery is seen as a major step in proving the Copernican theory correct, and it certainly was. Yet it was not the make or break argument for Galileo's position it is usually presented to be in the literature. Briefly, it is usually argued that opponents of Galileo claimed that if the geo-kinetic theory were true, then as Venus moved around the Sun in relation to Earth, the planet would be seen to go through phases, just as the moon does. This phenomenon was not seen occur by naked-eye observations. This, it is argued, was a critical problem for Galileo to overcome for the Copernican theory to be considered viable. So much so in fact, that if Galileo could not account for this problem, his theory could safely be disregarded.

In fact, Galileo did overcome this objection through his discovery of the phases of Venus when observed through a telescope. Yet consider; rather than being the straight forward theoretical vindication it seems to be, without which the Copernican theory would have been discredited, it is in fact a stepped hypothesis. Historians usually implicitly presuppose that Galileo and his opponents assumed Venus and other celestial bodies were intrinsically dark, opaque bodies. Thomason points out that this was not an unproblematic hypothesis in the 16th century (327). Whether the heavenly bodies were internally or externally luminous was a source of debate since the Greeks. Thus, if Venus was not seen to exhibit phases, it was not a death sentence for Copernican theory. It could, after all, be self-luminous. As Thomason writes,

> Copernicus, Galileo, and Kepler all understood that there were two problematic hypothesis: (1) Venus revolves around the Sun and (2) Venus is

> an opaque, intrinsically dark body. Neither hypothesis *by itself* makes the prediction that Venus has phases like the moon. But, given Galileo's telescopic reports of the phases of Venus, an astronomer could insist that the phases were strong evidence for one of the hitherto problematic hypotheses only if he acknowledged that the observations were strong evidence for the other as well. (328).

Despite the fact that Galileo, Kepler, and Copernicus all recognized the nature of this argument, Galileo's arguments are often presented as if the phases of Venus were a predicted phenomenon of the Copernican theory, when in fact they were not. This is a particularly clear example of the historical context fallacy. Thomason imagines the philosopher's or historian's line of thinking to progress thusly: "The Copernican hypothesis *must predict* the phases of Venus – why else would the phases have been such an excellent evidence for it? Further, since the prediction is so obvious, some Copernicans *must have* made it" (330). This is a precise example of the kinds of distortions that can occur by failing to take into adequate account the historical context in which Galileo worked.

A third source of misinterpretation which can be considered a kind of off-shoot of the "historical context fallacy lies in misconstruing Galileo's relationship to the philosophies that came before him. Feyerabend, for example, saw Galileo as a radical who rejected all previous theories. He believes it was due to this radical rejection that Galileo was a successful scientist, and used this interpretation to support his anarchistic theory of the philosophy of science (Feyerabend, 130). Feyerabend does make an important point in that it is clear that Galilean arguments were not based on the authority of Aristotle or the biblical apostles, and using the case of Galileo to support empiricism certainly poses serious problems (Godfrey-Smith 113).

Moreover, there *were* at least intuitively excellent reasons for doubting the Copernican theory that were scientifically sound (Finocchiaro 1989).

To name just a few of the most obvious, the relative sizes of the planets in relation to Earth do not appear to change to the naked eye, which they would if they and the Earth were rotating about the sun. Likewise the planet Venus should exhibit phases similar to the moon if the heliocentric theory were correct and this was not observed. Similarly, there was no observation of stellar parallax which would have been predicted on the Copernican model. Also, if the Earth were a planet, like the other observable planets, it would stand to reason that the features of those planets should be similar to the features of the Earth, yet they appear not only featureless, but luminous. The telescope which Galileo used to obtained his findings was a new and relatively untested instrument. And of course, there is the matter of our senses telling us that we are not moving. Thus for the Copernican theory to be the case, our senses must be deceiving us. These are just a few of many examples of why it would have been sound on the basis of direct evidence to doubt Galileo's claims.

