Hendrick Uwens: *Tratado da Estática*

Lisbon, 1645

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Commentary

Teaching Galileo's Experiments in 1640s Portugal

In 1638, five years after the famous trial by the Roman Inquisition, Galileo Galilei (1564–1642) published his final thoughts on physics in the book *Discourses on the Two New Sciences*.[1] This episode is about one of the first cases of Galileo's book being taught in a classroom setting. The source that you read and heard is an excerpt from class notes written in 1645 on Galileo's hydrostatics experiments. What is striking about it is that it shows Galileo's experiments being taught so soon—less than ten years after their publication—and in Portugal, which is not often considered one of the centers of scientific production in the early modern period. Moreover, the experiments were taught in Portuguese, and not in Galileo's original Italian and Latin. These notes thus show that Galileo's experiments were explained and adapted to a new audience from very early on.

The teacher of the class was Hendrick Uwens (1618–1667), who later became a missionary to the Mughal Empire in northern India. Uwens was born in Nijmegen in 1618 and entered the Society of Jesus in 1634. The Society of Jesus was then one of the leading and most recently founded religious orders of the Catholic Church, and its members, known as the Jesuits, underwent an intense and rigorous academic education in the liberal arts. In 1641—seven years after Uwens joined the Society, and three years after Galileo published his book in Leiden—Uwens left the Low Countries for the port of Lisbon, Portugal.

At the time, all Jesuit missionaries in Asia, regardless of their nationality, had to board a ship in Lisbon. But once there, instead of boarding a ship to Goa, Uwens was asked to

[1] Antonio Favaro (ed.), *Le opere di Galileo Galilei*, 20 vols. (Florence: Barbèra, 1890–1909), 8:39–318. English translation: Galileo, *Dialogues Concerning Two New Sciences*, trans. Henry Crew and Alfonso de Salvio (New York: Macmillan, 1914).

teach mathematics at the Portuguese Royal Academy of Mathematics, also run by Jesuits. It is important to note that by "mathematics," I mean what was understood as such in the early modern period; this included pure and mixed mathematics. Pure mathematics consisted of disciplines such as geometry and arithmetic, whereas mixed mathematics dealt with topics such as astronomy, optics, and statics. Uwens's class was on the mixed-mathematical science of statics, which at the time also included subjects that we now associate with classical physics, such as the calculation of centers of gravity, mechanics, and hydrostatics.

Galileo's 1638 treatise *Two New Sciences* was the culmination of several scientific developments on precisely these topics. Indeed, despite all of Galileo's work on astronomy and Copernicus, it was his *Two New Sciences* that constituted his greatest legacy in the history of physics. That is why it is worth taking a more careful look at this book and its dissemination in early modern Europe. In *Two New Sciences*, Galileo developed new ideas and concepts that all students of physics today have to study. He described the law of free fall, developed a new understanding of the relativity of motion, and explained the motion of projectiles using mathematics. In the words of the physicist Stephen Hawking, Galileo's contributions even "anticipated Isaac Newton's laws of motion."[2]

Yet Galileo's findings were much broader than that. In *Two New Sciences*, Galileo also wrote on hydrostatics, the corpuscular theory of matter, and the science of materials. Interestingly, the historian of science Renée Raphael has recently shown that these topics, and not the motion of objects, were the ones considered the most important by many of Galileo's readers in the seventeenth century. Research on the reception of these parts of Galileo's physics is recent because the readers of Galileo's writings on hydrostatics and so on were mostly Aristotelian philosophers. Since Galileo put himself at odds with Aristotelians, historians often failed to note that they were among the first to engage with his new ideas.

Many of Galileo's earliest readers were Jesuit natural philosophers, who discussed Galileo's theory of matter in their classes on Aristotelian natural philosophy. Their reading of Galileo was in line with Scholastic and humanist methods of scholarship, which were heavily textual, carried out in Latin, and not experimental. Galileo's own approach and rhetoric was very different—he favored novel, empirical methods, such as performing new experiments, and rejected the epistemic use of the texts of Aristotle and his commentators. Nevertheless, there is evidence of Jesuit teaching of Galileo's *Two New Sciences* as early as the 1650s, at a class of natural philosophy in the Jesuit Collegio Romano, Rome. The teaching there followed the traditional methods of Aristotelian scholarship, in the sense that it relied on conclusions drawn from the texts of Aristotle and his respondents, including Galileo. Indeed, the professor placed Galileo's ideas on par with those of other Aristotelian commentators, quite contrary to Galileo's goals.

