The Curious Case of Salvator Mundi

Figure 1. A reproduction of Salvator Mundi by Dianne Dwyer Modestini at New York University.

The Renaissance was a colourful period of European history, spanning from the 14th to the 17th century and signifying the rebirth of science, art, and culture following the Middle Ages.[1] This era began a new age of discovery during which classical Greek philosophy became the basis for the cultural movement of humanism, promoting the idea that people should enthusiastically embrace great human achievements. As a result, countless new inventions, techniques, and discoveries appeared in the arts and sciences, many of which were explored by Leonardo da Vinci.

Dubbed the "Renaissance Man",[3] Leonardo da Vinci (born in April of 1452) was an Italian inventor, widely regarding as one of the most diversely talented individuals to have ever lived. He was responsible for countless discoveries in the fields of mathematics, science, engineering, astronomy, art, and many more.[3] His drawings and paintings were famous because of his compositions, linear perspective, his ability to mimic light and shadow in paintings, as well as his outstanding knowledge of anatomy. He began his journey of oil painting at a young age, under the mentorship of the renowned Italian artist Andrea del Verrocchio.[4] In the very late 1400's, da Vinci composed a painting by the name of Salvator Mundi (*Saviour of the World*).[5] This painting, composed of oil paint on a plank of walnut wood, was exhibited in the Leonardo exhibition at the National Gallery in London in 2011. It was later sold in a public auction for a staggering $450 million, setting the world record for the most expensive publicly auctioned work of art. Although many specialists are confident that Salvator Mundi was made originally by da Vinci, some believe that the painting only contains elements of his artistic style.

Recent claims have been made that the painting, believed to be made in the 1490s, could potentially be a modern forgery created by an expert artist from a later era. In an attempt to verify Salvator Mundi as an original work of da Vinci, a team of art historians, conservation scientists and art forensic scientists gathered to perform tests on the painting in order to validate its authenticity. If the identity of paint pigments found by their elemental compositions agree with those used in the time of da Vinci's career, then it could be one way to invalidate the forgery claim.

Microscopic paint samples, each taken from different areas of the painting, were analyzed by X-Ray Fluorescence in order to quantify the elements and find the percent mass compositions of the paint pigments.[6] These compositions can be used along with the molecular weights of the pigments (determined by mass spectrometry) and element molar masses to find the molecular formulae of the sampled pigments. The identity of each pigment can then be determined by comparing it against the molecular formulae of common pigments to establish whether they had yet been invented during the time period in which Salvator Mundi was painted.

Sample 1:
Molecular weight: 764.05 g/mol

Atom	Percent Composition
Carbon	44.02%
Oxygen	16.75%
Chlorine	37.12%
Hydrogen	2.111%

Sample 2:
Molecular weight: 492.39 g/mol

Atom	Percent Composition
Carbon	53.66%
Oxygen	42.24%
Hydrogen	4.094%

Sample 3:
Molecular weight: 344.67 g/mol

Atom	Percent Composition
Copper	55.31%
Carbon	6.97%
Oxygen	37.14%
Hydrogen	0.585%

Sample 4:
Molecular weight: 240.21 g/mol

Atom	Percent Composition
Carbon	70.00%
Oxygen	26.64%
Hydrogen	3.357%

Sample 5:
Molecular weight: 452.26 g/mol.

Atom	Percent Composition
Cobalt	13.03%
Oxygen	42.45%
Nitrogen	18.58%
Potassium	25.94%

It is known that the original Salvator Mundi was painted directly onto a plank of walnut wood. As a secondary measure to attempt to refute any forgery claims, radiocarbon dating was performed on a microsample of the painting to determine its approximate age.[7] The element carbon possesses three different isotopes: ^{12}C, ^{13}C, and ^{14}C. Carbon-14 (^{14}C, or radiocarbon) is an unstable and weakly radioactive isotope, which is formed in the Earth's upper atmosphere when cosmic ray neutrons interact with ^{14}N. This ^{14}C is rapidly assimilated into atmospheric CO_2, which results in a constant and measurable concentration of ^{14}C atoms in the air. While plants are alive, they are constantly exchanging carbon in their cells through photosynthesis and cellular respiration. The result of this is that all living plants also contain a predictable concentration of ^{14}C. When those plants die however, the uptake of carbon from the atmosphere ceases, and the quantity of ^{14}C in their tissues gradually decreases as the radioactive carbon isotope decays. This decrease in concentration follows a first-order radioactive decay, which can be used to determine the amount of time which has passed since a plant (or animal) died. The following equations can be used to determine the age of the sample.

$$[A]_t = [A]_0 e^{-kt} \qquad (1)$$

Where A refers to the radioisotope (in this case ^{14}C), and:

$[A]_t$ is the quantity of the radioisotope remaining at time t,

$[A]_0$ is the initial quantity of the radioisotope (*i.e.* at time zero, when the tree was cut down),

k is the first-order rate constant, and

t is time.

When rearranged and integrated, this equation becomes:

$$ln \left(\frac{[A]_t}{[A]_0} \right) = -kt \qquad (2)$$

Where k is the first-order rate constant and relates to half-life ($t_{1/2}$) through the following relation:

$$t_{1/2} = \frac{ln2}{k} \cong \frac{0.693}{k} \qquad (3)$$

Data obtained from accelerator mass spectrometry analysis of the wood revealed that the sample contains 93.8% of its original ^{14}C. The first-order half-life ($t_{1/2}$) for ^{14}C decay is 5730 years.

Based on your analysis of the paint and wood samples, explain your conclusion of whether or not this is the original Salvator Mundi painting.

References

1. Renaissance. https://www.history.com/topics/renaissance/renaissance (accessed February 2020).

2. Mark, J. Protagoras. https://www.ancient.eu/protagoras/ (accessed February 2020).

3. Heydenreich, L. Leonardo da Vinci | Biography, Art, & Facts. https://www.britannica.com/biography/Leonardo-da-Vinci (accessed February 2020).

4. Leonardo da Vinci. https://www.history.com/topics/renaissance/leonardo-da-vinci (accessed February 2020).

5. Leonardo da Vinci (1452-1519), Salvator Mundi. https://www.christies.com/lotfinder/Lot/leonardo-da-vinci-1452-1519-salvator-mundi-6110563-details.aspx (accessed February 2020).

6. de Viguerie, L.; Walter, P. Revealing The Sfumato Technique Of Leonardo Da Vinci By X-Ray Fluorescence Spectroscopy. *Angewandte Chemie International Edition* **2010**, *49* (35), 6125-6128.

7. Wacker, L.; Synal, H.; Günther, D. Uncovering Modern Paint Forgeries By Radiocarbon Dating. *Proceedings of the National Academy of Sciences* **2019**, *116* (27), 13210-13214.