Certainly then, Galileo was rejecting much authority and tradition in proposing these "new" ideas. Yet the claim that Galileo rejected all authority that came before him cannot be historically supported. As Pitt points out, "in rejecting Aristotle's theory of motion, Galileo was also rejecting an entire mode of explanation. But he did not reject everything in the broader Greek tradition" (Pitt 93). For example, while it is of course true that Galileo threw out traditional Aristotelian conceptions of physics, it's also true that he relied very heavily on Archimedes and others within the classical Greek tradition (101). Moreover, I think Pitt has made a convincing case that a much more historically realistic approach Galileo is to view him as a dynamically progressive thinker.

That is, Galileo (and other early scientific innovators such as members of the Royal Society) are best viewed in a context of progressive rationality. They were "attempting to articulate a *new* view to replace the old characterization of science" (92). Essentially, I hold Drake to be correct when he argues that Galileo "agreed that in order to become science, philosophy must throw out blind respect for authority; but he also saw that neither observation, nor reasoning, nor the use of mathematics could be thrown out along with this. True philosophy had to be built upon the interplay of all three, and no combination could supply the absence of any one of them" (Drake 1957, 223-224).

Finally, a fourth source of confusion that can arise in the interpretation of the thought of Galileo when a scholar attempts to view the work of Galileo as a single whole without regard to the temporal progression of Galileo's thought. It is important to remember just how much Galileo's thought and his rational justifications for his own work developed over time, even leading in some cases to a repudiation of an earlier view.[5]

A brief summary of what we've discussed thus far: by far the most pervasive (and easily avoidable) source of misinterpretation of the thought of Galileo is confusing Galileo as scientific folklore with the historical Galileo. Yet even when this pitfall is avoided, there remain common sources of confusion. What I take to be

[5] An example is included below, in which Galileo's later views on the relative speeds of falling bodies contradicts an earlier view espoused in *De Motu*.

the four most common include transposing our criteria for what comprises “science” onto Galileo’s time, the “historical context fallacy” – essentially a failure to remain sufficiently aware of the context in which Galileo worked, a misunderstanding of the relation of Galileo to the traditions that came before him (such as Archimedean geometry), and a failure to acknowledge the temporal development of Galileo’s views.

Yet, if all of these errors are avoided, we are still left with an important question. Given that Galileo philosophy of science can and has been so prevalently and readily misinterpreted, a natural question to ask is whether or not there are any features of Galilean thought that we can with some sufficient degree of certainty accurately attribute to the historical Galileo. In fact there are readily apparent themes running throughout his work, and this is the topic of the next section.

Features of Galilean thought

Having now identified some of the more common misconceptions in characterizing Galileo’s thought within a framework of philosophy of science, we may look to what positive features of his thought we can definitely establish. Despite the above sources of misinterpretation, with careful reading there are features of Galilean thought which are easily recognizable. Most immediately apparent are three themes that run throughout his work – mathematics, experiment, and conceptual analysis.

Yet these three alone are not the entire story; we must also look to what may be the most uniquely Galilean feature of his conception of science - the intricate interplay between experiment, mathematics, and conceptual analysis. In the following sections, I will examine the role of each of these three themes within the structure of Galileo's methodology, before finally examining what can be said regarding the interplay between the three. Specifically, my thesis here is that while these three themes are easily recognizable, they in and of themselves are not unique to the Galilean endeavor. Yet when we understand the role each played individually within his approach to science, a picture emerges in which we can see what was unique, and this is the way in which Galileo combines these strands. It is this that most influenced his scientific successors.

The Role of Mathematics

For Galileo mathematics (and geometry in particular) played a pervasive and crucial role, serving as a kind of metaphysical basis for his scientific endeavors. Mathematics was foundational, and here again we see his appreciation for antiquity. He writes "If I were again beginning my studies, I would follow the advice of Plato and start with mathematics." Like Kepler, Galileo saw mathematics as the key to understanding the language of nature. He was no doubt influenced by Pythagorean and Neo-Platonic thought (Derry 61). The following famous quote illustrates the degree of importance Galileo placed on geometry:

> Philosophy is written in this grand book the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and to read the alphabet in which it is composed. It is written in the language of mathematics, and its characters are

> triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth (Galileo 237-38).

