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Leonardo da Vinci and the Development of Mechanics

Haoqi Ji

Shanghai Starriver Bilingual School, Shanghai, China

jiajie.wu@shssbs.edu.cn

Abstract. Art is an important carrier of history. Through understanding art, scholars can know the ideas and theories of the people at that time and make all kinds of correlations and inferences. Leonardo da Vinci, a famous artist of the Renaissance era, has many surviving paintings and notebooks that contain a great deal of knowledge related to mechanical theories, and the topic of this paper is the relationship between Leonardo da Vinci’s works and the development of mechanics. This paper uses the method of literature analysis to read and find the relevant literature and makes the final conclusion: the science involved in Leonardo da Vinci's paintings has played a leading role in the development of some of the later mechanical development in both direct and indirect aspects, but at the same time it needs to be clear that the theories written in the notebooks and whether they are practically correct are irrelevant, and it is necessary to make a practical model of the theories before concluding Leonardo’s influence.

Keywords: Renaissance; Leonardo da Vinci; mechanics; motion.

1. Introduction

History is not only a record of the past, but also a witness to development; from the long and slow river of history, the processes of evolution are discovered not only in organisms but also in theories, technology, and knowledge. There are all kinds of carriers of history, like books, letters, oral transmissions, paintings, and so on. Represented by painting in the field of art, history has wide dissemination and communicability for paintings to convey information in a more straightforward and direct way and does not require the same level of literacy as books do. Thus, understanding the art of different eras, allows historians to understand the theories and knowledge that were commonly spread at the time.

With the intensive study of Renaissance paintings by artists and historians, as well as the involvement of other fields such as anatomy, astronomy, astrology, etc, Leonardo da Vinci's works were found to be of significant scientific importance. In Leonardo da Vinci's Notebooks, there contained many drafts, such as the structure of the human body some detailed arm structures with annotations, and some design sketches. Reading and examining Leonardo's notebooks can help scholars understand the various scientific theories and models that were being developed during the Renaissance period. In addition, scholars could understand the history of science and compare the conclusions in Leonardo's notebooks with the various theories that have since been developed to become aware of the scientific influence Leonardo brought.

Currently, many scholars have made detailed studies of Leonardo’s works in the areas of bird flight, and hydraulic, and mechanical balance. Existing research has taken the contents of Leonardo da Vinci's notes and modernized them to create models through which the development of the principle of leverage can be understood [1]. Other papers introduce engineering concepts by quoting and describing details in Leonardo’s paintings or illustrating Leonardo’s scientific method and his inheritance [2].

Nevertheless, whether there was a correlation between the content of *Leonardo da Vinci's Notebooks* and the later mechanical development still needs further research and exploration [3]. In particular, the idea that the theories involved in the notes and the actual models and experiments are not equivalent needs to be confirmed. The exploration of the description of the theories in the notebook and the feasibility of the actual model can fill in the research gaps of the existing studies and make the understanding of the extent to which Leonardo da Vinci's work had an impact on the development of mechanics more complete, rigorous, and scientific.

This study focuses on the science contained in Leonardo da Vinci's works and whether or not they influenced the development of mechanical theory in later generations specifically. Literature analysis was used in the research to find and read relevant information and literature; the advantage of this method is that it can well analyze the different mechanical aspects contained in Leonardo da Vinci's works, such as motion, friction, hydraulic, etc., which is conducive to the research. The ultimate research goal of this study is to analyze what impact the science embedded in Leonardo da Vinci's work has had on the development of mechanics, and in order to achieve this goal, a detailed description of Leonardo da Vinci's work, the process by which his theories were derived, and an analysis of how Leonardo da Vinci's theories are relevant to later generations of mechanical theories were conducted.

2. Background

Leonardo da Vinci was born in the town of Vinci as the son of a Florentine lawyer named Ser Piero. Leonardo lived with his father's family and received elementary education. At around the age of fifteen, he entered the studio of Andrea del Verrocchio who was a Florentine painter and sculptor [4]. Verrocchio was sponsored by the famous patron, the Medici family, after around 1466. Leonardo was deeply influenced during his years of study in the workshop and experienced opportunities to understand some simple engineering principles to lay the foundations of his later masterpieces. It was said that he even outperformed his mentor Verocchio in painting Christ's baptism for his artistic ability to emphasize the angelic figures [3]. In 1482, he began his life in Milan where he received different commissions and became more famous. For instance, he was commissioned by Duke Ludovico Sforza to draw *The Last Supper*, to decorate the church, as well as to create a self-portrait for him. Leonardo spent the second part of his life mostly in Milan and Florentine due to the military invasions and conflicts with France.

Being influenced by time, instead of creating rigid and two-dimensional human figures, Leonardo and other famous artists like Michelangelo and Albrecht Durer developed artistic techniques like the use of light and shadow and linear perspective on their vivid and lively depiction of figures. Leonardo's knowledge of anatomy also contributed to his ability to demonstrate human bodies realistically.

