Advanced Chemistry: Applications in Art & Archaeology

Grades: 11,12

Length: Full Year

Environment: Classroom-based

Honors: Honors

Subject: Science (D)

Discipline: Chemistry

Institution: Thacher School

Course Overview

Course Goals:

1) to provide students who have completed their introductory study of physics, chemistry, and biology in the Integrated Science 1 and Integrated Science 2 year-long courses at Thacher with additional exposure to more advanced principles and topics in chemistry (including radiometric dating, stoichiometry, solutions, solubility & precipitation, electrochemistry, kinetics, acids & bases, chemical equilibrium, thermodynamics, and molecular structure & spectroscopy) as they apply to the production, analysis, historical understanding, restoration, conservation and authentication of works of art and cultural heritage

2) to learn to work collaboratively, collegially, and effectively with peers in a team environment

3) to apply scientific knowledge to a useful purpose (i.e., historical and cultural context, problem-solving, design thinking, engineering, etc.)

4) to design a laboratory experiment to address scientific questions and to revise and improve the experiment based on initial results

5) to critically read and evaluate primary source scientific publications

6) to appreciate where our scientific understanding is on firm ground and where it is not

7) to develop the skills and methods (i.e., scientific literature research, experimental laboratory research, data analysis skills) needed to advance the state of our collective scientific understanding

Course Pedagogies:

Collaborative learning teams composed of 3-4 students each will explore the application of chemistry and materials science principles to the study of archaeology, studio art, and art history in a partially self-guided and self-paced manner. For each content area, several guiding questions will frame the students' deeper exploration of the topic. An example of the typical workflow in a unit might look like the following:

1) introductory lecture(s) on a topic, either 1) presented by the instructor live in class or via video or pencast, or 2) presented by an expert live in class or via video or pencast obtained from the web

2) student literature research from books, professional science journals, lay-science articles, the web, or other sources

3) guided discussion, questions, and answers in teams with and/or without the instructor's assistance

4) homework (quantitative problem solving, case studies: articles or videos accompanied by Q&A to allow both students and instructor to formatively assess and improve student understanding)

5) formative assessments (quizzes taken individually, scored, compared, and discussed within a team to put the onus on team members to facilitate the understanding of everyone in their group, with additional versions taken again as necessary in order for each student to achieve mastery)

6) laboratory experimentation and/or computer modeling exploration, occasionally with the team's choice of a guiding question

7) synthesis and presentation of the material, undertaken both alone and/or in teams, utilizing multiple approaches to gauge student understanding in summative assessments including quizzes, tests, laboratory reports, oral presentations, scientific posters, infographics, student-generated videos, student-generated works of art, formal papers, and real-world, document-based queries, with the understanding that: 1) several of these assessments will be designed for a larger audience (the broader school, the Ojai community, etc.), 2) students will have some choice of their mode of assessment, and 3) each of these forms of assessment will be utilized over the course of the year.

1) Painting: Pigments, Binders, Surfaces & Analysis (10 weeks)

What is art? When was the first art made (and how do we know)? How do we understand the evolution of art from its historical origins until now? What is the biology of the human eye and how do humans see color? Which colors were the first used to paint? How has the available color palette evolved over time? What are the historical developments or technological advances that have prompted this evolution? How are pigments and dyes chemically synthesized? How are powdered colorants turned into paints and applied to a surface to make a painting? What are the chemical reactions involved in the fresco technique? How has the development of colorants influenced society and the production of art (or vice versa)?

Assignments

Sample assignment: **What is the chronology of art?**

Students will work in teams to conduct web-based research and construct and present for class discussion their team's chronological classification of art from its inception to the modern-day. Students will come to appreciate that artistic time periods are related to historically, culturally, and artistically significant events, have fuzzy boundaries and are geographically diverse.

Other example assignment(s):

'What is Art?' (exploration of various definitions of art)

'How do Humans See Color?' (eye anatomy and the biology of color perception)

'How Old is the Oldest Art?' (intro to U-Th dating of oldest cave art, case study where students calibrate C-14 age determinations of New Mexico rock art)

'What Does Cave/Rock Art Tell Us?' 'What's the big deal about ochre?' (understanding the significance of cave/rock art and red ochre to anthropology)

Pigment presentations (students will work in teams to present to their peers the chemistry and usage in artwork of 3 pigments (from Antiquity, the Renaissance, and the Industrial Period), using slideshows, infographics, and videos, respectively)