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[2] Stephen Hawking, *On the Shoulders of Giants: The Great Works of Physics and Astronomy* (Philadelphia, PA: Running Press, 2003), 397.

Moreover, he paid less attention to Galileo's experiments than to his conclusions, reflecting the scant epistemic value his readers accorded to experimentation. (That Galileo was read in this way confirms what historians have long known: Galileo was in fact much more deeply embedded in the Aristotelian tradition than he himself admitted.)

The class notes I discuss in this episode present a very different case, offering us new insights into the early reception of Galileo's hydrostatics and theory of matter. First, they show a Jesuit teaching Galileo's *Two New Sciences* more than five years before the Collegio Romano classes. Second, the book was taught in a class of mathematics and in Portugal, a very different context from a class of natural philosophy in Rome.

This particular institution for the teaching of mathematics, in Lisbon, was first designated as the "Class of the Sphere," taking its name from Johannes de Sacrobosco's textbook of astronomy *De sphaera* (ca. 1230), which was widely commented on in the sixteenth century. The name soon changed to the "Royal Academy of Mathematics," bearing witness to the Crown's interest in the school and in mathematics. The classes were taught in Portuguese in order to reach an audience of upper-class citizens who barely knew Latin and were not necessarily interested in humanist scholarship. Their interest in mathematics derived from practical applications in areas such as navigation, astronomy, military arts, and mechanics—all disciplines that were part of early modern mixed mathematics.

The course taught by Hendrick Uwens was one of the most important classes on mechanics in early modern Portugal, not only because he taught such up-to-date ideas on mechanics, but also because he left all of his notes, written in the vernacular. They were assembled to form one of the first mechanics textbooks written in Portuguese. The 400-page "Tratado da Estática" (Treatise on Statics) is extant in two manuscript copies from 1645 and derives directly from Uwens's teaching notes. One copy is signed by a famous Portuguese architect, suggesting that the treatise was used to teach mechanics to architects and engineers in Portugal in the second half of the seventeenth century. The fact that the treatise was never printed does not mean it did not circulate, but indicates the continuing importance of manuscript copies in the development of early modern science. Despite its very particular pedagogical context, the book is structured like other early modern mathematical treatises, with propositions and corollaries.[3] It is divided into five major parts: centers of gravity, mechanics, hydrostatics, aerostatics, and military arts or "pyrostatics."

Uwens's notes mention several important authors on mechanics, including Simon Stevin (1548–1620), perhaps the most famous mathematician of the Netherlands at the time, and the Jesuit François d'Aguillon (1567–1617), who founded the first Jesuit school of

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[3] On mathematical treatises, see Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago: Chicago University Press, 1995).

mathematics in the Low Countries. Strikingly, Uwens never mentions Galileo. Perhaps this was because Galileo published the *Two New Sciences* despite being prohibited by the Roman Inquisition from publishing more books. So how do we know that Uwens was writing about Galileo?

The answer lies in the first chapter of the part on hydrostatics. Before introducing the Archimedean propositions on buoyancy, Uwens addresses the question of the viscosity of water. He mentions three experiments on the thickness of water, which are the ones described in the excerpt I have presented and which Galileo also mentions in *Two New Sciences*.

Galileo argued that water is not viscous, and that this could be demonstrated with two simple experiments; Uwens makes the same argument with reference to the same experiments. A summary of Galileo's *Two New Sciences*, published in French in 1639 by the French mathematician and Catholic monk Marin Mersenne (1588–1648), also included reference to these two experiments, and since Mersenne was in good standing with the Church, Uwens could have read and quoted from his book without encountering any problems—yet the Portuguese experimental descriptions written by Uwens show that he was drawing directly from Galileo.

The experiments consist in varying the salinity and temperature of water to make a ball of wax rise or descend inside the water. Given that very slight variations in the density of water caused the wax ball to rise or sink, Galileo—and Uwens after him—concluded that water's viscosity is an absurd idea. In his version, Mersenne did not provide any measurements, whereas Uwens gave the same measures as Galileo, leaving no doubt that he was using Galileo's account and not Mersenne's.

