The Perfect Machine: The Reason behind the Anatomical Studies of Leonardo da Vinci

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Am a third-year Undergraduate at the University of Kentucky, with a major in Art History and Pre-Medical career focus. I am an Honors student and winner of the Oswald Research and Creativity Award in the category of Critical Research in the Humanities, with my paper entitled “The Perfect Machine: The Reason behind the Anatomical Studies of Leonardo da Vinci.” Together with the thought-provoking lectures given by my first Art History professor, Dr. Ben Withers, my lifelong love of art, history, and literature led me to choose an Art History major. I devote my time away from studies to volunteering at Kentucky Children’s Hospital with the organization Kreative Catz. I hope to attend Medical School after graduating from UK in 2009, and then to realize my dream of becoming a physician. In my paper, “The Perfect Machine: The Reason behind the Anatomical Studies of Leonardo da Vinci,” I combine my two greatest interests: Renaissance art and human anatomy. I presented “The Perfect Machine” at the UK Undergraduate Art History Research Symposium in December, 2007, and again at the Kentucky Honors Roundtable in March, 2008. I was guided in my efforts by Dr. Anna Brzyski, professor of Art History at UK, who taught me the key to meaningful research: “Ask more questions than can possibly be answered, then attempt to answer them all.”

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Few artists have attracted as much popular and scholarly attention as Leonardo da Vinci. In an age when specialization has become the norm, the breadth of Leonardo’s interests and contributions have justly earned him a reputation as the paradigmatic Renaissance man. Nonetheless, he is mainly remembered today as a brilliant artist — the painter of Mona Lisa, The Last Supper, and other remarkable works. Amanda Cothern’s insightful essay reminds us, however, that our tendency to see Leonardo primarily as an artist has significant implications for how we interpret key parts of his oeuvre. This reminder is particularly true of the numerous drawings of the human body found in Leonardo’s notebooks, which the scholars have tended to see in relation to his artistic practice. Noting Leonardo’s consistent engagement with what would be called today “scientific research,” the precision of his recorded observations, and the artist’s apparent interest not just in the appearance, but also in the physiology of the human body, Amanda presents a convincing argument that Leonardo’s extraordinary anatomical drawings should be viewed primarily as scientific and engineering studies rather than preparatory drawings for his paintings.

The Perfect Machine:
The Reason behind the Anatomical Studies of Leonardo da Vinci

Abstract
The legacy of Leonardo da Vinci is most often characterized by the works of his brush — however, there is more to Leonardo than what meets the art lover’s eye. His notebooks overflow with scientific studies, the most amazing of which are his detailed drawings of human anatomy. Scholars have long assumed that Leonardo dissected corpses in order to better represent the human form in his painting. In this paper, I counter that assumption, making the following points:

I. Leonardo’s anatomical findings did not significantly influence his painting.
II. Leonardo was an accomplished scientist and engineer.
III. Leonardo applied his knowledge of physics to human anatomy — in the same way that he applied it to his mechanical inventions.
IV. Leonardo was a scientist/engineer studying nature’s perfect machine, not a painter studying the human form.
V. Leonardo da Vinci cannot be defined as having been primarily a painter, therefore, his studies of anatomy cannot be defined as mere extensions of his art.

I will highlight the multi-faceted mind of Leonardo da Vinci, and demonstrate that his detailed dissections and application of the laws of physics to human physiology would have been unnecessary had he considered himself a career artist.
Introduction

“Oh Speculator of this machine of ours, you shall not be distressed that you give knowledge of it through another’s death; but rejoice that our Creator has his intellect fixed on such excellence of instrument.”

– Leonardo da Vinci

The legacy of Leonardo da Vinci is most often characterized by the works of his brush — such aesthetic treasures as The Last Supper, the Mona Lisa, and The Madonna of the Rocks, to name a few. Though it is the international renown and mystery surrounding his paintings that has immortalized Leonardo, it is no secret that he was more than just a painter. The so-called “Renaissance Man” also wore the hats of architect, musician, naturalist, philosopher, physicist, mathematician, and engineer in his lifetime (Bhattacharya and Cathrine). At the time of his death in 1519, he had filled more than 5,000 pages with his studies of physics, geometry, anatomy, and numerous other subjects (MacCurdy). Leonardo had a passion for learning in many different disciplines, the intensity of which was unusual even in the knowledge-hungry atmosphere of Renaissance Italy.

