Teaching Science in Art

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Technical Examination of 17th-Century Dutch Painting as Interdisciplinary Coursework for Science Majors and Nonmajors

Erich S. Uffelman
Department of Chemistry, Washington and Lee University, Lexington, VA 24450; *uffelmane@wlu.edu*

This paper exists in two forms. This printed, illustrated version is a synopsis of some of the topics and issues that are explored in a more extensive version online,W which is not illustrated. The online version attempts to provide a complete discussion of how the course is implemented, evaluated, and so forth, and also has a comprehensive bibliography of ~300 references.W

Background

The chemical education community has long recognized that the technical examination of artwork is a valuable tool for teaching science to students in primary school *(1)*, middle school *(2)*, high school *(3–6)*, and universities *(7–28)*. Among many outstanding programs, the author has been fortunate to recently visit the distinguished science in art classes taught by John Bordley (Sewanee: The University of the South) *(29)* and Ruth Beeston (Davidson College), and to thrice present work at a flagship institution in the field—the NSF-sponsored workshop conducted annually by Patricia Hill (Millersville University) *(30, 31)* and Michael Henchman (Brandeis University) *(32)*, based on their own courses *(33)*. In addition, new, increased efforts connect the benefits of study abroad programs to science education *(34)*.

Since the development phase began in 1994, two linked courses have been created at Washington and Lee University (W&L) in the technical examination of 17th-century Dutch painting for both science majors and nonmajors. Because the courses have been taught as an individual research seminar to a senior art history major (2002), as on-campus courses for all students (1999 and 2003), as study abroad courses in The Netherlands for all students (2005 and 2007), and have become a permanent part of our curriculum, sufficient experience has been gained to offer this short report of opportunities and limitations made possible by this approach. Significant efforts have been and are being made to release the full set of course materials to the wider community. These materials currently consist of more than 900 PowerPoint slides on the chemistry, physics, biology, geology, history, religion, economics, and art history required for a rich understanding of 17th-century Dutch painting.

Course Structure Overview

The class consists of two, three-credit courses run concurrently and linked as co-requisites: Univ 202 Science in Art (which counts toward nonlaboratory science general education requirements) and Art 380 Science in Art (which counts towards humanities GE requirements). All students in this course receive six credits towards graduation, regardless of their progress towards fulfilling their GE requirements. W&L has an unusual 12-week (fall term), 12-week (winter term), 6-week (spring term) schedule; the class runs during the 6-week spring term. Opportunities, limitations, and transferability issues to other institutions on other calendars are discussed in the extensive online version of this paper.W Three weeks of the class are used to teach the science background, and three weeks are spent teaching the art, art history, and elements of religion, economics, and history that are germane. At the course's conclusion, each student presents a case study of a 17th-century Dutch painting, considering its material structure and material history, its context in the artist's career, and its art historical context. With the 2005 and 2007 study-abroad version of the class, three weeks transpired at W&L, and the last three weeks were based at the Center for European Studies at Universiteit Maastricht.

The class is extremely rigorous yet presupposes no technical background beyond high school mathematics and science. Class enrollment is limited to 10–18 students (first year through senior year) with various majors (e.g., chemistry, psychology, biology, art, English, history, economics, etc.). The class is roughly evenly divided between science majors and nonmajors. Entrance into the class is by instructor permission, and the significantly increasing popularity of the course is making those permission decisions more challenging. Preference is given to seniors; two spots are saved for first-year students. Reasonable attempts are made to have the final composition (e.g., age, gender, background) of the class reflect the composition of the applicant pool, while simultaneously trying to balance the knowledge and experiences of the participants.

Class Topics

Science Content

We achieve depth with students who have a limited mathematics and science background (approximately half the members of the class) by focusing almost exclusively on 17th-century Netherlandish painting. By limiting the courses to this time period and by not discussing sculpture, fresco, pottery, photography, and so on, we target the chemistry and science needed to understand a more limited set of art materials and methods and can link the scientific analysis of the paintings to the culture, history, economy, and scientific milieu of the "Dutch Golden Age".