Galileo added another experiment to show that water has no viscosity, and once again, Uwens used the same one in his Portuguese textbook. Galileo wrote that if we turn a small vessel of water upside down and place it into a larger vessel of wine, we will see a peculiar interchange of water and wine. If the aperture of the water vessel is small enough, the observer sees wine moving upwards through the water in a little thread, without any mixture of the fluids. Unlike Galileo, Uwens did not use this experiment to discuss the viscosity of water, but mentioned it in a later chapter on the theory of siphons.

Uwens taught this experiment alongside examples taken from Hero of Alexandria's *Pneumatics*, written in the first century AD. This blending of Galileo's experiment with other examples renders it a little difficult at first sight to recognize the experiment as having been borrowed from Galileo, which is probably why the connection has not been noticed before. Uwens's combination of Galileo's experiments with other cases from the literature also reflects his own Jesuit training in textual methods. In a twist of historiography, in modern times this very experiment, exchanging wine and water, was reproduced in order to prove that Galileo actually performed his experiments.

It is important to stress the relevance and impact of Uwens's teaching on Galileo's experiments at the time. Although the viscosity of water may not seem an important topic in our times, in which physicists work on advanced fluid mechanics, it was quite revolutionary in Galileo's and Uwens's day.

In the summer of 1611, more than a year after attaining international fame with his novel astronomical observations, Galileo was invited to a debate at a villa in Florence. Galileo had just been hired as the Medici Grand Duke's "mathematician and [natural] philosopher." That meant one of his tasks was to debate science with princes and cardinals after dinner. In this particular debate, Galileo argued against the Aristotelian explanation of why ice floats on water. The university professors in attendance, who were Aristotelian natural philosophers, said that the ice cubes float because the viscosity of water resists the cubes' shape, thus keeping them afloat. Galileo responded that the ice cubes float because they have less density than water, and added that water does not have any viscosity at all, thus making the Aristotelian argument seem futile. This discussion, along with other encounters, bothered Galileo's adversaries so much that in the end they accused him of heresy, triggering the famous intervention of the Roman Inquisition.

Galileo first wrote about water in his *Discourse on Floating Bodies* of 1612, his first serious attack on Aristotelian natural philosophy. But as the Copernican debates intensified, Galileo's attention moved away from water onto other matters. His research on hydrostatics remained on pause until he was under house arrest at his villa in Florence. He published his thoughts in 1638 in *Two New Sciences*, where he wrote that the experiments described in this episode confirmed "how mistaken are those philosophers who ascribe viscosity to water."[4]

Uwens fully agreed with Galileo's experiments and conclusion. But he was not as quick as Galileo to criticize Aristotelian philosophers, many of whom lived with him in Jesuit colleges. Indeed, he was trained in Aristotelian natural philosophy himself. Precisely because of that training, he was aware of the problems that the new experimental results presented for Aristotelian philosophy and its claims about the heaviness of objects. Rather than setting out to solve them, though, Uwens avoided philosophical discussions by retreating to the disciplinary boundaries of mathematics. As he wrote in his manuscript notes, his class was a class of mathematics and, therefore, "it is enough to abstract [physical conditions] mathematically." By disregarding the physical conditions, Uwens recalls the epistemology of applied mathematics, which described natural phenomena but did not seek to explain their causes. It was left to natural philosophers, especially those studying Aristotle's *Physics*, to explain the causes of nature. That is why Uwens writes: "we leave that [i.e., the explanation] to the physicists."

Uwens thus used the specific context of a class of mathematics to argue that water has no viscosity, contrary to the claims of the Aristotelians, without having to address the problems that they raised. And rather than discussing the claim with logic, as was typical of Aristotelianism, he simply presented the experiments as evidence and decided not to explain any further. It was as if the experiments themselves showed without doubt that

[4] Favaro, *Le opere*, 8:115.

water has no viscosity. This approach reveals the greater epistemic value accorded to experiments in a class of mixed mathematics than in a class of natural philosophy.

To summarize, the manuscript notes from Uwens's mathematics classes in Lisbon reveal how mathematics enabled controversial topics to be quickly appropriated and taught even within the strongly Aristotelian setting of the Society of Jesus. Uwens's transformation and repurposing of Galileo's experiments in this classroom setting helped to spread them to the westernmost corner of continental Europe. Clearly, investigating mathematicians such as Uwens and how they saw the world can offer us a fresh perspective on the changing role of experiments and the spread of the new sciences in the early modern period.