Some of Leonardo’s most significant contributions to modern academia were his studies of human anatomy. He filled notebooks with carefully drawn two-dimensional representations of the organs, tissues, and skeletal formations uncovered during his dissections. He made glass casts of the internal structure of the heart’s pulmonary artery, and attempted to uncover the mechanics of its function (O’Neill and Cone). He drew amazingly accurate cross sections of the human skull — so accurate, in fact, that the drawings are still used in some lectures to medical students today (Fig. 1).

Because of the frequency of human subjects in Renaissance painting, scholars have long assumed that Leonardo’s motivation for performing his studies of anatomy was directly related to his painting. (For example, the writings of Edward MacCurdy, E.H. Gombrich, and several authors outside the Art Historical community either stated or strongly suggested that Leonardo conducted his anatomical studies to improve his artistic rendering of the human figure.) Edward MacCurdy, in his acclaimed translation of Leonardo’s notebooks, states, “[modern research] has made manifest how [Leonardo] studied the structure of the human frame...in order the better to paint and make statues...” (MacCurdy 26). He is not alone in this assumption. Though his work was published in the early 1900s, MacCurdy’s notion that Leonardo approached his anatomical studies with a mind to improve his painting is prevalent to this day among the general public as well as most art historians.

At the time of Leonardo, it was becoming common for painters to dissect human corpses in order to improve their depictions of the human body. It is documented that Donatello, Michelangelo, and even Verrocchio, Leonardo’s own painting master, performed human dissections (Xie and O’Leary 899-900). However, the extent to which Leonardo’s studies were taken exceeds any before them, even those conducted by physicians of the day (Fig. 2).

Their complexities would not be matched until the publication of Andreas Vesalius’ anatomical survey De Humani Corporis Fabrica, twenty-four years after Leonardo’s.
Leonardo began seeking his own commissions. To his patrons’ dismay, however, he was very easily distracted from his work. He would work feverishly for a day or two, then completely abandon his brush for four days or more (Paoletti). Leonardo spent his “breaks” in academic pursuits, studying subjects such as physics and mathematics. As time went on, these “breaks” became longer and longer, until it was obvious to his patrons that Leonardo had no intention of finishing their works for them. In fact, it is documented that the Confraternity of the Immaculate Conception had to take legal action against Leonardo to force him to finish The Madonna of the Rocks in 1508 (Paoletti). Due to his lack of commitment to commissions, and obsessive perfectionism when he was working, we can attribute only about a dozen paintings to his hand with any certainty (Paoletti).

As Leonardo left a trail of more and more grumbling patrons in his wake, it became apparent that painting was not his true love.

The young man continued to learn, and his areas of academic focus at the time are evident in his letter to nobleman Ludovico Sforza (c. 1480) offering his many services. Leonardo states, “I have a sort of extremely light and strong bridges, adapted to be most easily carried… And if the fight should be at sea, I have kinds of many machines most efficient for offence and defence…I will make covered chariots and catapults, safe and unattackable…I can give perfect satisfaction and to the equal of any other in architecture…” (Paoletti). To stifle any doubts of his abilities in his patron’s mind, Leonardo adds, “And if any one of the above-named things seem to anyone to be impossible or not feasible, I am most ready to make the experiment in your park, or whatever place may please your Excellency…” (Paoletti). In all this discussion of his military engineering capabilities, Leonardo almost forgets to mention that he can paint. Toward the end of the letter, he inserts, “…and I can also do in painting whatever may be done, as well as any other…” (Paoletti). Sforza was impressed, and Leonardo entered his court with the title “Engineer and Painter” (Kemp, 2004).

I. Leonardo’s anatomical findings did not significantly influence his painting.

About the time that he began working in the Sforza court, Leonardo began to study human anatomy (Kemp, 2004). He was no doubt assisted in his pursuits by his fellow court members, the prestigious Marliani family of physicians, who educated him on basic anatomical principles (Kemp). Leonardo was not alone in this cross-disciplinary work — anatomical studies were becoming popular among Renaissance painters as a way of improving their abilities to paint the human figure. Philosopher Leone Alberti had a profound influence on this trend,

![Figure 2 Study of an Infant in the Womb c. 1513](image-url)
writing in his treatise *On Painting*, “a painter should know anatomy” (Kemp, 2004).