During the three weeks on campus, the class meets 12–15 hours per week. Students demonstrate their science learning via two demanding, out-of-class, 120-minute tests. The first science week introduces basic mathematics and dimensional analysis; fundamental aspects of nuclear reactions related to the pigment analysis technique of neutron activation autoradiography; basic ray optics and atmospheric optical phenomena (e.g., "brown-green-blue" perspective); and the wave–particle duality for the photon and electron. Optical phenomena are demonstrated with inexpensive lenses, mirrors, laser pointers, gratings, and light sources. The second week is an accelerated course in chemical bonding and intermolecular forces; hydrogen-like atomic orbitals; electron configurations and periodic properties of the elements; Lewis dot pictures; covalent and ionic bonding; and valence bond theory and molecular orbital theory of bonding in organic molecules. The third week covers analytical instrumental methods such as x-radiography; X-ray powder diffraction; SEM; Raman microscopy; IR spectroscopy, microscopy, and reflectography; GC; LC; MS; UV–vis; UV photography; and laser ablation methods. The chemical and biological degradation of paintings is discussed. Degradation issues of paintings on the three principal supports of the era (canvas, wood, and copper) are compared and contrasted. A full set of resources is referenced in the extended online version of this paper.W

Student Background Presentations

Once students have a common science background that enables them to think about the material properties of 17th-century Dutch paintings, we establish several contexts of 17th-century Dutch art. Again, we generate depth by focusing on the Dutch Golden Age. The students have the responsibility of teaching each other much of the background material. Given some lead references, they manage the course and present lectures based on their own areas of expertise or interest. Presentation topics have included: a general overview of 17th-century Dutch history; the 80 Years War with Spain; the 17th-century Dutch wars with England; the religious context of The Netherlands in the 17th century; the economy of 17th-century Holland (particularly an art market geared toward an emergent middle class, rather than one geared toward ecclesiastical patronage, and the tulip mania that caused an economic collapse in 1632); evidence for Vermeer's use of the camera obscura (and rebutting viewpoints); theories on the use of optical devices by old master painters (and rebutting viewpoints); 17th-century Dutch architecture and interior spaces; portrayal of women in 17th-century Dutch painting; the history of the Dutch East India Company and its impact on Dutch art and culture; World War II's impact on The Netherlands and especially the still very alive issues of art repatriation; the impact of Dutch picture framing practices on the appearance of paintings; and finally the basics of the human visual system and the perception of art (especially *trompe l'oeil* paintings). A full set of resources are referenced in the online version of this paper.W

Study-Abroad Course Component

The class has been run three times entirely on the W&L campus (concluding with a trip to the National Gallery of Art in Washington, DC). That format succeeded, prompting the much more ambitious 2005 and 2007 study-abroad format. Several points arise from the study-abroad version:

1. A partnership with the Center for European Studies at Universiteit Maastricht (CES–UM) simplified satisfying administrative concerns involving security, health, and logistics. CES also has faculty who are experienced and enthusiastic participants in the various international programs visiting their campus.
2. Three extremely intense weeks on the W&L campus allowed the students to learn their science and complete the research for their presentations. Also, the foundation for appreciating the history and culture of The Netherlands was very carefully and rigorously laid.
3. As a group, we visited the following places in The Netherlands and Belgium over a three-week period in 2005: The Rijksmuseum (Amsterdam), the Amsterdams Historisch Museum (Amsterdam), the AMOLF-FOM Institute (key scientific laboratory for the MOLART and de Mayerne Projects, Amsterdam), The Frans Hals Museum (Haarlem), the Grote Kerk St. Bavo (Haarlem), the Royal Picture Gallery Mauritshuis and Mauritshuis Conservation Department (The Hague), Stedelijk Museum Het Prinsenhof (Delft), the Oude Kerk and Nieuwe Kerk (Delft), Boijmans van Beuningen Museum (Rotterdam), Koninklijk Museum voor Schone Kunsten (Antwerp), Rubenshuis (Antwerp), Antwerp Cathedral of Our Lady, Bonnefanten Museum (Maastricht), Basilica of St. Servatius (Maastricht), the Basilica of Our Lady (Maastricht), and Sint Janskerk (Maastricht). These sites all either hold vast amounts of art, are depicted in significant books on 17th-century Dutch painting, or are involved in the investigation of those paintings. In 2007, we visited the Instituut Collectie Nederland (ICN, Amsterdam) and the Stichting Restauratie Atelier Limburg (SRAL, Maastricht) in place of the Amsterdams Historisch Museum.
4. Volunteers, docents, conservators, and scientists enthusiastically shared their knowledge with the students, and the high level of preparation the students brought on the trip obviously increased the guest speakers' enthusiasm.
5. The students were given two, three-day weekends to do their own traveling. Different groups of students visited Paris, Cologne, Aachen, Brugge, Utrecht, and revisited Amsterdam and Rotterdam. Even though the three-day weekends were entirely their own, the students reported going to art museums and cathedrals in all of the major cities they visited, in many instances recommending exhibits to their professor.
6. Although Maastricht is two hours from the "Randstad Arc" of cities where most of the major museums reside, the students all agreed by the end of the course that Maastricht's charm, as well as the CES-UM infrastructure, made Maastricht an excellent "base camp".
7. One unfavorable issue with the study-abroad version of the class, compared to the entirely domestic version, is the added expense. Some students obtained financial aid for the trip, although most had to absorb the $3000 extra cost. We are currently pursuing this issue with W&L development office staff, in order to increase financial aid for study abroad.

Examples of Artwork

While the online version of this paperW gives a detailed listing of case studies presented by the professor and the students (along with comprehensive references) and discusses the benefits of the class, the limitations of the class, transferability issues, and assessment, this synopsized version of the paper will provide a few samples of the art and a *very* brief taste of the analyses. Mirroring the current theme in this *Journal*—

