

The Blossoming of Leonardo da Vinci, Engineer

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1. Introduction

“I am well aware that, because I am not a scholar, some presumptuous people will think that they can belittle me as an uneducated person. Bunch of ignoramuses themselves!”
—From the Codex Atlanticus¹

In this statement by Leonardo da Vinci in his Codex Atlanticus, “uneducated person” or *omo senza lettere* (*uomo senza lettere* in modern Italian) is a reference to his failure to understand Latin, which was the common language of the intellectual class of the time. Although many writers, including Dante and Petrarch, composed poetry and prose in the vernacular language (Italian), to qualify as a true man of culture, one had to write in Latin. The rather defensive quote from Leonardo above reveals his inferiority complex vis-a-vis the Latin language, which tormented him throughout his life.

Leonardo descended from a line of notaries, which was considered an intellectual class at the time, but was born out of wedlock (a bastard child) because his parents did not marry, probably because of their different class statuses. Ironically, the notaries’ union at the time did not admit illegitimate children, so it was clear from an early age that he would not inherit the family business. As a result, Leonardo grew up with an emotionally distant father, without access to Latin, the abacus, and other elements of a primary education that the sons of the wealthy at the time received.

Three times in Leonardo’s manuscripts, he makes note of the books currently in his possession. The first such mention is in the Codex Trivulzianus, where he lists five book titles: Donato, Lapidario, Plinjo, Abacho, and Morgante². The first of these, Donato, refers to a Latin grammar book by Donatus. It is interesting that Pliny’s *Natural History* and Luigi Pulci’s epic poem *Morgante* are accompanied by a grammar book and a book on calculation with the *abaco* (a kind of abacus). It is likely that Leonardo, who was in his mid-30s, taught himself out of necessity.

As this shows, his image as an “all-powerful genius” who can do anything without difficulty is not in line with reality. This paper will consider how Leonardo the engineer blossomed from such an inauspicious starting point.

2. Leonardo’s learning

Looking at Leonardo’s next two mentions of the books currently in his possession, you can see his collection expanding at an accelerating rate. The Codex Atlanticus lists 40 volumes, and the final mention in the Codex Madrid lists 116 volumes. The latter dates to around 1503–05, when Leonardo was already over 50 years old. Some classics such as Ovid, Pliny, Aristotle, and Augustine are listed, but most of the titles were written in the vernacular by contemporary writers such as Palmieri, Burchiello, and Alberti³. The scarcity of Latin texts can be attributed to Leonardo’s difficulties with the language mentioned above; even his editions of *Aesop’s Fables* and similar works were translations into the vernacular.

The list of books was apparently part of a list of belongings Leonardo left behind on his travels, so it is possible that there were other books that he brought with him. In any case, it can be seen that Leonardo’s collection of books expanded dramatically over the course of about 20 years, despite the fact that today’s printing technology did not exist, and books were basically copied by hand. Borrowing a manuscript and copying it yourself took a lot of time, and buying a completed manuscript was very expensive. Leonardo’s final cited inventory of 116 volumes represents a staggering number of books for an individual around the age of 50 to possess at the time.

While it is clear that he is a voracious reader, another of Leonardo’s qualities is his humility. Hearing that a famous bridge built in the time of ancient Rome still stands in Verona, he actually goes to the city and sketches it. In his manuscripts, there are several entries stating, in effect, “So-and-so is knowledgeable about this, so I must go ask him.” One example is a note to ask someone named “Gian di Paris” about “coloring methods using the secco technique (*il modo de colorire a secco*)”⁴. This was the French court painter Jean Perréal, also known as Jean De Paris, who actually came to Milan while in the service of Louis XII. This reminds us that Leonardo, who had just painted *The Last Supper* without the use of the fresco method, was always on the lookout for the best techniques. Despite having trained in Florence, the center of the art world, he humbly shows his willingness to learn from French painters,

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¹ Leonardo da Vinci, *il Codice Atlantico*, Biblioteca Ambrosiana, Milano, f. 327v.

² Leonardo da Vinci, *Ms. Trivulziano M 39*, Castello Sforzesco, Biblioteca Trivulziana, Milano, f. 2r.

³ Leonardo da Vinci, *il Codice Madrid*, Biblioteca Nacional de Madrid, Madrid, II, f. 2v.

⁴ Leonardo da Vinci, *il Codice Atlantico*, cit., f. 669r.

driven by a desire to learn more about oil techniques from the north.