Renaissance artist Michelangelo began his own explorations of human anatomy at approximately the same time (c. 1490) (Hall). Though very few of his anatomical drawings (Fig. 3) survive, the influence of Michelangelo’s dissections on his painted figures is obvious.

When looking at details from his work on the Sistine Chapel ceiling (completed 1512), the painstaking depiction of the figures’ underlying musculature is noteworthy. Giorgio Vasari wrote in his biography *Life of Michelangelo* (c. 1568), “[Michelangelo] was constantly flaying bodies, in order to study the secrets of anatomy, thus beginning to give perfection to the great knowledge of design [of the human figure] that he afterwards acquired.” (Hall). The artist studied the muscles and skeleton in great detail, but gave little regard to the internal organs. Michelangelo’s motivation for doing anatomy lay solely in his depiction of the human figure; studies of the body’s physiological mechanisms were not necessary.

Michelangelo’s anatomical knowledge brought normally invisible muscles to the surface on his figures, so much so that even his female figures look like body-builders (Fig. 4).

He was not the first to do so — exaggeration of musculature in rendering the human figure dates back to the ancient Greeks. Leonardo was well aware of this artistic convention, and he disapproved. He wrote,

You should not make all the muscles of your figures conspicuous; even if they are shown in the correct place they should not be made too evident, unless the limbs to which they belong are engaged in the exertion of great force or labour; and the limbs that are under no strain should have no display of musculature. If you do otherwise you will have produced a sack of nuts rather than a human figure. (Clayton, 1996).

Leonardo believed that any body structure not visible in a surface nude study, including the majority of the muscles, had no place in a painting. This belief makes it highly unlikely that his own anatomical studies, begun around 1490 and so focused on physiology, would have significantly affected his painting. Compare the anatomy of the Christ child in the original *The Madonna of the Rocks* (completed around 1485) (Fig. 5a) to that of the same figure in *The Madonna and Child with St. Anne and St. John the Baptist* (completed around 1513) (Fig. 5b).
The child’s body structure barely changes. (Recall that Leonardo dissected the bodies of young children as well, as is evident in Fig. 2.) This point is further demonstrated by his work entitled *St. John the Baptist* (c. 1509) (Fig. 6), the subject of which has almost no visible musculature.

These pieces of evidence, together with the fact that Leonardo rarely painted nudes, make clear that his findings in the dissection of corpses did not have significant influence on his pictures. (The only true nude that can be attributed to Leonardo is the subject of a painting entitled “Leda and The Swan;” engraved copies done by other artists are all that remain of this lost work.) If Leonardo’s intentions for his anatomical studies had nothing to do with painting, what exactly was their purpose?

Though Leonardo’s studies of the body did not ultimately affect his painting, it is possible that he started them with intentions related to his art. Several early studies of external human proportions done by Leonardo survive and date to approximately 1487. His earliest dated anatomical drawings are his studies of the human skull (Fig. 1) drawn in 1489 and mentioned earlier. Thus, it is reasonable to assume that Leonardo’s artistic explorations of *external proportion* progressed to scientific explorations of *internal anatomy*. Shortly after completing his studies of the skull, Leonardo mysteriously abandoned his anatomical investigations for a period lasting almost twenty years (Kemp, 2004).

**II. Leonardo was an accomplished scientist and engineer.**

During this twenty-year period after 1489, Leonardo pursued knowledge in conceptual and mechanical physics, and his time spent conducting experiments in the field gave rise to some significant conclusions. According to Kemp, “Leonardo reasoned that the falling body gains increments of speed according to the physical pyramidal law in reverse...the speed at each stage was proportional to the distance traveled.” (Kemp, 2004). Leonardo had developed the concept of *velocity* (the speed of an object is directly proportional to the distance traveled by the object over the elapsed time, \( v = x/t \), more than a century before Isaac Newton would include it in his Laws of Physics (Serway et al.). He also developed other physical concepts for which Newton would later receive credit. Leonardo wrote on the movement of objects, “All movement tends to maintenance, or rather all bodies continue to move as long as the impression of the force of their movers remains in them.” (Schlain). Newton later defined this idea in his First Law of Motion, as follows: “Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.” (Serway et al.) In fact, this concept was known as “The Principle of Leonardo” until Newton published his *Principia* in 1687 (Schlain). Leonardo wrote in another study, “The same force is made by an object encountering the air as the air against the object.” (Schlain). This statement bears an uncanny resemblance to Newton’s Third Law of Motion, which states: “For every action, there is an equal and opposite reaction.” (Serway et al.) When celebrated for his achievements, Newton was quoted as saying, “If I have seen further than other men, it is because I stood on the shoulders of giants.” (Schlain). He never specified...
who these “giants” were, but there is strong evidence suggesting that Leonardo da Vinci was one of them.