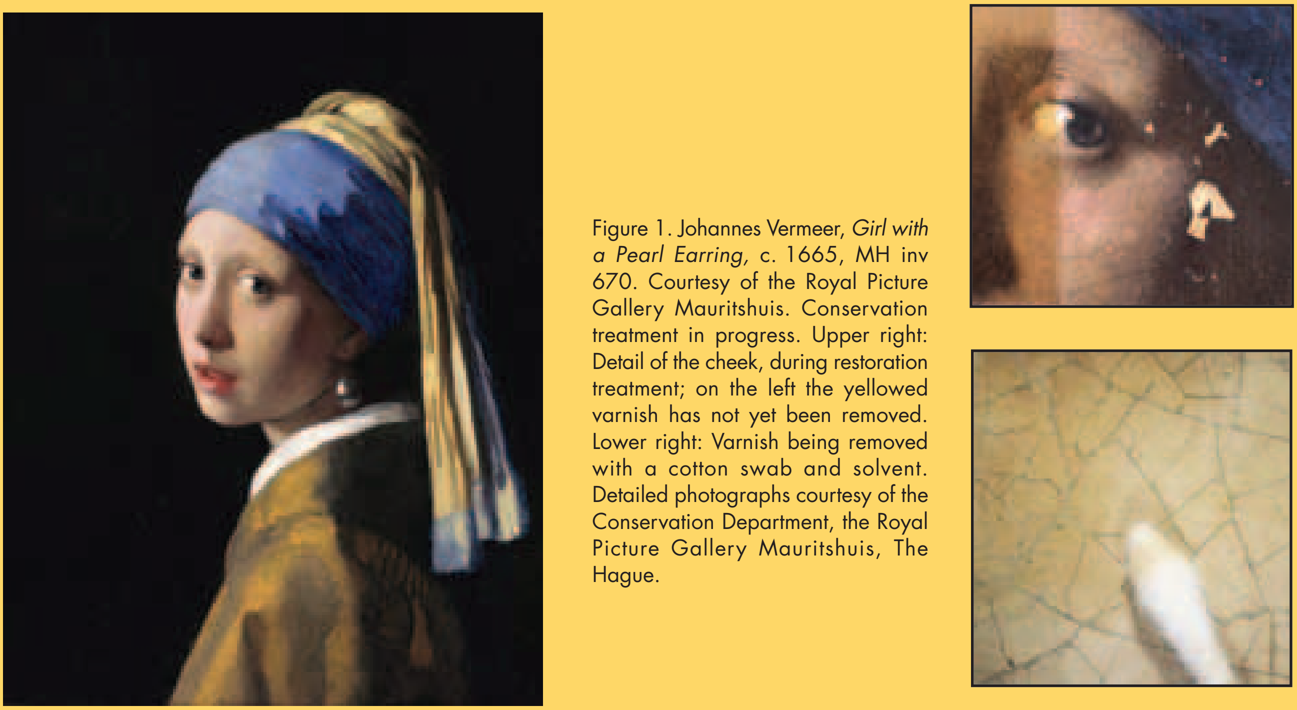

Figure 1. Johannes Vermeer, *Girl with a Pearl Earring*, c. 1665, MH inv 670. Courtesy of the Royal Picture Gallery Mauritshuis. Conservation treatment in progress. Upper right: Detail of the cheek, during restoration treatment; on the left the yellowed varnish has not yet been removed. Lower right: Varnish being removed with a cotton swab and solvent. Detailed photographs courtesy of the Conservation Department, the Royal Picture Gallery Mauritshuis, The Hague.

"the many faces of chemistry"—we will visually pun and present the chemistry that may be illustrated from some of the most famous faces in 17th-century Dutch painting. We will move across the globe from east to west, starting at the Royal Picture Gallery Mauritshuis in The Hague, then going to the National Gallery of Art in Washington, DC, then going to The J. Paul Getty Museum in Los Angeles. The examples chosen have been studied extensively by numerous methods, although we will highlight a single chemical idea or analytical technique with each painting.

The Royal Picture Gallery Mauritshuis, The Hague

Varnish Removal: Vermeer's *Girl with a Pearl Earring*

One of the iconic images of 17th-century Dutch painting, Vermeer's *Girl with a Pearl Earring* underwent extensive analysis and conservation at the Royal Picture Gallery Mauritshuis in 1995 *(35)* (Figure 1). Many students are familiar with the painting via the eponymous novel by Tracy Chevalier *(36)* and the movie from Lions Gate *(37)*. The painting is a classic example of the Dutch "tronie"—a painting that is not intended as a portrait of a particular person, but that is intended as a study of facial features, expression, and so forth. This work dramatically illustrates Vermeer's powers of observation of light and his command of painterly technique.

Girl with a Pearl Earring also serves as one of myriad examples where the removal of old varnish dramatically enhances a painting's appearance. This process, although never trivial, has been systematized by considering various organic solvent properties typically organized in a Teas diagram. The key is to remove the old varnish, typically an aged dammar resin *(38)*, from the surface of the aged oil paint, typically a mixture of plant fatty acid triglycerides *(39)* (usually linseed oil, but sometimes walnut or poppy seed oil) that have polymerized by free radical pathways involving air oxidation *(38)*. Various mild mixtures of acetone, ethanol, or isopropanol, and mineral spirits are typically tried on minute and inconspicuous areas of the painting. Once the conservator decides upon a particular solvent system, the conservator painstakingly removes the varnish using a multitude of cotton swabs, often under stereomicroscopy. Clearly, skillful removal of old varnish, followed by a careful reintegration of the paint losses and an application of fresh varnish (as a surface protection layer and to restore saturation), dramatically improves a painting's legibility.

Using SIMS To Assess Lead Soap Formation: Rembrandt's *Anatomy Lesson of Dr. Nicolaes Tulp*

Frans Hals and Rembrandt are typically credited with revolutionizing the group portrait. Prior to their work, the northern European group portrait was static in composition. Frans Hals and Rembrandt infused their group portraits with dynamism. Newly arrived in Amsterdam from Leiden, the young Rembrandt's masterful *Anatomy Lesson of Dr. Nicolaes Tulp* made him one of the most highly sought portraitists in the city. The painting attracts students because of its intrinsic power, yet it also attracts students interested in medicine or history, particularly given differences in the way in which public anatomy lessons were actually performed compared to the scene that Rembrandt depicted *(40)*.