Further Reading

Castel-Branco, Nuno. "Beyond Stevin and Galileo: Seventeenth Century Hydrostatics in the Jesuit Class of the Sphere." In *The History of Water Management in the Iberian Peninsula between the 16th and 19th Centuries*, edited by Ana Duarte Rodrigues and Carmen Toribio Marín, 351–68. Cham: Springer Nature, 2020.

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Heilbron, John. *Galileo.* Oxford: Oxford University Press, 2010 (esp. 177–83).

MacLachlan, James. "A Test of an 'Imaginary' Experiment of Galileo's." *Isis* 64 (1973): 374–79.

Raphael, Renée J. "Reading Galileo's *Discorsi* in the Early Modern University." *Renaissance Quarterly* 68 (2015): 558–96.

Source Text

Lisbon, Biblioteca Nacional de Portugal (BNP), Cod. 4333, Hendrick Uwens, "Tratado da Estática" (1645), fols. 113v–114v, 129r, 135r, 136r–137r.

Note on the transcription: I have transcribed the original text faithfully, retaining the original spelling but standardizing punctuation and justification and spelling out most of the Portuguese abbreviations.

[113v]

…

PARTE 3ª.

Hydrostatica.

Hydrostatica he sciençia que trata do movimento que se faz nas agoas e nas outras couzas liquidas. Dividoa em 2 capítulos. No 1º trato das couzas que nadão sobre a agoa e das que deçem de baixo della. No 2º explico vários modos de levantar e emcaminhar a agoa por diversas vias.

Capítulo 1º.

Das cousas que nadão sobre a agoa e deçem debaixo della.

Axiomas.

Primeiro. A agoa não tem de si resistência nenhuma, ou viscosidade com que resiste a divizão de suas partes. Este axioma não somente se pode supor na consideração mathematica, em que se [114r] abstrahe de todo o impedimento exterior, mas também está fundado em experiençias phisicas:

> 1ª he que vemos que huma bola de cera equilibrada com agoa bem limpa, de sorte que fique no fundo de hum vazo, vem sobindo por amor de poucos grãosinhos de sal que se botão nesta agoa. De modo que 2 grãos botados em 6 libras de agoa bastão para este effeito.
>
> 2ª experiençia he que nas mesmas 6 libras de agoa, botadas 4 gotas de agoa mais fria, fazem sobir a mesma bola, e botadas 4 gotas dagoa mais quente a fazem deçer.

Donde assi argumento. Se a agoa tivera alguma viscosidade com que resistisse a divizão de suas partes, impossível fora, com tão pouca desigualdade do pezo que se faz por estes poucos grãos de sal ou gotas de agoa diferente, que sobisse ou deçesse a tal bola de çera logo etc.

Dirá algum. Vemos que a agoa botada no chão fica recolhida em esferasinhas sem se desfazer, mas isso se faz por razão da viscosidade intrinseca que tem, logo etc.

> Respondo negando a menor. Porque se isso se fizesse pella vis[114v]cosidade, estas esferinhas menos se desfarião estando cercadas de algum meio, em que a agoa teria menor propensão de deçer. Donde botando outra agoa, ou vinho, em roda destas esferinhas menos se desfarão do que fazem estando rodeadas do ar, do que a experiença ensina o contrario. Logo a razão de se terem na sua esfericidade não está na viscosidade intrínseca. Porem deixamos isso aos físicos, bastanos abstrahir mathematicamente della.

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[fol. 129r]

Capítulo 2º: Varios modos de emcaminhar e levantar as agoas

…

[fol. 135r]

Proposição 2ª: O siphão de hum só cano practicado.

