Vincenzio Renieri and the Law of Falling Bodies

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Introduction

The first appearance of the best known story about Galileo appears twelve years after his death in 1657. His biographer, Viviani recollects what Galileo told him during his final years of blindness, "…speeds of unequal weights of the same material…did not preserve the ratio of their heavinesses assigned to them by Aristotle, but rather, these all moved with equal speeds, he showing this by repeated experiments made from the height of the Leaning Tower of Pisa in the presence of other professors and all the students" (Viviani, 1657). This passage has been treated as legendary with many variations embellished in handed-down children and adult books about the life of Galileo (Drake p. 20). Contemporary Galilean authorities have largely refuted the Leaning Tower demonstration as "mainly the product of many writers' lively imaginations" (Martinez, p. 2). One key exception is the historian Stillman Drake, who holds that a missing letter written from Galileo to his follower at the University of Pisa, Professor Vincenzio Renieri,[1] "would provide definite evidence to the contrary" (p. 415). This essay makes a case for the contents of Galileo's missing letter based upon his (Renieri's) return letter.

At the age of seventeen Vincenzio Renieri went to Rome, in 1623, to become a priest in the Olivetan Order (Drake, p. 464). Father Renieri soon developed profound curiosities for natural philosophy with special interests in mathematics, astronomy, poetry, and Greek translations into Latin. All of this led him to the University of Siena where he first met Galileo in 1633. It was in this same year that Galileo was convicted of "vehement suspicion of heresy" by the Roman Inquisition for his writings about the Eucharist and heliocentrism (Redondi, p. 203). The punishments included imprisonment at the

[1] The role of Vincenzio Renieri (1606-1647) in this historical debate became personally intriguing when a geneaology of my mother's side of the family (Liliana Renieri) listed him as secretary to Galileo and professor of mathematics and astronomy at the University of Pisa.

pleasure of the Inquisition, but due to his fame and for medical reasons including failing eyesight, Galileo's sentence was commuted to “house arrest” at his villa in Arcetri in Florence (Finocchiaro, p. 23).

Also in 1633, Vincenzio Renieri became the Chair of the Mathematics Department at the University of Pisa, a position Galileo held nearly forty years earlier. Renieri made the commute to Florence to visit his mentor when possible. It was rather unusual for a priest to concur with Galileo’s impatient interpretation of ancient Greek writings by Aristotle, that he had derided Pythagorean knowledge not with mathematical demonstration, but with inane reasoning and moralistic conjecture. Galileo entrusted Renieri with the tedious job of updating astronomical tables predicting the positions of Jupiter's four moons, and using them as a celestial chronometer for the measurement of longitude (Drake p. 413, and de Santillana, p. 148). By 1637 Galileo had become completely blind and in 1639 was granted the assistance of Vincenzio Viviani to complete his memoirs. From then until the end of Galileo's life, his communications to Renieri were dictated by Viviani.

The level of comfort in communications between Renieri and Galileo (ie. his biographer) is found in a letter from February 5, 1641. Renieri informs, "Not infrequently I am in some battle with the Paripetetic [2] gentlemen, particularly when I note that those fattest with ignorance least appreciate your worth, and I have just given the head of one of those a good scrubbing" (Drake, p. 413-4). One goal that emerged among natural philosophers at 16th and 17th century universities was to find ways to empirically test the reasoning of recently translated ancient Greek scholars like Aristotle. Renieri apparently held the same impatience with the old scholars at Pisa as Galileo, but to be fair, many opponents of Aristotle during the Renaissance mistranslated his writings and created historical anachronisms (Cooper 40-43).

[2] Paripetetic's were those who continued to follow the ancient teachings of Aristotle in the face of Renaissance period “experience and demonstration” based empiricism.

On March 13, 1641, Renieri sent a letter to Galileo requesting his interpretation of two experiments regarding Aristotle's statements that heavier objects always fall faster than lighter objects.