The painting underwent extensive conservation treatment and research in the late 1990s *(40)*, which revealed, among many things, the deleterious formation of lead soaps within the paint layers (Figure 2). Oil paint obviously consists of more than just plant fatty acid triglycerides; suspended within the oil are insoluble solid pigment particles ground to a certain

Figure 2. Shown at top, Rembrandt van Rijn, *The Anatomy Lesson of Dr. Nicolaes Tulp,* 1632, MH inv 146. Courtesy of the Royal Picture Gallery Mauritshuis. Assessing the formation of lead soaps within the paint layers. Middle row, left: Protruding lead soap aggregates have resulted in masses of tiny crater-like holes in the paint surface. Middle row, right: The aggregates are not color-dependent but are present in dark- and light-colored areas of the painting. Lower left: In this painting the aggregates appear as gray spots in the x-radiograph. Lower right: In cross-section the aggregates appear as a globular translucent mass with a diameter about twice that of the (lead white-containing gray) second ground layer from which they originate. Detailed photographs courtesy of the Conservation Department, Royal Picture Gallery Mauritshuis.

level of fineness or coarseness. The polymerized oil traps the pigment particles. However, over the course of centuries, the oil is not inert to pigment particles with Brønsted base properties, particularly lead white, which is the compound basic lead(II) carbonate that contains Pb(II), carbonate, and hydroxide. Given sufficient time, the ester linkages in the fatty acid triglycerides are hydrolyzed, and the liberated fatty acids are deprotonated by bases in the lead white, resulting in lead soaps. These lead soaps slowly migrate through the paint layer, form aggregates, erupt through the surface of the painting, and are abraded away, leaving tiny craters in the painting *(41).*

Jaap Boon's group has used, among other techniques, secondary ion mass spectrometry (SIMS), in which a primary ion beam may be swept across the surface of a minuscule paint sample, generating secondary ions that are analyzed. Because the primary ion beam may be controlled with high precision in the X–Y plane, and because the primary ion beam may be used to excavate into the paint sample, stunning 3-D maps of the paint components are obtained *(41).* Petria Noble spearheaded a worldwide survey of museums to assess the dimensions of this problem *(42),* and the results were sobering: lead soap aggregate formation has now been identified in oil paintings throughout the world's collections and in paintings as recent as the late 19th century.

The National Gallery of Art, Washington, DC

SEM-EDS Discoveries: Jan Steen's *The Dancing Couple*

Jan Steen is probably the most famous exponent of 17th-century Dutch genre painting. It is not appropriate in this space to delve into the intricate iconography Steen employs in *The Dancing Couple* (Figure 3), although it is worth mentioning that many students are drawn to this particular painting, not necessarily for aesthetic reasons, but because they are either amused by the social situation portrayed, or, in the case of many female students, feel a certain empathy with the central female figure.

The work was studied intensively in the mid-1990s by E. Melanie Gifford and Michael Palmer *(43);* we will focus here on one result: there is no green pigment in the painting. This result was obtained by SEM–EDS (scanning electron microscopy–energy dispersive X-ray spectroscopy, sometimes also called SEM–EDX). Many students think of SEM purely as an imaging technique in which a beam of electrons is focused on a target and secondary electrons are detected. However, in the analysis of tiny paint cross sections, imaging is usually not relevant. Instead, conservation scientists capitalize on the X-rays produced when the electron beam ionizes core electrons from atoms, and electrons from higher lying orbitals "fall" into the hole in the core. This X-ray emission is quantized and thus permits elemental analysis. Because the beam may be extremely

