WAS DA VINCI THINKING OF THE SPHERICAL LENS OF THE FISH EYE IN HIS PAINTING SALVATOR MUNDI?

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ABSTRACT

The image of Christ's robe, seen through the orb held by Christ in the painting Salvator Mundi by the Italian Renaissance artist Leonardo da Vinci, has led to speculation that the orb consists of a glass (or rock crystal, calcite) sphere that is either hollow or solid. Da Vinci's drawings and notes indicate that he had an intense interest in the optics of the eye and in the natural world around him. Is it possible that he was depicting the optical quality of the spherical fish lens, a lens with a gradient refractive index that neutralizes the spherical aberration that would otherwise exist?

KEYWORDS

Leonardo da Vinci, Salvator Mundi, Christ, orb, optics, fish crystalline lens.

Salvator Mundi (Savior of the World, 1499-1510), attributed to the Italian High Renaissance artist Leonardo da Vinci, or one of his disciples, is one of the world's most celebrated works of art. The painting, which a few years ago sold for a record $450 million, depicts Christ making a sign of the cross with his right hand and holding a large clear orb (globe) in his left. The optics of this orb has attracted controversy.

In *Leonardo da Vinci*, Walter Isaacson[1] noted that da Vinci failed to paint the distortions that should appear if the orb was made of solid glass. Instead, the folds in Christ's robe seen through the globe appear to be undistorted, as though it were a hollow glass bubble, perhaps, as Isaacson goes on to say, because Leonardo thought that the distortions would be a distraction.

Earlier, Martin Kemp, Professor of Art History at Oxford University, drew attention to small points of light in the globe painted by da Vinci. He referred to them as inclusions, characteristic of rock crystal and calcite.[2] Kemp noted that da Vinci was aware of the double refractive properties of calcite, and this property is represented by the doubled edge of the heel of Christ's hand as it holds the orb.

However, André Noest of Utrecht University wrote that the globe in the painting cannot represent a solid glass or calcite sphere.[3] Portions of Christ's body and robe seen through it do not appear distorted and or inverted. Moreover, the double image of the heel of Christ's hand is likely a pentimento, leftover from an earlier stage of the painting.

Three computer scientists at the University of California described the use of a computer graphics model to image of the folds in Christ's robe, as they would appear through the orb if it were solid or hollow.[4] The results (published in arXiv, an open-access archive) clearly show that the orb would have to be a thin-walled hollow sphere.

In referring to the copious notes and drawings left by da Vinci, Liang et al., add that da Vinci had the scientific knowledge, and the necessary materials, to produce an accurate optical portrayal of the image in the painting. Today we would call someone like da Vinci a polymath, one with wide-ranging knowledge of multiple fields of study, or, both figuratively and literally, a "Renaissance man."

As Isaacson points out in his book, da Vinci understood that art and perspective were dependent on a knowledge of optics. However, his wide-ranging interests included problems related to engineering and weaponry, as well as the study of human anatomy and physiology. For example, he developed a technique to examine the ventricles of the brain and carried out accurate dissections of spinal and cranial nerves. He was the first scientist to describe the neuro-motor effects of pithing a frog.

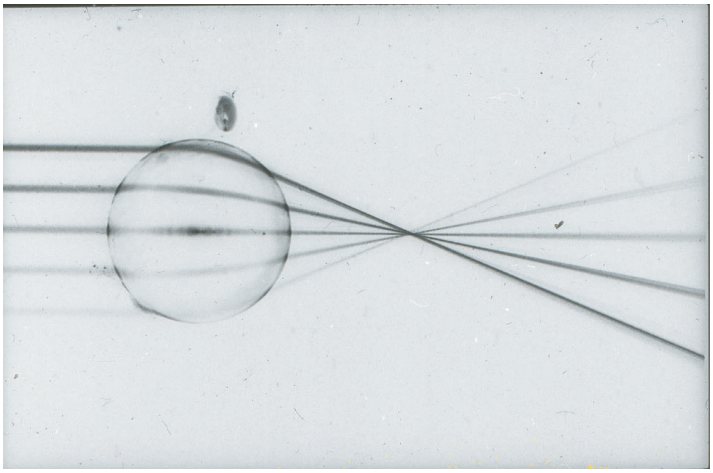
Da Vinci's diagrams indicate that, unlike many of his generation, he was aware of the refractive nature of the eye. Puzzled by the resulting inverted retinal image, he drew a diagram depicting an intriguing experiment involving an observer placing his face in a water-filled globe, which represented the eye, in order to see what the refracted image would be like. In fact, his interest in the effect of immersing the eye in water, has suggested to some that da Vinci understood the principle used in contact lens practice.[5]