It is easy to find throughout the thought of Galileo this use of mathematics as a kind of basis upon which to build and organize the remainder of his conceptual work. The recognition of the importance of the role mathematics played for Galileo has been a key starting point for many authors dealing with his work. Pitt, for example has argued that for Galileo, geometry served as a "touchstone for certainty in a world of infinite variation and magnitude that he has been partially responsible for bringing to our attention" (96). Geometry was the unchanging universal constant truth against which his exegesis could explain the results of experimentation. It thus provided the metaphysical foundation for his philosophy of science. To the degree that Galileo was convinced of the rationality of his method, it was due to his use of geometry (101).

Conceptual Analysis

Conceptual analysis and explanation were equally crucial for Galileo. Indeed, it is in his conception of what a proper explanation of physical phenomena entailed that was one of the most important parts of his legacy. His theory of conceptual analysis involves both a geometric proof (the language of the Universe), and an explanation which accompanies and interprets it. In a sense, we might think of Galileo's conceptual analysis as serving a mediating role which brings the universal truth of geometry to the realm of concrete empirical knowledge.

If mathematics served for Galileo the function of a "touchstone for certainty in a world of infinite variation and magnitude," then conceptual analysis and explanation were a way of bringing the truths written in mathematics more directly into understanding; that is, explanation expounded on mathematical truths and made them more fully graspable. Thus we find Galileo writing, "Facts which at first seem improbable will, even on scant explanation, drop the cloak which has hidden them and stand forth in simple and naked beauty."

On this view Galileo is essentially an explanationist for whom a hypothesis is justified by having suitable explanatory power. Consider, for example, Galileo's discoveries related to pendulums. His chief contribution here was the claim that the period of swing of a pendulum was independent of its amplitude. This hypothesis is justified in that it adequately explains the observed phenomena, and can be expressed mathematically, in that the square of the period of swing varies directly with the length.

The importance of explanation and conceptual analysis for Galileo has led some philosophers to undervalue the role of experimentation for Galileo. One striking example would be Alexandre Koyre who went so far as to write that "It is obvious that the Galilean experiments are completely worthless: the very perfection of their results is a rigorous proof of their incorrection" (Koyre 1968, 94). This was in reference to Galileo's famous experiments using an inclined plane (see below). This surely goes too far, however. While it is true that much of Galileo's work in this area can be considered something of a thought experiment, Galileo *did* indeed perform experiments on incline plains, and these results did inform his theories.

The above case of his work with pendulums is an even better example. Galileo posited that the period of swing of a pendulum was isochronous and independent of its amplitude. Neither of these claims are strictly true. The period of swing does vary somewhat with the amplitude of the swing. Yet the results are still too accurate to justify throwing out the experiment altogether as worthless. It would be more accurate to say that the periods differ very little. So little in fact, that Galileo's observations led to the development of vastly improved time keeping devices, some of which (the familiar grandfather clock) we still use.

Yet it is true that often Galileo's experiments are more thought experiment than empirical in nature. Moreover, there is a valid question we might ask here – given the role of mathematics and conceptual analysis for Galileo, where does experimental data fit in to the picture? Maarten Van Dyck frames this as what he calls the "paradox of conceptual novelty." That is, "where do Galileo's new concepts come from, if they cannot be abstracted from experimentally established regularities? Whence conceptual novelty?"

I would argue that Van Dyck's use of the phrase "conceptual novelty" can be misleading here, as it lends itself to the fallacy outlined above of failing to take into consideration the historical framework in which Galileo's work takes place, but I am happy to agree with him that what is "novel" about Galileo's work is his ability to produce theorems in terms of classical mechanics using a pre-classical conceptual apparatus (Van Dyck, 866). The point is again simply that Galileo's work did not arise from a historical vacuum. Yet his theorems were radical enough that for those that came after, that it could easily seem as though they were a clean break from the historical framework in which they arose. Damerow writes,

> Thus, while for the first discoverer, the law of free fall is achieved by applying and modifying an independently grounded, pre-existing conceptual system, for his disciples it is the law of fall that canonically defines key concepts in a new conceptual system. The very same reading of these theorems that establishes classical mechanics also obliterates the traces of its real historical genesis because the original problems that the concepts involved are now understood within a very different theoretical and semantic framework. But since the successors themselves derive the inherited theorems on the basis of the new concepts, they impute these concepts to the discoverers. (Damerow et al. 2004, 5)

In essence, Galileo was developing his science contemporaneously with a pre-classical conceptual system, and it did represent a break with that system for thinkers that came after him.