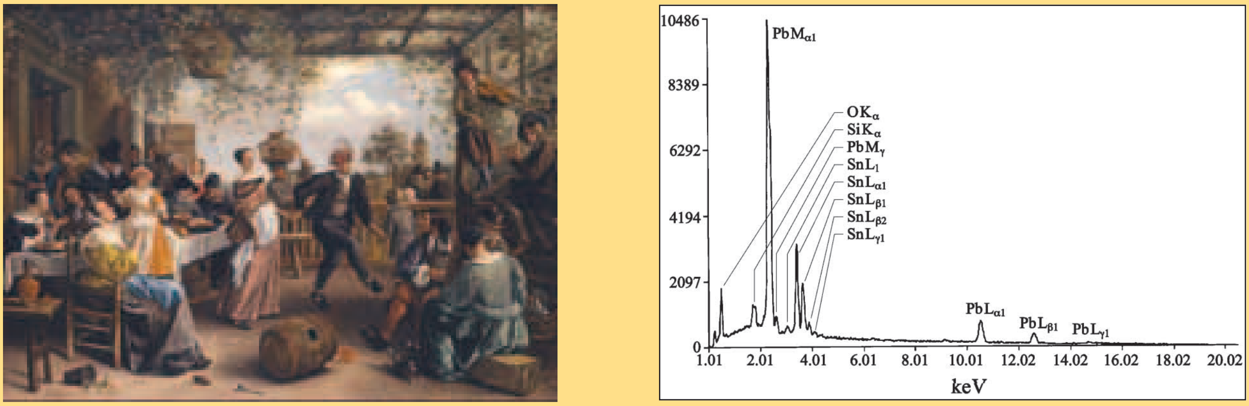

Figure 3. Jan Steen, *The Dancing Couple,* painting (left) and the SEM–EDS spectrum (right) *(43)* reveals lead–tin-yellow. Widener Collection, Image © 2007 Board of Trustees, National Gallery of Art, Washington, DC. 1663, oil on canvas [1942.9.81.(677)/PA].

precisely aimed, conservators obtain exquisite resolution of the elemental composition of pigment particles in each layer of paint. When SEM–EDS, polarized light microscopy, and other methods were applied to *The Dancing Couple,* every instance of green was determined to be a mixture of blue (smalt—a ground cobalt glass, azurite, or indigo) and yellow (lead–tin yellow, yellow iron oxide, or yellow lake). Dutch painters knew that several green pigments could be fugitive and discolor *(44);* clearly Steen strove to avoid that problem.

Revealing X-rays: Willem Drost's *The Philosopher*

Originally attributed to Rembrandt, *The Philosopher* (Figure 4) is now attributed to Rembrandt's workshop, with Willem Drost, a Rembrandt apprentice, currently tentatively receiving credit. This painting is one of many that permits a discussion of attribution problems. Many students, especially science majors, enter the class naively expecting that science can be used to make definitive statements about the authorship of paintings. In the case of recent forgeries done of old master paintings, if the forger did not use 17th-century Dutch supports (e.g., paintings on wood panel can be dated by extensive dendochronological databases), pigments, binding media, and varnishes, and if the correct analytical methods were used, these fakes may be readily debunked. Even if a forger used the correct pigments, MS isotope analysis can establish whether or not the source of the pigment was a source available to the 17th-century Dutch. It is, of course, critical to examine areas of the painting that have not been retouched by 18th-, 19th-, or 20th-century restorers, or anachronistic pigments can lead to false deattributions.

However, the much greater problem involves sorting authorship in large workshops. Given that apprentices worked in the studio with the master, using the master's supports, binding media, pigments, and varnishes, and given that apprentices were taught to imitate the master's technique, frequently by copying the master's works, assigning attributions becomes extremely challenging. *The Philosopher* is one example of many in which x-radiography has proven invaluable *(45).*

Students can be quickly taught that X-rays are most easily stopped by atoms possessing large numbers of electrons. X-radiography is directly analogous to X-raying a patient. A painting is placed between a source of diffuse X-rays and X-ray film, and the X-rays expose the film where they are not stopped by heavy elements. Since lead white was a critically important pigment on the artist's palette, assessing its distribution in a painting can tell the conservator volumes about