In this way, he learned a great deal from his contemporaries, and indeed, there were apparently many learned people who had direct contact with him in Milan and Florence. Among them were the geographer Toscanelli; the navigator Amerigo Vespucci (namesake of America); Argyropoulos, a Greek lecturer in Florence; the architects Luca Fancelli and Giovanni Antonio Amadeo; the artillery engineer Giannino; the physician and mathematician Giovanni Marliani; university professor Fazio Cardano; and the intellectual Baldassare Castiglione. On the other hand, not all scholars and intellectuals are worthy of the name, and Leonardo wrote unfavorably about astrologers such as Ambrogio da Varese, an important figure in the Milan court.

3. Apprenticeship in a workshop

Once it is clear that young Leonardo will not take over the family business, his father, Ser Piero, sends him to apprentice in the workshop of an acquaintance. Andrea di Michele de' Cioni, aka Andrea del Verrocchio, born around 1435, was about 17 years older than Leonardo. He began his career as a goldsmith and established a workshop that was one of the largest in Florence at the time, rivaled only by the workshop of the Pollaiuolo brothers, who were about the same age. While Leonardo was at the workshop, Perugino (Pietro Vannucci), who would eventually become Raphael's mentor, was also there, and for a time Botticelli also came to the workshop to collaborate with the artists there. In short, Verrocchio was not only an excellent artist but also a good educator,



Fig. 1 Agostino Veneziano (Agostino de' Musi), "The Academy of Baccio Bandinelli," 1531, Metropolitan Museum of Art, New York.

and it was Leonardo's great fortune to become his pupil.

However, what we imagine today as an "artist's workshop" did not exist before the High Renaissance. To begin with, there was not yet a profession called "artist." Of course, there were people who painted pictures, carved statues, built houses, or practiced crafts such as goldsmithing and carpet weaving. However, their occupation was no different from that of bakers and leather goods manufacturers at the time, in the sense that creativity and individuality were rarely required.

An apprenticeship in a workshop takes years. At first, you do only small, simple drawings, and the rest of the day is mostly spent cleaning and running errands. Next, you learn how to make materials such as pigments, plaster, and stucco. The master would make several preliminary sketches and small models for each piece he completed, and the apprentices would use these as textbooks and learn by copying them. Unlike a modern art school, there were no instructors giving careful instruction; almost all of the education was based on the dutiful imitation of the professional's work.

After a few years, the apprentice is gradually given the responsibility of underpainting his master's works. By the time they had chosen their own subject matter and practiced drawing slightly larger sketches, a clear pecking order of who was better among the apprentices in the workshop was established, and their areas of expertise were solidified. At that point you would be entrusted with parts of the master's work as an assistant. For example, if you were good at musical instruments, you would be entrusted with drawing musical instruments. Similar to the roles of today's manga artists and their assistants, it was common for the master to draw the main characters and for the assistants to draw the

scenery. Verrocchio's workshop produced many excellent pupils, partly because he divided the work between his pupils and collaborators appropriately.

A little after Leonardo's time, an engraving was made depicting the sculptor Baccio Bandinelli (who was also a rival of Michelangelo) giving art lessons to his disciples in his workshop, which he called the *accademia* (engraving by Agostino Veneziano, Fig. 1). The word *accademia* refers to the Renaissance attempt to revive Plato's school in ancient Greece (Academia Platonica), the prototype for today's academies. In fact, Bandinelli started a private *accademia* in Rome in the 1530s and then in Florence in the latter half of the 1540s. The print depicts a group of young people gathered in a candlelit room, sketching around Bandinelli,



Fig. 2 *Cartelle of the Accademia Vinciana*, based on the design of Leonardo da Vinci, a noted Milanese printmaker, three types, 1497–1500, copperplate engraving, Milan, Ambrosiana Art Gallery.

who is holding a small statue of Venus. Small statues and vases in various poses are arranged on the shelves in the room, indicating that opportunities for this kind of practice were provided daily. Perhaps a similar kind of practical education was provided at the Verrocchio workshop.

Leonardo was another who sought to revive the academy. In his late 40s, he created at least six different original engravings known as the “cartelle of the Accademia Vinciana” (Fig. 2). Perhaps he was designing an emblem for his own school? The *cartelle* feature complex string-like patterns drawn with a single stroke, and one can imagine that he worked on them with considerable enthusiasm. However, perhaps due to his unsociable personality, in the end he never opened the school. Alternatively, he may have considered the *Accademia Vinciana* to be his small workshop in Milan, where he had five or six apprentices.