…

[fol. 136r]

…

A 3ª Praxe seja o modo com que tendo só dous siphoes ou dous vazos hum cheo de vinho e o outro cheo de Agoa, poderemos trocar estes licores e botar o vinho no vazo dagoa e a agoa no do vinho sem fazer quasi mestura nenhuma. Tomese hum vazo AB com a boca A, algum tanto estreita cheo dagoa, e outro vaso CD cheo de vinho vermelho para maior destinção. E poense a boca A do vazo AB bem dentro do vaso CD, começará logo deçer a agoa por ser mais pezada que o vinho, [136v] e o vinho sobir no lugar dagoa nesta forma, que pello meio dagoa appareça hum raio vermelho de vinho puro, e sobe ate o fundo B sem se misturar com a agoa, por amor das calidades contrarias com as dagoa[.] E quanto mais for mergulhada a boca A dentro do vazo CD, comtanto maior preça sobirá o vinho, por amor do pezo e força maior que então padeçe da maior quantidade do vinho que está no vazo CD, o qual carrega sobre o vinho inferior que sobre[sic] por entre a agoa. Advirto que senão ade tomar demaziada estreitura da boca A; porque poderá ser tão estreita que nem a agoa hade deçer nem o vinho sobir, porque então o pezo da agoa que passa pellas ilhargas da boca A he tão pouco que não basta para levantar ao vinho … .

Dahi se poderá tomar hum modo de refrigerar de preça e muito vinho ou outros licores. Não temos mais que no vazo AB, [137r] da garganta estreita botar o vinho e no outro agoa bem fria.

Translation

By Nuno Castel-Branco, Villa I Tatti, Harvard University, Florence, 2022

THIRD PART

Hydrostatics

Hydrostatics is the science that studies the motion that occurs in waters and other liquid things. I divide it into two chapters. In the first [chapter] I deal with things that swim upon the water and things that descend underneath it. In the second [chapter] I explain various modes of raising and forwarding the water through diverse paths.

Chapter One. On things that swim upon the water and descend underneath it

Axioms

First. Water does not have any intrinsic resistance or viscosity with which it resists the division of its parts. This axiom can not only be supposed upon a mathematical consideration, in which one abstracts all exterior hindrances; but is also grounded in physical experiments [*experiências*]:

> The first [experiment] is that we see that a ball made of wax at rest in very clean water, if it is at the bottom of a vessel, will move upwards because of a few small grains of salt that can be dropped into the water, such that two grains [of salt] in six pounds of water are enough for this effect.
>
> The second experiment is that in the same six pounds of water, if we drop in four drops of colder water, the same ball will rise, whereas four drops of warmer water will make it descend.

From which I argue. If the water had any viscosity that resisted the division of its parts, it would be impossible with so little inequality of weight, made by these few grains of salt or drops of water, that the ball of wax would rise or fall. Thus, etc.

Someone will say. We see that water dropped on the floor remains united in little spheres, without breaking apart, but that only happens due to its intrinsic viscosity. Thus, etc.

> I answer denying the minor [proposition]. Because if that happened due to viscosity, these little spheres would break apart even less when surrounded by some medium in which the water has less propensity to descend. Wherefore, dropping another [drop of] water or wine around these little spheres, would break them less apart than if they were surrounded by air, but experience teaches otherwise. Therefore, the reason for [the drops] remaining in their sphericity is not in [their] intrinsic viscosity. However, we leave that [explanation] to the physicists, [for us] it is enough to abstract of it mathematically.

…

Chapter Two: Various ways of forwarding and raising waters

…

Second Proposition: The siphon used with only one pipe

…

Third custom. Let there be only two siphons or vessels, one filled with wine and another filled with water. We can exchange these fluids, and drop the wine in a vessel with water and the water in a vessel with wine, without making any mixture. Take a vessel AB with water, with the opening A somewhat narrow, and another vessel CD filled with red wine for greater distinction. Placing the opening A of the vessel AB deep inside the vessel CD, the water immediately starts descending because it is heavier than the wine, and the wine rises in place of the water in this way: in the middle of the water a red ray of pure wine appears, and it rises all the way to the bottom B without mixing itself with the water, for the sake of the [wine's] opposite qualities with the water. And the farther the opening A dives inside the vessel CD, the more quickly the wine rises, for the sake of weight and the greater strength that it then suffers from the great quantity of wine that is in the vessel CD, which carries the wine that rises through the water. I advise you that the opening A should not be too narrow, because it could be so narrow that not even the water will come down or the wine rise. Because then the weight of the water that passes through the sides of the opening A is so small that it is not enough to raise the wine … .

From this one can draw a way to quickly refrigerate a large amount of wine or other liquids. We only have to place the wine in the vessel AB, with a straitened opening, and very cold water inside the other.