In addition to the differences in painted figures, Renaissance painters also began to study science based on preserved sources from ancient Greece and Rome. According to Leonardo's handwritten notes that had been handed down, Leonardo was considered a great contributor to the theories of mechanics, human anatomy, water currents, flight, etc. Eventually, Leonardo da Vinci died at Cloux in 1519, and a collection of his writings in the notebook was compiled into the book *Treatise on Painting* by his student Francesco Melzi.

3. Scientificity

3.1. Motion

Leonardo da Vinci argued that motion and velocity were directly proportional in free fall [3].

Leonardo also introduced the idea of the moment and related it to his proposal of lever equilibrium [5]. He established the rule that if the endpoint of a lever was named ab, a point c was taken on the lever and its plumb line was made to obtain a point d, then the ratio of the distance cb to distance ac should be equal to the ratio of weight in position c and the weight in position a [3]. When the previous rule was followed, the lever would be in equilibrium. Furthermore, in his notebooks, he drew sketches about designs for lever cranes for the purpose of both lifting and lowering a weight [1]. There were also drawings about dynamic and fixed pulleys that also applied the idea of lever equilibrium. Dynamic pulleys were examples of levers that saved labor considering the relationship between resistance arm, power arm, resistance, and power.

Despite the equilibrium point during the exertion of force, Leonardo was also advanced in the idea of motion transformation. He suggested several strategies for converting rotations parallel or orthogonal to the ground [1]. According to his notebooks, these strategies included the use of gears or the use of bullwheels and ropes. For instance, in one of his engineering drawings, Leonardo demonstrated wind-up automation with three wheels that were regarded as the first "robot". In its "body", lots of gears were used to enable motion as well as the transfer of motion.

3.2. Friction

Leonardo's drawings on the notebook laid the foundation of the laws of friction. After the discovery of several parameters in friction, including the object's weight, surface area, and inclination degree, Leonardo further developed the study of friction in the manuscript *Codex Arundel* which contained hundreds of pages of notes and graphs [3]. He included a sketch of an experimental apparatus for his analysis of friction coefficients [3]. A cuboid object was placed on the top of the table. Using a thin rope, it was connected to a cylinder on the inclined part of the desk to act as a pulley, and then the rope eventually connected to a hanging sphere.

Through experiments, Leonardo concluded a friction coefficient between the weights of the two masses with a value of 0.25 [6]. Leonardo eventually concluded that the force of friction was proportional to the moving item's weight and was irrelevant to the surface area in contact during the movement. He also discovered that surface smoothness was inversely proportional to the force of friction; thus, friction could be minimized if the smoothness of the surface was reduced.

He later applied his discoveries to the invention of wooden ball bearing. It was primarily made of two grooved and circle tracks and several balls. By installing rollers, heavy objects could be transported since sliding friction was converted into rolling friction, and the force of friction was minimized during the movement. According to his notes, ball bearing was also applied in screw jack as the rollers could reduce the friction between the gears and the planks for the jack to operate smoothly.

3.3. Hydraulic

Leonardo was deeply interested in water for he believed that water in the veins was earth's blood [4]. He came up with the law of transmission, meaning that the amount of water passing through a given point in a river or canal was proportional to the cross-section of the stream of water at that location. Leonardo also noted that one would need to follow the law of flow to remain regular and non-turbulent during motion [4].

Apart from the theoretical studies of waster, Leonardo was often thought to be the first who describe a hydraulic jump. In *Codex Atlanticus*, he included a small sketch with written explanations of the flow running down the waterway to explain the phenomena.

His designation of water wheels and pumps both reflected his erudition of fluid mechanics [7]. The water flowed down from the aquifer and rotated the wheel, which led to the rotation of the screw connected to the wheel. Then, power could be generated from the water wheel. The idea of water power influenced the modern development of the use of hydroelectricity through the construction of the dam [7].

Leonardo's use of water was not only limited to its power-generating use but also considered using fluid flow as construction power. When planning for the river Arno, Leonardo planned to utilize vortex instead of human labor to construct channels [5].

In addition to his knowledge of hydraulics which refers to the practical ways to use water force, Leonardo da Vinci also engaged in the study of hydrostatic, meaning the laws of the equilibrium of fluids. He examined the relationship between hydrostatic force and floating bodies in his notes. Yet, although he eventually noticed the equilibrium of fluids, his ideology of hydrostatics was still incomplete [8].

3.4. Turbulence

Leonardo mentioned the word turbulence several times in his notebook; however, instead of “turbulence” in modern mechanics, turbulence was used by Leonardo to convey several meanings. The first meaning was close to murky and chaos based on the interpretation of Leonardo’s contrast between turbulence and Lucida [5]. Its second meaning was identified when he wanted to create a violent moment when a “turbulent flow” of soil, rock, and bushes rushed down from the mountain, implying that “turbulent” meant furious motion. Leonardo's paintings that depicted the deluge mentioned in the *Bible* were excellent illustrations of multi-scale turbulence [5]. The swiftness of the current, the bends, and the sense of weight hitting the bank all contributed to the turbulence of the drawing, which demonstrated not only Leonardo’s fine observation of water flow but also served as a precursor to his later ability to think about harnessing the power of water currents and his later study of hydraulics.