Leonardo was perpetually fascinated with the possibility of human flight, and spent much of his time away from anatomy in attempts to engineer a man-powered flying machine. He made studies of birds in flight, hoping to discover the physical principles underlying the birds’ amazing ability. He had some concept of gravity from his studies of physics, and kept it in mind as he watched the birds shift their centers of mass while flying (Kemp, 2004). He took his curiosities a step further with his dissections of the birds’ wings, making careful visual records of these as well. Leonardo paid close attention to the mechanical aspects of the wing’s function, noting on one such study, “The tendon ab moves all the tips of the feathers towards the elbow of the wings; and it does this in flexing the wings, but in extending it [the wing] by means of the pull of the muscle nm, these feathers direct their lengths towards the point of the wings.” (Fig. 7) (Clayton, 1996).

Leonardo imagined several different flying machines, but it was a simple glider of his design that proved successful when built and tested in 2003 by English hang glider Judy Leden (Kemp, 2004). His man-powered flying devices are not capable of flight due to the limitations of human strength, but the success of his glider proves that Leonardo was on the right track.

III. Leonardo applied his knowledge of physics to human anatomy — in the same way that he applied it to his mechanical inventions.

In order to achieve flight for humans, Leonardo turned to studying birds — nature’s perfect flying machines. If the wings of birds were the perfect mechanisms for achieving flight, what mechanical principles could be taken from another perfect machine, the human body? Perhaps it was this thought process that led to his renewed interest in human anatomy around 1510. Leonardo picked up his anatomical studies with a new fervor, this time going beyond mere visual representation into unexplored territory — human physiology.

As he did in his studies of birds, Leonardo began to look at the body’s functions in terms of physics. He even used physics vocabulary, referring to the brain as a “motor,” the neck and joints as “fulcra,” and the jaw as a “lever” (Clayton, 1996). While at the dissecting table, Leonardo’s thoughts often ran to physical concepts. This is evident from the seemingly unrelated side drawings of mechanical objects found on his anatomical studies.

Upon close examination of a particular study of anatomical proportions, a small drawing of a pulley is visible on the lower right side of the page (Fig. 8).

Under the drawing, a note reads, “Five men against one thousand pounds in one hour; one man in five hours; a fifth of the force of one man in twenty-five hours. And in this way it always goes, he who lightens
the work prolongs the time.” (Clayton, 1996). The use of pulley systems allows a large amount of work to be done quickly, using small amounts of force contributed by each member of the system. The same is accomplished by dividing a large work load among several able-bodied human workers. Here, it seems that Leonardo was comparing the mechanical efficiency of a pulley system with that of a group of human bodies.

Similarly, on a drawing of the muscles of the neck, a sketch of what look like ship’s oars can be observed on the right side of the page (Fig. 9).

Leonardo’s note at the top of the page reveals his thoughts, “You will first make the spine of the neck with its tendons like the mast of a ship with its rigging...Then make the head with its tendons which give it its movement on the fulcrum [the neck].” (Clayton, 1996). He reasoned that the considerable weight of the head was distributed among its supporting neck muscles, just as the weight of a ship’s mast was distributed among the ropes of its rigging. The elasticity of the muscles allowed for movement of the head on a stable axis (Kemp, 2004).

When studying the teeth, Leonardo attributed their shapes and functions to their relative positions along the “lever” of the jaw (Fig. 10) (Kemp, 2004).