4. A direct mentor in the field of engineering

During his apprenticeship, Leonardo had several significant interactions that influenced his subsequent engineering career. The Cupola of the Cathedral of Santa Maria del Fiore (Fig. 3), a symbol of Florence, is a monumental masterpiece by the early Renaissance architect Filippo Brunelleschi. However, when Brunelleschi passed away, the final task of placing the bronze ball atop the tower remained unfinished. The Verrocchio workshop was contracted to undertake this unprecedented project, which required lifting a heavy object weighing more than two tons to a height of about 100 meters. Brunelleschi himself had already devised a crane for installing a lantern (lighting tower) at the top of the tower, and several people had copied the blueprints. Leonardo was one of them (Fig. 4).

The commission was received around 1468, and the Verrocchio workshop completed it in about three years. Leonardo, who was in the workshop at the time, was around 18 years old. This was shortly before he qualified as a master at the age of 20, and it is assumed that he was in a position of being his master’s right-hand man. Considering Leonardo’s remarkable activities in the engineering field later on, there is no doubt that this project helped him cultivate significant engineering skills.

Among his predecessors in the field of engineering, Siena-born Francesco di Giorgio Martini is a particularly large presence. Francesco himself was active in many countries as a military engineer, as well as an architect, painter, sculptor, and writer. In that respect, it can be said that he was quite Leonardo-like in his versatile talents. When Leonardo arrived at the Milanese court, Francesco, 13 years his senior, who

had previously worked in Urbino and Naples, was already widely known.

The two hit it off and went to visit the ancient equestrian statue of “Regisore” in Pavia together. Leonardo also obtained and studied Francesco’s manuscript draft, which now resides in the Biblioteca Laurenziana in Florence. To date, this is the only book definitively known to have been a part of the personal library of Leonardo, who annotated its margins in his distinct mirror writing (Fig. 5). Leonardo’s style of showing a figure and adding commentary to it, demonstrates how much he owed to his predecessor. Leonardo learned much of his engineering from him, and it is now clear that the famous self-propelled cars and other vehicles



Fig. 3 Cupola of the Cathedral of Santa Maria del Fiore, Florence

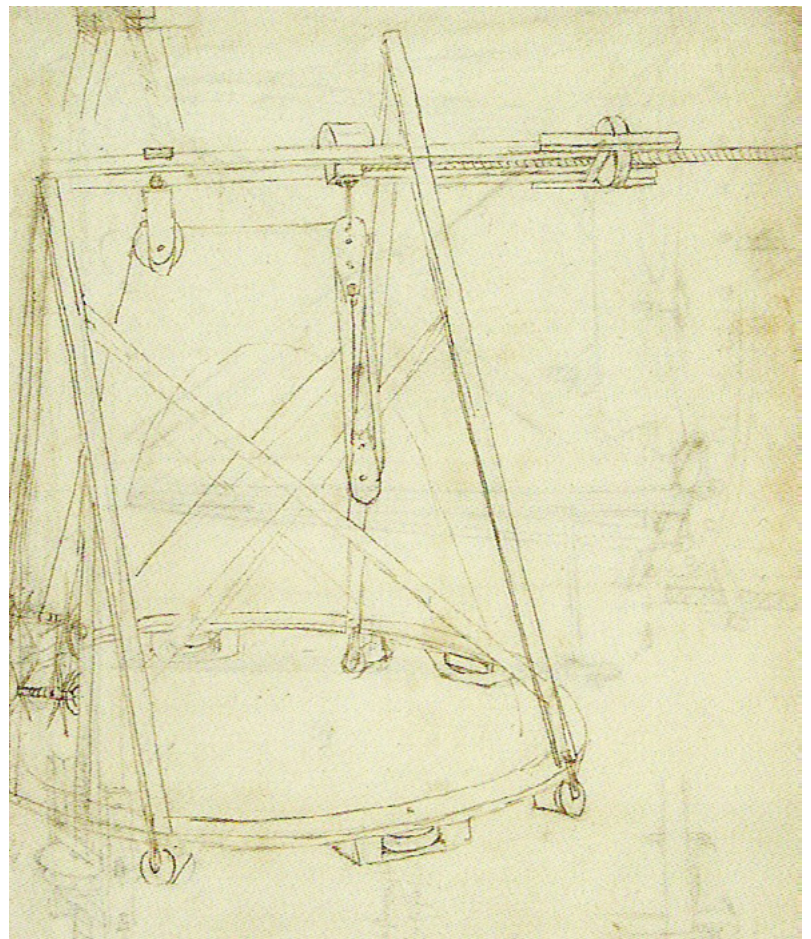


Fig. 4 Leonardo da Vinci, sketch of a crane, circa 1478–80, Codex Atlanticus, f. 808r.

that were once considered Leonardo's inventions owed most of their design to Francesco.