The Role of Experimentation

Finally, we turn to the question of exactly what role experimentation did play for Galileo before discussing how mathematics, conceptual analysis and experimentation synthesize into a whole. While it is certainly going too far to say that Galileo's experiments were worthless, it is fair to say that many experiments (such as those in which he abstracts from a perfectly smooth inclined plain) never were, nor could they ever be, perfectly performed in reality before Galileo reported results. Yet this is not to say that Galileo did not perform any experiments. In fact it seems he held experimentation to (at least some of the time) be a starting point for inquiry, writing, "I think that in the discussion of natural problems we ought to begin not with the Scriptures, but with experimentation and demonstration."

In his experiments on the speeds of falling bodies, Galileo eventually observed that bodies of different weights falling in a semi resistant substance such as water fall at different speeds. He realized that this variation was a result of the differing densities of the objects reacting to the resistance of the medium through which they passed, since he had already established that, contra Aristotle, falling bodies of different weights will still fall at the same speeds. This led him to ask, what would happen if two bodies were to fall in a perfect vacuum, with no resisting medium at all.

After seeing that objects with varying densities pass through liquid at varying speeds, he notes that "Having observed this I came to the conclusion that in a medium totally devoid of resistance all bodies would fall at the same speed" (Galileo 116). Obviously, Galileo could not have performed experiments in a perfect vacuum, but it is important to note that he is not only here contradicting Aristotle, but also his own earlier view in his work *De Motu*. Van Dyck points out that in this earlier work, Galileo had modeled the phenomenon of free fall on hydrostatic phenomena, claiming that the speed of a falling body is proportional to the difference between its specific gravity and the medium's specific gravity… This model would imply that in a void, the speeds of different bodies would stand in the same ratio as their specific gravities, and that the differences in speed should become less perceptible in more resisting media. (869)

In essence, Galileo's later view has been constrained by empirical information, and it is in this that we can most clearly see the role that experimentation played for Galileo. While his experimental program may not have been what we would today call purely empirically derived, it nonetheless did serve a function toward conceptual analysis that was sometimes constraining in nature, and sometimes informative.

The above account of the evolution of Galileo's views about the speeds of falling bodies in a vacuum is an example of how experimentation served a constraining role on explanation, in that we emerge with a picture in which Galileo contemplates bodies falling in a pure vacuum and derives results. While these results are an extrapolation, there is some empirical evidence for why the conclusion of this extrapolation might be the case. This is why Van Dyck states that in using extrapolations as empirical evidence, Galileo "has shown how to separate the pure phenomenon from possible disturbances, how to retract a meaningful signal from the noisy actual behavior. To put it in a language relevant for the discussions on conceptual novelty: Galileo has experimentally secured the reference of his theoretical models" (871).

This is surely a debatable claim, yet the point stands that while many of Galileo's "experiments" were certainly not strictly empirically accurate (consider the variation of pendulums swings, are the impossibility Galileo of actually performing an experiment on falling bodies in a vacuum), Galileo had enough evidence from actual experiments to draw a general conclusion or principle. That is, he had enough evidence to "secure a reference" for his theoretical models. My argument here is that this view of experimentation as serving a constraining or informative function is the best way to view its role in relation to the previously discussed features of Galilean thought – mathematics and explanation.