The rounded molars, meant for crushing, were placed toward the back of the mouth. In this area, they were closer to the “fulcrum” — the hinges of the jaw. Here, they would channel the maximum force from the closing of the jaw, which enabled them to crush hard food materials. The pointed incisors, located at the end of the jaw, were made for cutting. This function did not require as much force, and so the incisors were placed farther from the fulcrum of the jaw.

![Figure 8a. (above), Study of Anatomical Proportion with Pulley](image1)

![Figure 8b. (right), Detail, Study of Anatomical Proportion with Pulley](image2)

![Figure 9a. (left), Study of the Muscles of the Neck, c. 1514](image3)

![Figure 9b. (above), Detail, Study of the Muscles of the Neck](image4)

![Figure 10. Detail, Study of the Human Skull c. 1489](image5)

IV. Leonardo was a scientist studying nature’s perfect machine, not a painter studying the human form.

Leonardo’s increasing knowledge of the body eventually enabled him to determine his corpses’ respective causes of death. Around 1507, Leonardo met a dying man at the Hospital of Santa Maria Nuova in Florence, whose body he would later dissect (Kemp, 2004). He wrote of the experience, “This old man, a few hours before his death, told me that he had lived 100 years and that he was conscious of no bodily failure other than feebleness. And thus sitting on a bed in the Hospital of S. Maria Nuova, without any movement or sign of distress, he passed from this life. And I made an anatomy to see the cause of a death so sweet.” (Kemp, 2004). Upon dissection, Leonardo discovered that the blood vessels nourishing the man’s heart had shrunked and withered, drastically reducing blood flow to the cardiac tissues (Fig. 11).
He concluded that the ‘Centenarian’ had succumbed to vascular failure (Kemp, 2004). Meeting one of his experimental subjects in life had a profound effect on Leonardo, as he often referred to his dissection of this man in his writings from that point on.

Between dissections, Leonardo kept up his studies of the physical sciences. He began to examine the turbulence of water, making note of the various forms it assumed in its natural flow. He found its formation of whirlpools most fascinating, watching as the water was drawn into a central vortex by some invisible force (later identified as “centripetal acceleration”) (Kemp, 2004). He wrote, “The spiral or rotary movement of every liquid is so much the swifter as it is nearer the center of its revolution.” (Kemp, 2004). Leonardo kept this image in mind as he returned to the dissecting table, and had a flash of insight while exploring the heart.

He had been examining the pulmonary artery, and wondered how it delivered blood upward from the heart (against gravity) to the tissues of the lungs (Fig. 12).

He reasoned that the heart must expel the blood upward in a forceful manner, and in order for the lungs to receive it, a mechanism must exist to keep it from flowing back down into the heart (Kemp, 2004). He searched and found a structure consisting of three hollow, dome-shaped pieces of tissue in place at the artery’s exit point (Fig. 13) (Kemp, 2004).

He guessed that this structure must act as a valve, somehow allowing blood to flow in only one direction — away from the heart. After some thought, he came up with an idea for the valve’s operation. The heart sent a forceful push of blood upward, the turbulence of which forced the upside-down dome-shaped structures to collapse toward the wall of the artery (Kemp, 2004). When the upward force of blood from the heart lessened, the blood would fill the three valve structures, causing them to expand and seal the entryway back into the heart. Using his knowledge of water turbulence, Leonardo explained that the fast flowing blood formed vortices. These spiraling vortices of blood were responsible for opening the valve when entering the artery, and also for snapping it shut when attempting to flow back into the heart (Fig. 14) (Kemp, 2004).

Martin Clayton wrote on the subject, “Leonardo’s analyses of visceral function were primarily in terms of hydrodynamics, for he had no understanding of biochemistry: his many observations on the turbulence of flowing water and understanding of the formation of vortices lay behind his acute analysis of the functioning of the heart’s valves.” (Clayton, 1996). Leonardo’s application of centripetal acceleration to the operation of the pulmonary artery was accurate. In fact, recent studies have proven that his thoughts on the artery’s function were exactly right — almost 500 years after his dissections were conducted (Kemp, 2004). (Kemp, with the help of a team of scientists, successfully demonstrated Leonardo’s thoughts on blood flow in the pulmonary artery. Photographs of the experimental apparatus can be found on p. 80 of Kemp’s (2006b) book.)
V. Leonardo da Vinci cannot be defined as having been primarily a painter, and so his anatomical studies cannot be defined as mere extensions of his art.