Leonardo was also active in Milan in the field of architecture. Fortunately, Milan was also home to the iconic Renaissance architect Donato Bramante, who must have been an invaluable mentor to Leonardo, who until then had had little opportunity to learn about architecture. The results soon became apparent. In 1487, about five years after Leonardo moved to Milan, a competition was held for the proposed renovation of the ceiling of the crossing tower on the Milan Cathedral. Of the five submitted designs, the judge, Bramante, selected Leonardo's, and there followed three recorded payments to Leonardo for this task.

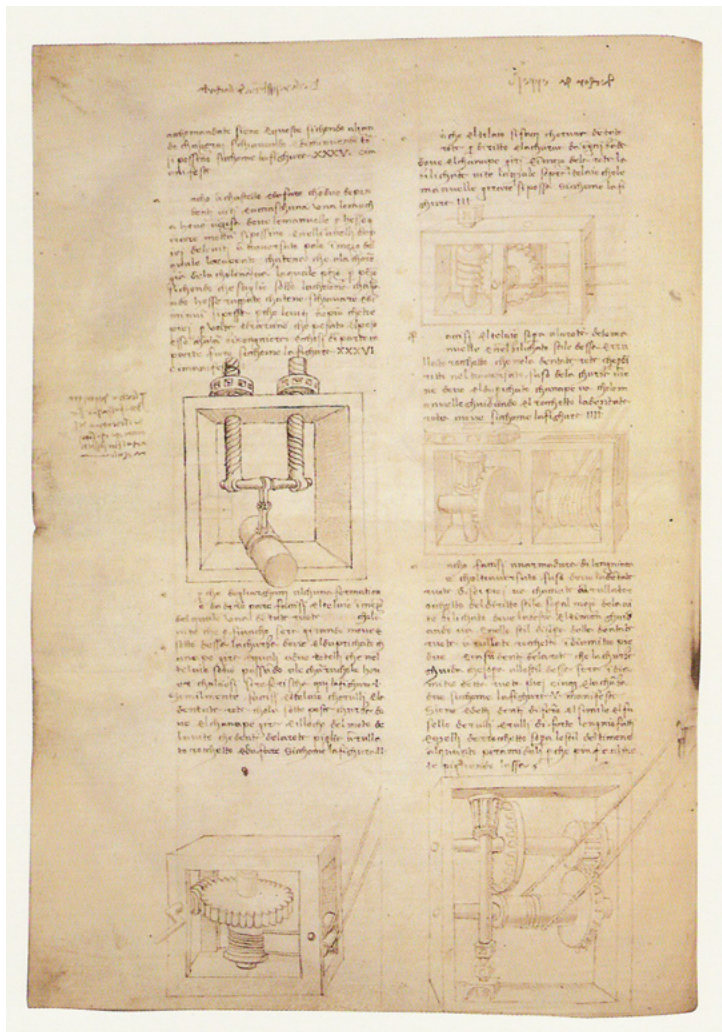


Fig. 5 Francesco di Giorgio Martini, *Treatise on Architecture* (formerly in the Leonardo Collection), Florence, Biblioteca Laurenziana, f. 44v.

5. Engineering development

Leonardo's greatest innovation in industrial design renderings is his "exploded diagram." This technique combines a diagram showing the overall appearance with a diagram that shows the disassembled parts and how they fit together (Fig. 6). In the device shown, when the operator moves the lever on the side of the device back and forth, the two rotating discs rotate in opposite directions and the bar rotates to raise the load. When gears are switched, each disc rotates in the opposite direction from before, and as a result, the load is lowered. In other words, it is a device that converts horizontal back-and-forth motion into vertical up-and-down motion⁵. The left side of the figure shows the overall view, and the right side of the figure shows an exploded view, with each part drawn at a slight distance from the others. The beauty of this method is that it not only reveals the shapes and roles of hidden and invisible parts, but also easily conveys the size, shape, and arrangement of all the parts used.