> We have had occasion here to make an experiment of two heavy bodies falling from on high, of different material, that is, one of wood and one of lead, but of the same for a certain Jesuit wrote that these fall in the same time and arrive at the earth with equal speed, and an Englishman affirmed that Liceti had made a problem here and offered the reason. But finally we found the fact contrary, because from the top of the campanile of the cathedral there were at least three braccia of difference between the lead ball and the wooden one. Experiments were also made of two lead balls, one the size of an ordinary cannonball and the other that of a musket bullet, and it was seen that between the larger and the smaller, from the height of the campanile, the was a good palmo of difference by which the larger anticipated the smaller. What I noted in these experiments was that it seemed to me that the motion of the wooden ball, having accelerated to a certain point, then began to fall not vertically but transversely, in the same way as we see drops of water that fall slantingly, which, coming near the earth, turn sideways, whence their motion begins to be less rapid (Drake, p. 414).

Renieri was confused because in both of his experiments the objects failed to land at the same time. He believed this to be in conflict with his colleagues who said they would land at the same time, and Aristotle who he thought said there would be large differences proportional to their weight. For most modern observers it is surprising that Renieri failed to consult or site the literature of his time, but this was not uncommon prior to the flowering of Cartesian scientific method and the spread of printed word. Results of experiments were often spread by word of mouth resulting in a plethora of variables when replicating original experiments.

As early as 1544, Florentine historian Benedetto Varchi contradicted Aristotle reporting that heavier objects do not fall faster in proportion to their weight (Martinez p. 4). Perhaps better known to Galileo was an experiment conducted in 1576 by Giuseppe Moletti, a professor of mathematics at the University of Padua. Moletti provided a detailed account of two balls of lead one weighing twenty pounds and the other of one pound arrived at the same time from a tower (Martinez, p. 5). He also found that a ball of wood landed at the same time as a lead ball of the same size. Perhaps the most well known report was by Simon Stevin and Jean Grotius of Bruges, who published a much earlier experiment in 1605. They found that when they dropped one ball weighing ten times the other from 30 feet they landed “so equally with the other that they sound of the two in striking will seem to come back as one single report Cooper, p. 79). In 1597, Galileo’s predecessor at Pisa, Jacopo Mazzoni wrote that a wood ball landed ahead of a lead ball dropped from his apartment window (Reston, p. 30). Giorgio Coresio, a professor of Greek, reported in 1612 that a whole body fell faster than a separate piece of it from the top of the Leaning Tower of Pisa (Martinez, p. 7). Coresio was critical of the experiments of others before him believing they had not dropped test weights from sufficient height. None of these authors make mention of Galileo’s experiments with falling bodies or his views on the subject.

According to Galilean researcher Stillman Drake, after Galileo received a letter on March 13, 1641 from Renieri, he would have been prompted to tell his biographer about his Leaning Tower experiments, presumably from the time he was a Professor at Pisa in 1590. Lane Cooper's exhaustive investigation of Galileo's writings and those of others during this era failed to provide verification of his experiments at the Leaning Tower of Pisa (1935). If professors and students were in attendance at such a repeated popular demonstration someone would have written about the event. Lane Cooper suffered strong criticism for his publication on this subject but most authorities find him correct. Many children and adult storybooks continue to perpetuate incorrect conclusions about undocumented experiments by Galileo at the Leaning Tower of Pisa.

The legend evidently gained a measure of verisimilitude based on unpublished writings found in *The Motion,* a manuscript he began to work on in Pisa in 1590. Galileo did conduct experiments from “a high tower” in Pisa. These writings were not published until long after Galileo's death. A passage from *The Motion* says,

> If the large amount of air in wood makes it go quicker, then as long as it is in the air the wood will move ever more quickly. But experience shows the contrary; for, it is true, in the beginning of its motion the wood is carried more rapidly than the lead; but a little later the motion of the lead is so accelerated that it leaves the wood behind; and if they are let go from a high tower, precedes it by a long space; and I have often made test of this (Cooper 54-55).

This is in direct opposition to the legendary story purported by Viviani where Galileo found two falling objects of different weight landing at the same time. Galileo provides no other details about the types of objects, their size, their weight, or the height or location of a "high tower." Galileo's results are not in disagreement with Aristotle, but he argues that the speed of the falling objects is proportional to their density and not their weight. He adds, "What moves moves, as it were, by force and by extruding action of the medium" (Drake, p. 22). Galileo could not make a mathematical explanation and decided not to publish his experiment. He wrote that these experiments could only be accurately understood free from the external friction of air in a vacuum. Since *The Motion* had not been published, Renieri at best could only have been told by Galileo of his mentor's thinking.

Galileo received a letter from Renieri on March 20, 1641 that strikes an apologetic tone in response to the missing letter Stillman Drake finds critical to the historical narrative.