Salvator Mundi by Leonardo da Vinci with the orb and optics in question in the lower right corner.

Isaacson's book portrays da Vinci as someone with an insatiable curiosity about the natural world, including, for example, the nature of the tongue of a woodpecker, a tongue that can extend more than three times the length of its bill, used to access insects and to protect the brain from shock. He describes how da Vinci swam underwater with fish in order to observe the propulsive action of the tail. Is it possible that da Vinci would likely have been aware of the optical qualities of spherical lenses that appear in nature, namely the lens of the fish eye?

Those familiar with the evolutionary optics of animal eyes might think of the fish lens when looking at the photograph of Salvator Mundi in Isaacson's book. In fish, the lens is virtually the only refractive element of the eye because the cornea does not refract light when the eye is underwater. The typical lens of a fish eye is spherical in shape with a constant relative focal length (lens radius to focal length).

All vertebrate eye lenses are cellular ectodermal structures that develop initially as surface invaginations in sequence with the developing optic cup of the embryo eye. The early embryonic lens consists of a single layer of epithelial cells forming a spherical hollow vesicle, later filled by the elongation of the posterior cells.



A photograph showing a spherical fish lens (rainbow trout, Oncorhynchus mykiss) in water focussing an array of five parallel helium-neon laser beams. The sharply focussed beams indicate little or no spherical aberration.

The lens develops through life by cell division (mitosis) and growth around the lens equator, with new cells forming shells around the posterior outer lens surface and under the anterior (front) layer of epithelial cells.

Continued lens development, with older tissue compressed centrally, results in the formation of a lens with a gradient refractive index, in which the refractive index increases from the lens periphery to the core. This in turn results in a lens which minimizes spherical aberration (the aberration characterized by lack of a common focus for light rays travelling through central and peripheral portions of the lens), a significant optical improvement.

Not only does the lens represent the optical quality of the whole fish eye, but because in most fish the pupil is immobile, the eye operates at low f-stop levels at all times and the iris cannot shield the retina from aberrant light rays. In other words, the optical quality of the lens is very important, particularly in fish species with life histories requiring superior vision.

Because the lens is spherical, lens shape is not a factor in the control of spherical aberration. The variation of lens refractive index resulting from continual lens development is the only control for spherical aberration of the fish eye. This is a feature that has fascinated scientists, at least as far back as 1816 (David Brewster[6]) and 1854 (James Clerk Maxwell[7]).

The optical quality of the spherical lens of the fish eye is vastly superior to that of a glass (or calcite) sphere. The continued development of the lens and the formation of concentric layers of lens cells, was established by German anatomists in the early 1800s. While it is unlikely that da Vinci knew about this aspect of lens embryology, it is possible, and perhaps likely, that he dissected fish and fish eyes. If he did, his interest in the optics of the eye would surely have made him aware of the optical quality of the lens. There is little in nature that escaped da Vinci's attention, as highlighted in Isaacson's book, and it is reasonable to suggest that he had the optics of a fish lens in mind when painting the orb.

Experts at the Museo Nacional Del Prado have recently questioned whether da Vinci, or someone he supervised in his

workshop, actually painted *Salvator Mundi*.[8] Either way, da Vinci's knowledge of the optical quality of the lens of the fish eye could have contributed to the portrayal of the orb held by Christ in the painting.

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