The introduction of exploded diagrams of mechanical parts was probably influenced by Leonardo's unique concept of "mechanical elements" (*elementi macchinali*). Leonardo used many parts such as springs and gears, but before him, there was no concept of functional classification or standardization in the engineering world, which is what prompted him to introduce the concept of "mechanical elements." For example, in the case of springs, he made illustrated lists of springs of various types⁶. In fact, he probably prepared stocks of pre-made parts and tools in advance, organized by function and specification, so that he

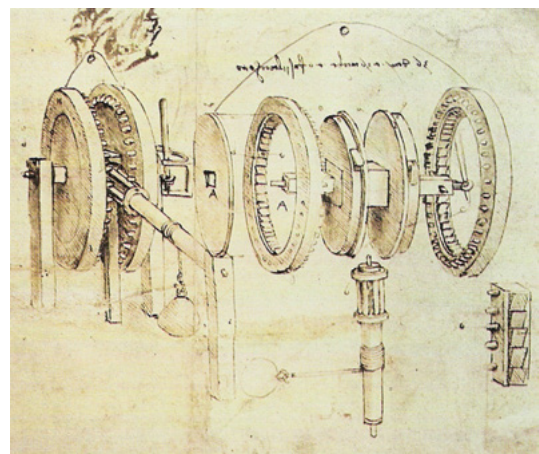


Fig. 6 Leonardo da Vinci, Converter from reciprocating motion to rotary motion, Codex Atlanticus, f. 30v.

⁵ This is one of Leonardo's engineering inventions that may have actually been built, as it could be made with the techniques and materials of the time. For a description of the device's operation, see the following: Domenico Lini, Kazuhiro Susowake, Shigetake Nagao, et al. (dir.), Catalog of the exhibition "Shirarezaru kagaku gijutsusha Leonardo da Vinci" NHK Kinki Media Plan, 1998. Alternatively: Domenico Lorenza et al., "Da Vinci tensai no shigoto" translated by Takako Matsui, Futami Shobo, 2007.

⁶ For Leonardo's unique concept of mechanical elements, see: Shingo Tabata, "Leonardo and Engineering," in Hidehiro Ikegami (ed.), *The World of Leonardo da Vinci*, Tokyo Do Publishing, 2007. In addition: Marco Cianchi, *Leonardo da Vinci's Machines*, Firenze (publication year unknown); *La mente di Leonardo*, a cura di Paolo Galluzzi, Firenze 2006.

could simply select them by desired function when devising a new apparatus.

It is not easy for those of us living in modern times to imagine the hardships that Leonardo and other engineers had to face in an era when they had to make most of their own tools and parts. Before inventing or building a machine, Leonardo first tried to obtain the necessary craft tools in an efficient manner (Fig. 7). In the device in the figure, the weight causes the shaft to rotate, lifting a hammer that periodically swings down, etching dents into the iron plate. The platform itself is also designed so that it inches forward as the shaft rotates, automatically shifting the position where the hammer hits.

Leonardo was keen to pursue such automation to reduce overall workload. That is why his papers so frequently mention ideas that harness not only water flow, which had been used since antiquity, but also the potential energy of a falling weight, as in the above-mentioned machine, or the reaction force of a large, stretched spring. An amusing example is a device that attempts to take advantage of the updraft generated by the heat of roasting meat on a spit to turn the spit mechanically, which is hard work when done manually (Fig. 8). Leonardo installed a fan on top of the narrowed chimney-like structure, with the idea that the rotation of the fan by the rising air current would automatically turn the roasting spit. While admittedly a bit ridiculous, this device could be called a primitive prototype of a steam engine.