Supporters of MacCurdy’s assumption about Leonardo’s intentions for his anatomical knowledge would argue that several of his writings point to his agreement with Leone Alberti — that painters should know of human internal structure. This is true; Leonardo wrote on the subject, “The painter who has acquired knowledge of the nature of the sinews, muscles, and tendons will know exactly the movement of any limb...and he will not do like many who in different actions always make the same things appear in the arm, the back, the breast, and the legs; for such things as these ought not to rank in the category of minor faults.” (MacCurdy). Theirs would be a valid argument — if Leonardo were only a painter. The depth of his work concerning the body, and the fact that most of his time was spent attempting to discover the mechanisms by which it functioned, make clear that he was not taking a “painter’s approach” to the subject. Those in agreement with MacCurdy would also maintain that Leonardo’s painting _St. Jerome_ (c. 1480) (Fig. 15), which depicts an emaciated man, would have required application of his anatomical findings.

This assertion is inaccurate as well. Leonardo could not possibly have applied anatomical knowledge to his work _St. Jerome_ because it was completed approximately ten years before he began his studies of human anatomy.

Leonardo hoped that his scientific findings would be shared with future generations, and left many indications that he wanted his writings published. He asks of the heirs of his knowledge, “I pray you, O successors, not to be constrained and get them [the writings] printed in...” (O’Neill and Cone). His practice of mirror writing, in backward letters from right to left, is most often attributed to some witty desire of his to confuse his readers, and therefore “encode” his ideas. A more logical explanation lies in simple printing methods of the day: words and drawings were somehow traced over with wet ink and transferred directly to another page (Bambach). Leonardo’s mirror letters, when directly transferred to another sheet, would read legibly from left to right. Perhaps Leonardo did not publish his writings himself out of fear; after all, the great astronomer and physicist Galileo did not get in trouble until after he started publishing his ideas. (Galileo Galilei (1564-1642) was persecuted by the Catholic Church for maintaining his belief that the Earth and other planets revolved around the Sun.) Leonardo willed his notebooks to trusted friends, hoping they would find a way to print them after his death.

His desire to be published indicates that Leonardo viewed himself as a scientist and thinker. His thoughts on himself and his work make it clear that he could not have conducted his studies of anatomy, nor of any other subject, merely to improve his painting. Granted, he was an artistic genius, but an apathetic one. Though he continued to run a studio, Leonardo thrived in court employment, which allowed him almost total intellectual freedom. It was said of Francis I, Leonardo’s employer from 1516 until his death in 1519, “he took such pleasure in hearing [Leonardo] talk that he would only on a few days of the year deprive himself of [Leonardo’s] company.” (MacCurdy).

For years, scholars have attempted to define Leonardo as a painter who “occasionally” dabbled in scientific study. This persistent classification of him is far from accurate. A painter would not have spent so much time studying falling bodies, water turbulence, or principles of mechanics. A painter would not have cared about portable bridges, catapults, or flying machines. A painter would not have spent more than ten years in painstaking study of the structure and function of the human body. As the evidence shows, it is more likely that Leonardo’s anatomical findings were applied in his engineering pursuits than in his artistic ones. In fact, Leonardo believed that the only difference between the human body and a well-built machine was the presence of a soul in the former (O’Neill and Cone). Therefore, it cannot be assumed that his anatomical studies were mere extensions of his art, like preparatory drawings for a painting. They were academic pursuits in themselves — knowledge for the sake of knowledge. James Hall, a Michelangelo scholar, makes an important distinction between the respective anatomical approaches of Michelangelo and Leonardo, “Leonardo’s anatomical studies were an end in themselves, with no obvious relationship to his paintings...” (Hall).

The fact is that Leonardo was a true intellectual, with an insatiable desire to learn. He was just as much physicist as he was astronomer, as much musician as he was architect, and as much anatomist as he was painter. To him, the body was a complex structure consisting of many integrated parts, and his drawings served as schematic diagrams of its operation. The fact that Leonardo devoted so much of his time to studies of the human body makes it indisputable that he saw more in it than just a beautiful form to be rendered on a canvas. To Leonardo da Vinci, the human body was fascinating, divine; it was the Perfect Machine.
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