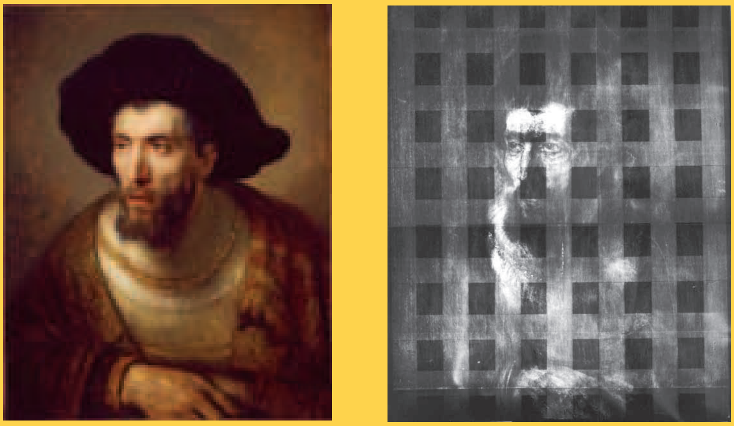

Figure 4. Workshop of Rembrandt van Rijn (possibly Willem Drost), *The Philosopher* (near right), Widener Collection, Image ©, 2007 Board of Trustees, National Gallery of Art, Washington, DC, c. 1653, oil on panel [1942.9.66.(662)/PA]. X-radiograph (far right), courtesy of the Conservation Department, National Gallery of Art, Washington, DC, Workshop of Rembrandt van Rijn (possibly Willem Drost), *The Philosopher,* Widener Collection, Image © 2007 Board of Trustees, National Gallery of Art, Washington, DC, c. 1653, oil on panel [1942.9.66.(662)/PA].

Figure 5. Rembrandt Harmensz. van Rijn, *An Old Man in Military Costume,* c. 1630–1631, oil on panel; unframed: 66 × 50.8 cm (26 × 20 in.); framed: 98.4 × 82.2 × 9.5 cm (38 3/4 × 32 3/8 × 3 3/4 in.) The J. Paul Getty Museum, Los Angeles, 78.PB.246. Painting (far left) and neutron activation autoradiograph (left). Autoradiograph courtesy of the Conservation Department, The J. Paul Getty Museum.

an artist's technique, pentimenti that were changed, and additions or deletions that prior conservators may have made to the painting. When this author first saw *The Philosopher* as a high school student in the 1970s, the subject's hands were obscured by dark paint. X-radiography revealed the hands underneath the dark paint, the dark paint was removed, and the hands are now on view.

The J. Paul Getty Museum, Los Angeles, California

Neutron Activation Autoradiography: Rembrandt's *Old Man in Military Costume*

In the 1980s, x-radiography revealed what appeared to be the head of a young man in paint layers underneath the current painting (Figure 5). Neutron activation autoradiography provided compelling proof of this face. A classic book on neutron activation autoradiography *(46)* explains that if a painting is exposed to a source of slow thermal neutrons, some of the pigment atoms and ions will gain neutrons and become radioactive. Neutron-rich isotopes decay by β^- emission (typically accompanied by a γ ray). Prior to the 1990s these decays were detected with photographic film; now they are monitored with solid-state detectors. Because different isotopes of different elements have different half-lives, a time plot of decays will identify the isotope that is decaying. If the isotope in question has a half-life in the range of minutes to a few years, it is possible to measure it. Thus, maps of pigments may be generated by this nondestructive technique. In 1995, Henry Prask and Michael Rowe at NIST were conducting neutron activation autoradiography studies of paintings. Mark Leonard at The Getty brought the painting to the Reactor Radiation Division at NIST in 1996 for autoradiographic study. The results produced a dramatically more legible image of the underlying portrait. The underlying portrait appeared to have stylistic similarities to several other Rembrandt portraits, some of which are signed and dated 1631 or 1632.