3.5. Flight

Leonardo saw wind as a liquid just like water and viewed the wing's compression of the air as an important process for lift [5]. He discovered and concluded dynamic soaring, a technique invented by Lord Rayleigh in 1883, through the sketch that demonstrated birds experiencing an across-wind soaring in four phases [9].

Leonardo illustrated and detailed two techniques that birds utilize to soar aloft in ascending wind currents. Birds could follow the updrafts along the edge of a cliff to maintain altitude during their flight, or, they could spiral up like hot air balloons [9]. As shown in his notes, sometimes, the birds would move in a circular motion as they spread their wings to fly upward with the help of the wind. Through tilting their bodies and one wing to the circulation’s center, the birds were able to maintain stability when flying upward.

Beyond the study of the bird’s flight and the observation of dynamic soaring, Leonardo also engaged in human-powered flight [5]. His sketches and designs of an ornithopter were contributed by his deep knowledge of birds’ bone structure through anatomies. The pilot would control the crack by turning a crank, causing the wings to flap. In this way, humans were able to mimic birds’ ability to adapt to the wind and change their wings’ angles when necessary.

His design of parachutes further illustrated his deep interest in aerodynamics. Leonardo’s design involved linen that tautly stretched over a wooden frame to form a sturdy pyramid structure [7]. Then, the pilot was able to descend safely as the parachute slowed him during his fall.

4. Discussion

Leonardo da Vinci's notes and studies were undoubtedly a huge influence on the development of mechanics in later times even if the influence was not direct. The introduction of the lever crane, friction and inclination angle, and equilibrium in water and air brought notable inspiration for later authors, including Jerome Cardan and Jean-Baptiste Benedetti [3].

Leonardo da Vinci's sketches of the ornithopter laid the foundation for the structural construction of later airplane wings, both mimicking the structure of a bird's wings to achieve the effect of driving the entire body with the wings. Furthermore, Leonardo da Vinci's idea of utilizing the flow of water as a force and a way to generate power influenced the construction of today's dams and the introduction of hydroelectricity. His canal lock designs were still widely employed on waterways. Early engineers used the principles of undershot, overshot, and vertical water wheels to better understand fluid dynamics and enhance their design [10].

The famous Pascal Principle, which was introduced by Blaise Pascal, was indirectly influenced by Leonardo’s study of fluid equilibrium. As Pascal read the *Physico-Mathematic Cogitata* written by Marin Mersenne, Pascal came to learn about the study of several other scientists like Steven and Benedetti after they were influenced by Leonardo da Vinci, which eventually resulted in an indirect influence of Leonardo’s sketches and notes on the formation of the Pascal Principle [3].

At the same time, Leonardo's manuscripts did not always have an impact on later generations, but it was without doubt that Leonardo’s study in mechanics was a pioneer of the era [10].

In addition to the influence or lack thereof on later mechanical developments, it was also worth exploring the fact that Leonardo da Vinci's research was not always correct. For instance, Leonardo did not mention the direct proportion between the altitude and the rise in wind speed in his notes on dynamic soaring, implying that he did not perceive it as vital to soaring, which served as a drawback of Leonardo’s study [9]. Also, it was crucial to understand that the sketches of a design did not equate to whether or not it could be successfully invented. Leonardo did create lots of sketches and notes for mechanical designs, yet their practicability was uncertain. Although the designs could still provide ideas, those that were supported by experimental data would serve a more important role in the later development of mechanics.

5. Conclusion

The findings of this study are that Leonardo da Vinci's studies and travels in various countries paved the way for his knowledge in various fields like anatomy, astronomy, and so on and that his paintings and notebooks contain a great deal of knowledge related to science, especially mechanics, including the concept of motion, friction, hydraulic, turbulence, and flight. This finding further leads to the conclusion that Leonardo da Vinci's art is a guide to the development of machinery in later generations. Nevertheless, distinguishing between theory and practice is an important element when determining possible correlations and making final conclusion since some of Leonardo’s written theories might not have practicability which will affect his impact on scientific development. This study provides a number of valuable references for future research in this direction, mainly influencing existing views on the relevance of Leonardo da Vinci's work and science, especially in the field of mechanics. In addition, future research should focus on exploring in depth the long-term effects of Leonardo da Vinci's paintings, for example, whether those paintings still have an impact on mechanical theories in the later centuries. Through analyzing the long-term effect of his works, more indirect influence will be discovered, and the importance of Leonardo’s works on the development of mechanics could be assessed more accurately and critically.

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