Fall term final project (students will work in teams to design a laboratory investigation that combines gravimetric and colorimetric data collected during a pigment synthesis experiment to address a question of their choosing, with the option to present their results as a traditional lab report, a scientific poster, or an oral presentation and slideshow)

Resources (assignment-specific URLs and references):

- https://www.theatlantic.com/entertainment/archive/2012/06/what-is-art-a-few-famous-definitions-from-antiquity-to-today/258871/
- https://www.thoughtco.com/what-is-the-definition-of-art-182707
- https://plato.stanford.edu/entries/art-definition/
- http://www.visual-arts-cork.com/site/search.htm
- http://www.webexhibits.org/pigments/intro/history.html
- https://www.dummies.com/education/art-appreciation/art-history-timeline/
- https://www.livescience.com/32559-why-do-we-see-in-color.html
- https://www.youtube.com/watch?v=l8_fZPHasdo (How we see color)
- https://www.nationalgeographic.com/news/2012/6/120614-neanderthal-cave-paintings-spain-science-pike/
- https://www.bbc.com/news/science-environment-18449711 (Red dot as oldest cave art)
- https://www.bbc.com/news/science-environment-29415716 (Cave paintings and origin of art)
- https://www.theguardian.com/science/2014/oct/08/cave-art-indonesia-sulawesi
- https://www.discovermagazine.com/planet-earth/prehistoric-use-of-ochre-can-tell-us-about-the-evolution-of-humans
- https://en.wikipedia.org/wiki/Carbon-14
- https://c14.arch.ox.ac.uk/calibration.html
- https://c14.arch.ox.ac.uk/oxcal/OxCal.html

- Steelman, K., Dillingham, E., Berrier, M., Bates, L., Mark, R., and Billo, E. (2019) Radiocarbon Dating the Guadalupe Red Linear Style in the Guadalupe Mountains, New Mexico, in *American Indian Rock Art*, K. Hedges and A. McConnell, eds., v45, 15 pages.
- http://www.webexhibits.org/pigments/
- https://colourlex.com/
- https://cima.ng-london.org.uk/documentation/index.php
- Vyhnal, C., Mahoney, E., Lin, Y., Radpour, R., Wadsworth, H., (2020) Pigment Synthesis and Analysis of Color in Art: An Example of Applied Science for High School and College Chemistry Students, Journal of Chemical Education, *accepted, in press*, 11 pages.
- https://www.khanacademy.org/partner-content/pixar/color
- https://www.artistsnetwork.com/art-terms/binder-in-paint/
- https://willkempartschool.com/getting-started-what-your-paints-are-made-from/
- https://gharpedia.com/blog/basic-components-of-paint/
- https://www.youtube.com/watch?time_continue=138&v=A3rzrW493VI&feature=emb_logo (Gesso & priming)
- https://gharpedia.com/blog/base-in-paint/
- https://gharpedia.com/blog/binder-in-paint/ (Descriptio of oil binders)
- http://www.atelier-st-andre.net/en/pages/technique/fresco_technique/fresco_definition.html
- https://en.wikipedia.org/wiki/Fresco
- https://www.youtube.com/watch?v=G7szIL-0vrU (Painting with the fresco method)
- https://artyfactory.com/art_appreciation/art_movements/italian-renaissance/italian-renaissance-art-fresco-painting.html

Lab Activities

For lab activities this unit **students will conduct hands-on chemical synthesis experiments of 4 different pigments**: madder lake (red), Prussian blue, cobalt green, and cobalt yellow. Students will collect gravimetric data and be exposed to a variety of chemical concepts, including molecular geometry, balanced chemical reactions, stoichiometric calculations of theoretical, experimental and percentage yield, solutions, solubility & precipitation, oxidation-reduction reactions, and chemical kinetics. Students will also combine their synthesized pigments with appropriate binders to make paints, and **they will collect UV-Vis-IR reflectance spectra** on both their powdered pigments and their paints in order to compare and analyze reflectance spectra, calculate CIE *L*a*b** values, and quantify the effects of adding a binder on the color of a pigment as it becomes paint. Products will include traditional quantitative lab reports on the synthesis, gravimetric analysis and color quantification of each pigment as well as 2 art pieces: a painting of birch trees using Prussian blue paint, and a ceramic tile on which students apply lime plaster and paint in the fresco technique with their synthetic pigments.