I have already mentioned that not all of Leonardo's engineering ideas sprang from his own head. Of course, obsolete scientific ideas were ubiquitous. The "impetus" theory to explain the law of inertia is an example. In order to create a "perpetual motion machine" that can continue

to run indefinitely without power, Leonardo concocts a mechanism in which the rotation of a wheel causes bars with weights attached at the end to swing down, and the resulting reaction keeps the wheel spinning (Fig. 9). As we all know, a perpetual motion machine is impossible, and

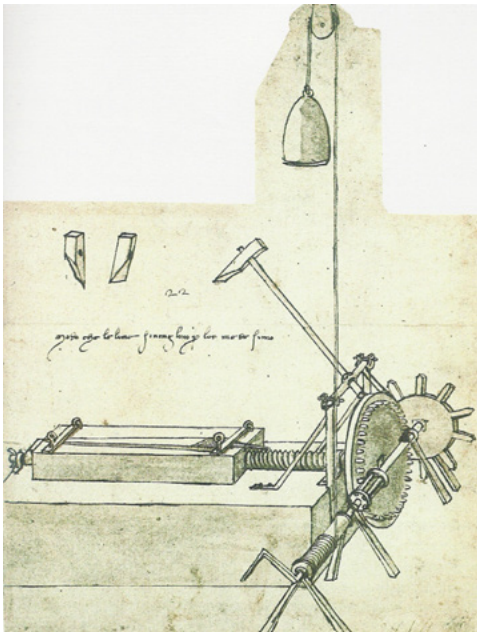


Fig. 7 Leonardo da Vinci, Automatic file-cutting machine, Codex Atlanticus, f. 24r.

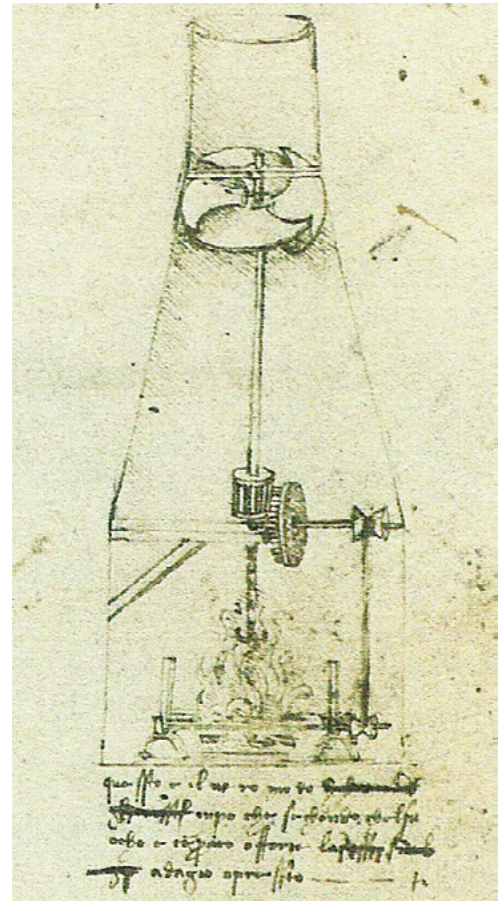


Fig. 8 Leonardo da Vinci, Automatic roasting mechanism, Codex Atlanticus, f. 21r.

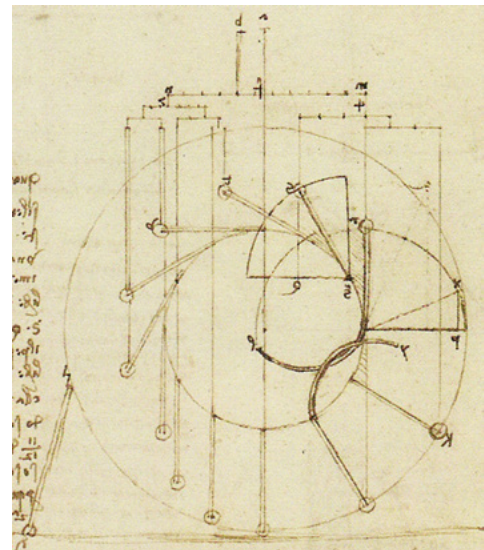


Fig. 9 Leonardo da Vinci, Perpetual motion machine, Codex Madrid I, f. 145r.

6. Conclusion

Leonardo soon realizes this and repudiates the alchemists who claim that perpetual motion is possible.

But Leonardo, being Leonardo, was not content to just assert “it can’t be done”—he also questioned why a perpetual motion machine was impossible. He verifies that the explanation was energy loss due to friction (Fig. 10) by putting weights on objects of various shapes and materials and observing the differences in the degree of friction.

Going one step further, he tests various ways to minimize the generation of frictional heat (Fig. 11). In this experiment, to reduce the energy lost in rotation, he uses a recess containing three balls as an axle bearing. This is clearly a prototype of modern thrust bearings.