> Your last Dialogue [*Two New Sciences*] has been read by me only here and there because last summer, when I might have been able to attend to this with due diligence, you know how I was; and later I did not have time look at it with the application required by its demonstrations. I know it is true that two bodies of different specific weight, though equal in volume, follow no ratio of weights in [their] descending, and indeed that for example, in water, wood will move opposite to lead; hence from the outset I laughed at the Jesuit's experiment, who affirmed that lead and a loaf of bread would be moved unequal in weight, of the same material, falling vertically from the same height, can arrive at the center with different speeds and at different times seemed impossible, as I had heard said you, or had read, for indeed I do not recall which. Therefore I shall read in these few days of [Easter] vacation your last Dialogue, though I reserve complete reading to the next summer with more leisure. Meanwhile we shall return to making the experiment of the wood balls and see if we were mistaken in the observation that when they near the ground they turn and do not go vertically, and I will give you notice of this (Drake p. 415-416).

It is surprising that Renieri had not read pertinent parts of *Two New Sciences* prior to conducting his own experiments because he had a personal copy of the surreptitiously published book in 1638 (Redondi, p. 234). Galileo wrote *Two New Sciences* in persuasive Italian prose in order to reach the public. There is mention of experiments with falling bodies in two different sections of the book. The first is in the Platonic section where Galileo expressed his theory of falling bodies by means of an imagined conversation between three characters: Salviati, a spokesman for Galileo; Simplicio, who represents a younger Galileo accepting of Aristotelian physical laws; and Sagredo, an intelligent layman who might be persuaded by the best argument. Here is an example of their debate:

> Salviati: I greatly doubt that Aristotle ever tested by experiment whether it be true that two stones, one weighing ten times as much as the other, if allowed to fall at the same instant from the height of, say, 100 cubits[3] would so differ in speed that when the heavier had reached the ground, the other would not have fallen more than 10 cubits.
> Sagredo: I, who have the test, can assure you that a cannon ball weighing 100 or 200 pounds, or even more, will not reach the ground by as much as a span ahead of a musket ball weighing only half a pound...
> Simplicio: Your discussion is really admirable; yet I do not find it easy to believe that a bird-shot falls as swiftly as a cannon ball.
> Salviati: Why not say a grain of sand as rapidly as a grindstone? But, Simplicio, I trust you will not follow the example of many others who divert the discussion from its main intent and fasten upon some statement of mine that lacks a hairsbreadth of the truth, and under the hair, hide the fault of another that is as big as a ship's cable. Aristotle says that an iron ball of 100 pounds falling from a height of 100 cubits reaches the ground before a one-pound ball has fallen a single cubit.' I say that they arrive at the same time. You find, on making the experiment, that the larger outstrips the smaller by two fingerbreadths....now you would not hide behind these two fingers the 99 cubits of Aristotle, nor would you mention my small error and at the same time pass over in silence his very large one (Bixby, p. 28).

The first problem with Galileo's discourse is that Aristotle never wrote that he did such an experiment, and it therefore led to unfounded modern citations (Cooper, p. 41). The second is, as with *The Motion*, there is no mention of The Leaning Tower of Pisa. The discourse infers that someone, Sagredo, conducted experiments with falling bodies and found a slight difference in the landing times of two objects of different weight and not the large amount specified by Aristotle. Galileo's knowledge of the topic, as represented by Salviati, says falling objects landed at the same time. The now more vexing problem is how *Two New Sciences* contradicts what he recorded in *The Motion* when an unspecified object of wood and one of lead was dropped from a high tower resulting in the wood object starting out ahead but the lead object landing far before the wooden one.

[3] A cubit is the distance from the elbow to tip of the middle finger. One cubit is about 20.6 inches. 100 cubits is about 171 feet. The top of the Leaning Tower of Pisa is 183.27 feet.

Galileo naturally had a better grasp of the subject in later years and neglects to bring up his earliest experiments at Pisa. In the Platonic section of *Two New Sciences,* it appears that Galileo is refuting Aristotle in a generalized sense. That is, based on the fact that sometimes objects of different weights land at the same time, and at other times they do not, but in any case, never in the proportions he believed Aristotle deemed true.