2) Pottery & Ceramics (4 weeks)

When were the first fired ceramics made? When and how were the first functional pottery vessels made? What are the chemical reactions and phase transformations that occur during the firing of pottery and ceramics? What are the redox reactions and their thermodynamics in the 3-stage firing process of Athenian black and red-figure pottery made from the 6th to 3rd centuries BCE? How

can we utilize modern, chemical analytical methods to inform our historical understanding of ancient pottery production techniques and the trade of both raw materials and finished products?

Assignments

Sample assignment: **Thermodynamic calculations of redox reactions in ancient Athenian pottery**

Students will work individually to complete thermodynamic calculations (of DH, DS, DG) from standard thermodynamic data tables and the Gibbs-Duhem relationship for redox reactions observed to occur in the 3-stage firing process of ancient Athenian pottery, comparing their answers with their teammates. Students will come to appreciate that the beauty and technical sophistication of ancient Athenian pottery production was informed by the trial and error of ancient potters over the centuries despite their lack of a firm theoretical understanding of the underlying chemistry involved.

Other example assignment(s):

'Archaeology of Pottery' vocabulary assignment (defining pottery-specific terms)

'Chemistry of Pottery' problem set (reaction balancing, stoichiometric and gas-law calculations, phase transformations, graphical analysis and linear regression of SiO_2 phase density and refractive index data, glaze chemistry--all in the context of pottery during firing)

'The Via dei Sepolcri Ceramic Workshop in Pompeii' (a case study with questions that address the application of modern, chemical analytical methods to ancient pottery that was buried by the eruption of Mt. Vesuvius in 79 CE and what these analytical methods tell us about ancient Campanian pottery production)

Pottery presentations (students will work in teams to present a slideshow on the chemistry and artistic features of a pottery style from a time period and culture of their choosing)

Resources (assignment-specific URLs and references):

- https://research.britishmuseum.org/research/publications/online_research_catalogues/ancient_cypru
- https://www.historyfiles.co.uk/KingListsEurope/GreeceCyprus.htm
- https://ceramicartsnetwork.org/ceramic-recipes/reference/kiln-firing-chart/
- https://edu.rsc.org/feature/the-chemistry-of-pottery/2020245.article
- https://ahotcupofjoe.net/2007/01/basic-concepts-pottery-in-the-archaeological-record/
- https://youtu.be/2CQAdMxjBik (pinch pots)
- https://youtu.be/ri1h7CIGS0g
- https://youtu.be/f9hzPyewwAY
- https://youtu.be/12Q2z61azPg (slab pots)
- https://youtu.be/u-dIdKI-exI
- https://youtu.be/t3rXnauCyEg
- https://youtu.be/gkuXqVB53D0
- https://youtu.be/AE3IfHVQuus
- https://youtu.be/B22BgihFcVE

- https://youtu.be/o8FmgUQtLHk (coil pots)
- https://www.youtube.com/watch?v=WhPW50r07L8&t=4s (making Greek vases)
- https://www.youtube.com/watch?v=FpLPx_Akl7Y (ancient Greek vase production: black-figure technique)
- https://www.youtube.com/watch?v=99NWA4f7Lhs (intro to Getty panel discussion on Attic pottery)
- https://www.youtube.com/watch?v=r2rvV5bfpqs (Getty panel discussion on Attic pottery)
- Grifa, C., Germinario, C., De Bonis, A., Cavassa, L., Izzo, F., Mercurio, M., Langella, A., Kakoulli, I., Fischer, C., Barra, D., Aiello, G., Morra, V. (in preparation) The Via dei Sepolcri ceramic workshop in Pompeii: a snapshot of Roman crafting tradition, *in preparation*, 21 pages.

Lab Activities

For lab activities this unit **students will complete hands-on reproductions of ancient pottery using hand-forming techniques** (pinch-formed, coil-formed, slab-formed) and painting with a slip to produce color variations after firing. Students will collect gravimetric data on their pots to quantify water loss during both drying and firing. **They will also collect UV-Vis-IR reflectance spectra** on their pots after forming, after drying, and after firing in order to compare and analyze reflectance spectra, calculate CIE *L*a*b** values, and quantify the effects of drying and firing on the color of clay and slip as they become a decorated pot. Products will include traditional quantitative lab reports on the gravimetric analysis and color quantification of each pottery piece as well as 3 art pieces: a pinch-formed cup, a coil-formed bowl, and a slab-formed plate.

3) Metallic Artifacts (3 weeks)

When and how were the first metals produced? How were kiln technologies originally developed for ceramics adapted for the production and purification of metals from their ores? How can we utilize modern, chemical analytical techniques to inform our historical understanding of ancient metals production methods and the trade of both raw materials and finished products?