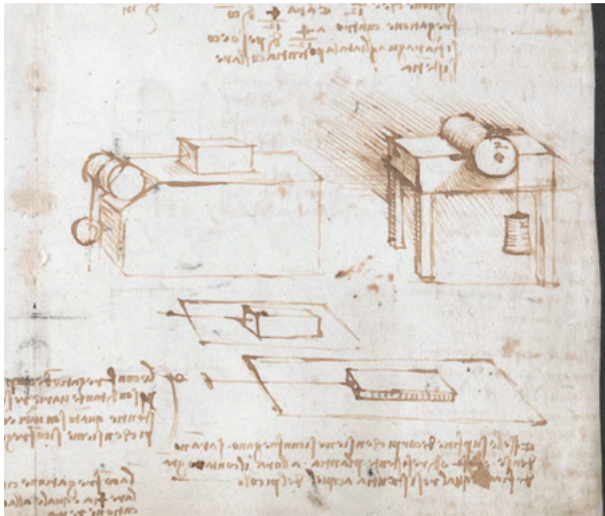


Fig. 10 Leonardo da Vinci, Friction experiment, Codex Arundel, f. 41r.

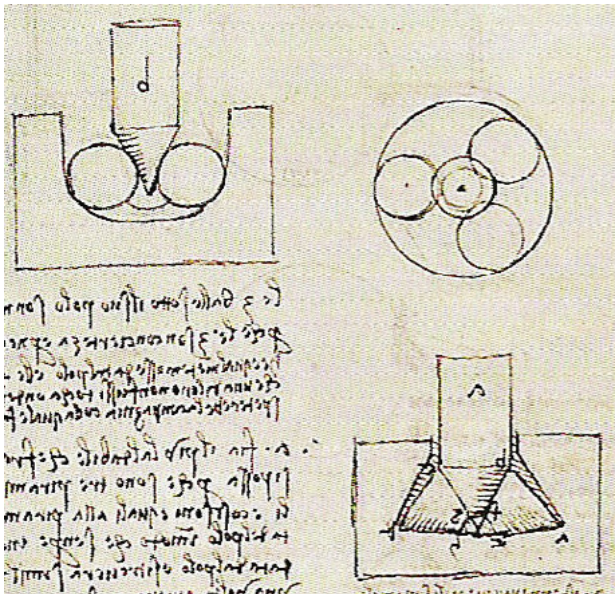


Fig. 11 Leonardo da Vinci, Thrust bearing experiment, Codex Madrid I, f. 101v.

Despite having written down a number of ideas connected with the modern world, Leonardo’s influence on the later history of engineering was not as great as it could have been. Above all, his biggest mistake was never publishing his ideas in a book. It is not that he did not intend to do so. In the past, some even went so far as to claim that Leonardo’s ideas were too radical to publish, a theory that also accounted for his mirror writing. In fact, however, he had a desire to publish and a clear vision for doing so. The Codex Leicester, for example, is clearly a draft intended for publication. There is also a list of chapters to be published under the title “Book on Water” documenting his long-standing observations on water flow. He also left behind a similar chapter-by-chapter structure for an Eastern travelogue, although this would have been completely fictional.

Had his publication plan come to fruition, he would have had a much greater impact on the development of science. However, Leonardo passed away without ever being published. Francesco Melzi, who was entrusted with the legacy of his mentor’s thoughts at a young age, throughout the remainder of his long life managed to organize only Leonardo’s notes on paintings and ended up compiling them into a single volume, *Treatise on Painting*.

After that, as is well known, a significant portion of Leonardo’s vast accumulation of thoughts was lost. Of course, as Pedretti points out⁷, some of Leonardo’s ideas, even if now lost, may have left some influence on future generations of engineers. Surely there were engineers, either contemporaries or later generations, who saw some of the devices he created.

In fact, it has been reported by Rosheim that the exact same “telescopic spring structure” found in a manuscript by Leonardo appears in the writings of Giovanni Alfonso Borelli in the 17th century⁸. This is one example of a contribution to the history of science by Leonardo’s engineering, which was thought to have had little influence on later generations.

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⁷ Carlo Pedretti, “Leonardo da Vinci: Art and Inventions [Mechanics],” translated by Kumiko Tanaka, Yasuyuki Ogura, and Manabu Morita, Toyo Shorin, 2008, pp. 102–113.

⁸ Mark Elling Rosheim, “L’automa programmabile di Leonardo,” in: *Lettura Vinciana*, XL, 2000.