In the much less vague experimental section of *Two New Sciences*, Galileo reports that he rolled differently weighted bronze balls down an inclined wood ramp. By changing the degree of incline Galileo was able to measure rates of acceleration. Using a modified version of the Egyptian water clock to measure time, Galileo figured out that the rate of acceleration was the same for an object that falls straight down as it is for any one that moves forward (horizontal) and down (vertical) at the same time (Bixby, p. 33). Once this equation is coupled with mathematical consideration for the resistance of air on differently shaped and surfaced objects, later scientists were able to formulate the mathematical law of falling bodies.[4]

These two pertinent sections of *Two New Sciences* are what Galileo undoubtedly expected Renieri to read. Reading these sections would not only potentially help Renieri understand his results at the Leaning Tower, but cause him to look more closely for deflection of a wooden ball in further experiments. It seems doubtful the missing letter from Galileo to Renieri would have contained specifics about his methodology at a 'high tower' in 1590 since *Two New Sciences* adequately explains his view of the concept without need for details about his older confounding unpublished results in *The Motion*. It does seem plausible that Galileo discussed these early experiments with his biographer in light of Renieri's letter as Drake believes. The eventually comes out as the embellished legendary Leaning Tower of Pisa experiment along with several other errors made by his biographer written twelve years after Galileo's death (Martinez, p. 8-9). Whether it was Viviani's exaggeration, or Galileo's, the "high

[4] Thomas Bradwardine, an Oxford English scholar of the early 14th century, had come to a similar mathematical conclusion as Galileo two-hundred years before him.

tower" falling bodies experiments in 1590 were not repeated often and did not receive the public fanfare held in Viviani's account. We must accept that it is a human tendency to make things interesting with additions or twists to the story especially years after the fact.

To the modern day observer, it is easy to conceive that Galileo would have conducted outdoor experiments at the Leaning Tower of Pisa since it is close to the University and offered an ideal place to push objects off without hitting the side of the building. The top of the Leaning Tower is within twelve feet of the height Aristotle is alleged, by Sagredo in *Two New Sciences,* to have conducted his falling body experiments. Probably the best argument for using the Leaning Tower is that it was the highest tower available in Pisa. As early as 1590 for Galileo, and for others to follow, there is concern that plenty of space is needed to witness the loss or gain of speed of experimental falling bodies (Cooper p. 87, 90). It is hard to explain why Galileo would not have mentioned a specific tower and its height used in his own experiments in light of the precise height description given for his thought experiments regarding Aristotle in *Two New Sciences*. It is doubtful that he would have been told by Church officials not to use the Leaning Tower, that he would have wanted to avoid having others use the tower to verify his results, or that he would have forgotten where the event took place. Without documented evidence the correct historical conclusion is that Galileo did not use the Leaning Tower of Pisa for his experiments.

Renieri's observations of Jupiter's moons remained unpublished at the time of his sudden premature death at Pisa on November 5, 1647 (Drake, p. 464). Renieri's additional research on longitude, also entrusted to him by Galileo shortly before he died on January 8, 1642, were said to have been stolen by Agostino when Renieri died, but were rediscovered two-hundred years later (Fahie, pgs. 374-375). That Galileo entrusted Renieri with his unfinished research papers creates a unique place for Vincenzio Renieri in the history of science, and lies at the heart of Galilean myth. As a priest, Renieri was willing to take personal risk to carry on Galilean experimental tradition and philosophical discourse.

These events offer Socratic irony by virtue of Renieri's unwitting creation of the impetus for a Galilean myth forged by Viviani based on his (Renieri's) experiments at the Leaning Tower of Pisa.

Galileo was able to predict the distance objects traveled through air as a perfect mathematical square before the invention of derivative mathematics or vacuums to test his hypothesis. His results were refined by later 17th century mathematicians such as Sir Isaac Newton and found to be useful in predicting the distances traveled for flying projectiles.

One of the craters on the moon, called Renier,[5] was recently named in honor of the short-lived priest and natural philosopher, Vincenzio Renieri. One is left to contemplate what Renieri could have accomplished in science if he had lived a full life like Galileo and been allowed to collaborate more freely with his old master. In cases of science fiction, and proven scientific endeavor, Galileo and his colleagues were the sources of thought that altered our self-centered views of the cosmos.

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[5] Vincenzio Renieri's also went by the following given-name of Vincentio, and the surnames, Reiner, Reinieri.

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