XRF Analysis: Frans van Mieris the Elder's *Pictura*

Gerrit Dou was one of Rembrandt's first pupils. As an independent master, he became one of the most highly regarded "fijnschilders" of the Dutch Golden Age. The fijnschilders (literally, "fine painters") were renowned for their imperceptibly fine brush strokes and highly finished paintings. Frans van Mieris the Elder was a student of Dou's and also became one of the leading fijnschilders. His *Pictura* at The Getty is a small magnificent gem of a painting executed not on a support of canvas or wood, but on copper (Figure 6). Paintings done on copper permitted artists to use extremely fine brushwork. In addition, if the artist properly prepared the copper plate to accept paint so that paint adhesion is not a problem, these works can be in excellent condition *(47).* Since canvas and wood are both hydrophilic and oil paint is hydrophobic, when the oil paint polymer becomes brittle with time and loses its elastomeric properties, the paint film cracks when the support expands and contracts with changing humidity. Copper does not expand and contract with changing humidity, and its thermal coefficient of expansion is comparable to that of the oil paint polymer.

Figure 6. Frans van Mieris the Elder, *Pictura (An Allegory of Painting),* 1661, oil on copper; unframed (arched top): 12.5 × 8.5 cm (5 × 3 1/2 in.); framed: 15.2 × 11.9 × 1.3 cm (6 × 4 11/16 × 1/2 in.). The J. Paul Getty Museum, Los Angeles, 82.PC.136. Painting (left) and indication of pigments from XRF (right). Indication of pigments from XRF courtesy of the Conservation Department, The J. Paul Getty Museum.

In addition to the palette and brushes that identify *Pictura,* the statuette she is holding almost certainly refers to the centuries-old debate at the time concerning the relative intrinsic merits of painting versus sculpture. Clearly, van Mieris, with his highly realistic painting of the statuette, is claiming superiority on the part of painters. Recent scholarship has linked the ordering of the colors on *Pictura*'s palette with the ordering of colors recommended to artists in the de Mayerne manuscript. Intriguingly, in 1996, Joris Dik delved into questions involving the paints depicted on *Pictura*'s palette using X-ray fluorescence (XRF). XRF has been a powerful technique for many years in art conservation science *(48);* and relatively inexpensive portable XRF devices are currently revolutionizing the field. In XRF, no paint sample is required. Instead, an X-ray beam impinging on the painting at close range causes core electrons of atoms to be ionized. Subsequently, higher energy electrons "fall" into the core vacancies, emitting quantized X-rays of characteristic frequencies. If the painting's XRF spectra are taken with systematic variation in the X–Y plane, 2-D element maps are possible. With proper interpretation, pigment analysis results. Joris Dik's analysis of the *Pictura* revealed that the pigments on *Pictura*'s palette are not the pigments that van Mieris used to paint the figure of *Pictura.* The red used to paint *Pictura* was cinnabar; the yellow was lead–tin yellow. The reds on the palette are earth colors and a red lake; the yellow is a yellow ochre. Exciting new developments with confocal X-ray fluorescence are making 3-D nondestructive pigment maps possible in the analysis of painting *(49, 50).*

Conclusions

This article has briefly introduced two linked courses that bring together science majors and nonmajors into an intense examination of 17th-century Dutch painting. The class has succeeded strongly when offered either on campus, or as a course that is split between study time in the U.S. and in The Netherlands. This paper has attempted to give a flavor of the examples that may be discussed. It must be emphasized that the examples presented here, as well as many others, are the subject of much more comprehensive treatment in our class—both from a scientific standpoint and an art historical standpoint. Readers who want to examine a full treatment and description of the course, along with a comprehensive set of ~300 references for course topics in science, art history, economics, religion, and so on are referred to the extended online version of the paper.**W** Ongoing efforts are being made to give the wider chemical education community access to more than 900 PowerPoint slides that cover those topics and that form the basis of the course.

Acknowledgments

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$^{\text{w}}$Supplemental Material

Comprehensive references (~300) for science, art history, economics, religion, and other course topics are available in the full-length version of the paper that appears in this issue of *JCE Online;* that version also treats subjects not discussed in this print version. Also included are two examples of course case-study descriptions, as well as students' course evaluation responses.

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