<u>Synthesis</u>

We can now point to three distinct features of Galileo's conception of science – specifically, mathematics as a touchstone for certainty, experimentation, and conceptual analysis. I would argue that what is historically unique about Galileo's approach is the synthesis of these three features. Indeed, my supposition is that if we are to seek what was most unique in Galileo's approach to science and what feature of this approach was most influential for his successors, it is in the interplay between these three themes that we must look. It is the pairing of mathematical reasoning with experiment and observation that was Galileo's chief contributions to the way science was to be conceived in the 17th century. Consider, for example, his discovery that $d_1/d_2=t_1^2/t_2^2$: that distance is proportional to the square of time, $d=k \, X \, t^2$ (Gower 1997, 937).

Briefly, Galileo claimed that an object's speed increases as it falls, but the rate at which it increases in speed stays constant. Thus a falling body gains equal amounts of velocity in equal amounts of time. To test this Galileo replaced falling bodies with balls rolling down an inclined plane, writing "In order to make use of motions as slow as possible ... I also thought of making moveable objects descend along an inclined plane not much raised above the horizontal" (Galileo, 1954). This allowed him to measure the velocity of the balls indirectly by measuring the distance a ball would travel over a set amount of time. The square of the time needed for the ball to complete its journey was then shown to be proportional to the distance it travelled. So if a ball were released down a sloped plane and travelled for three seconds, it would travel 9 times as far as it would have if it had been stopped after only one second of travel (Hewitt, 155).

In fact, much can be said about this particular discovery as an example Galileo's philosophy of science. In essence, for Galileo, results are to be framed geometrically, as a harmonious equation is the surest sign of certainty and correspondence with reality. Yet this somewhat theoretical mathematical framework or sketch must be explained by a conceptual analysis that admits of empirical correspondence. This is especially evident in the *Dialogue*. Indeed, Pitt holds the *Dialogue* as containing the heart of Galileo's philosophy of science. He writes "if we read the *Dialogue* as an articulation of a new view of justification as explanation and simultaneously as a defense of Galileo's own approach to explanation, we will also be able to account for what, on more standard interpretations, appear to be tensions and conflicts within Galileo's work" (90). He regards the geometric aspect of the proof as an "explanatory sketch" which can be "filled in by appeal to empirical correspondence" (100).

On this view, Galileo's philosophy of science arises from the interplay between the identifiable aspects of the thought of the historical Galileo. Not only does it provide an adequate account of the role of mathematics, it does not at first glance fall prey to any of the identifiable mistakes discussed early. Moreover, it connects the role of Galileo's exegesis and experimentation with his use of mathematics as a metaphysical base.

Furthermore, this conception of the interplay between mathematics, conceptual analysis, and experimentation retains the innovative nature of this system of thought without having to label Galileo an intellectual anarchist or ignore his historical influences. As Pitt notes, "since the use of geometry as an appropriate tool for describing the heavens was not disputed, and since geometry was equally well accepted for terrestrial purposes, Galileo did in fact have the foundation for a unified general theory. By appeal to the traditions of both Ptolemy and Archimedes he also had authority behind him" (101).

In conclusion, the case of Galileo has much to teach about the role of historical example within the philosophy of science. Certainly we cannot discount case studies such as this from significant theories within the field. That is, we would expect any viable philosophy of science to be able to give an adequate account of Galileo's innovations (Chalmers 142). Yet there are dangers in relying too heavily on historical examples to develop a philosophy of science, especially if there is an over-reliance on a single historical example.

Case studies within the philosophy of science can also pose methodological problems. The fact that Galileo has been used to support such a wide range of divergent views within the field is proof that focusing on case studies presents the danger of only selecting those historical examples which tend to support favored theories (Vicedo 492). Yet these methodological problems can be avoided by carefully balancing scholasticism with historical context and by recognizing that any single case study is part of a wider class of historical occurrences. No one example can provide sufficient evidence for a philosophy of science.

An understanding of the outline of the history of science is indispensable to the philosophy of science, though not exclusively so. Science, after all, is a historical enterprise, and theories historical entities. Marga Vicedo sums this point up concisely when she writes “Our epistemic values and our understanding of the world are the results of the contingent facts of history. This is why the history of science is relevant to the philosophy of science. After all, in history we may find reasons that logic alone cannot show us” (Vicedo 495).

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