Assignments

Sample assignment: **Ceramics and metals production of the Qin terra-cotta army, ~240 BCE**

Students will work individually to answer a series of questions related to ceramics and bronze manufacturing methods utilized for the construction of the Qin terra-cotta army. Alloy composition and performance characteristics of bronze arrowheads and crossbow trigger mechanisms will be investigated and discussed. The implications of chromium identified on the surfaces of some of the bronze artifacts will also be explored as a case study. Students will come to appreciate more fully that chemical analysis can inform archaeological investigations and our understanding of past civilizations.

Other example assignment(s):

'Chemical Metallurgy' (an introduction to the terminology of metals production methods, classification of alloy type based on atomic radii, stoichiometric calculations in the copper smelting

process, chemical formulas and nomenclature review)

'King Tut's Dagger' (a case study with questions that address the chemical basis for a meteoritic origin of the iron used to make King Tut's dagger)

'XRF Analysis of Roman Imperial Coins' (a case study with questions that address the variation in alloy compositions of Roman coinage from the reign of Augustus as a function of both time and minting location)

Metals presentations (students will work in teams to present a slideshow on the chemistry and artistic features of metallic artifacts from a time period and culture of their choosing)

Resources (assignment-specific URLs and references):

- Baggieri, G., Giardino, C., Gigante, G., and Guida, P. (2000) Archaeometallurgy of the Etruscan Dental Prostheses: Prestige, Magic of Biocompatibility? Acta Universitatis Carolinae Medica, v41, n1-4, p69-74.
- Comelli, D., D'Orazio, M., Folco, L., El-Halwagy, M., Frizzi, T., Alberti, R., Capogrosso, V., Elnaggar, A., Hassan, H., Nevin, A., Porcelli, F., Rashed, M., Valentini, G. (2016) The meteoritic origin of Tutankhamun's iron dagger blade, Meteoritics & Planetary Society, v51, n7, p1301-1309.
- https://www.discovermagazine.com/planet-earth/king-tut-was-buried-with-a-cosmic-dagger
- https://www.livescience.com/61214-king-tut-dagger-outer-space.html
- https://www.youtube.com/watch?v=OO747eWvGME (early copper smelting)
- https://www.youtube.com/watch?v=_OrBw4L490Y
- https://www.youtube.com/watch?v=VVV4xeWBIxE&t=5s (early iron smelting, forge blower)
- https://www.pbs.org/wgbh/nova/video/emperors-ghost-army/
- https://www.youtube.com/watch?v=mP5p4QbvPtc
- Martinon-Torres, M., Li, X., Xia, Y., Benzonelli, A., Bevan, A., Ma, S., Huang, J., Wang, L., Lan, D., Liu, J., Liu, S., Zhao, Z., Zhao, K., Rehren, T. (2019) Surface chromium on Terracotta Army bronze weapons is neither an ancient anti-rust treatment nor the reason for their good preservation, Nature Scientific Reports, v9, n5289.
- Gorghinian, A., Esposito, A., Ferretti, M., Catalli, F. (2013) XRF analysis of Roman Imperial coins, Nuclear Instruments and Methods in Physics Research B, v309, p268-271.
- Baldassarri, M., de Holanda Cavalcanti, G., Ferretti, M., Gorghinian, A., Grifoni, E., Legnaioli, S., Lorenzetti, G., Pagnotta, S., Marras, L., Violano, E., Lezzerini, M., Palleschi, V. (2014) X-Ray Fluorescence Analysis of XII-XIV Century Italian Gold Coins, Journal of Archaeology, 6 pages.

Lab Activities

For lab activities this unit **students will 1) utilize redox reactions to etch a brass medallion,** and **2) observe and record the melting and freezing points of Onion's fusible alloy** (a mixture of 50% Bi, 30% Pb, and 20% Sn, by weight). Products will include traditional quantitative lab reports for each experiment and one art piece: an etched, brass medallion.

4) Glasses (3 weeks)

When and how were the first glasses produced? How has the chemical composition of glass changed over time? Which chemical species have been used as glass opacifiers and colorants? How are stained glass windows made? How can we utilize modern, chemical analytical techniques to inform our historical understanding of glass production methods and the trade of both raw materials and finished products?

Assignments

Sample assignment: **Chemical composition of ancient Egyptian glasses from Malkata and Lisht, 1391-1070 BCE**

Students will work individually and in groups to answer a series of questions related to the chemistry of ancient Egyptian glass samples, the evidence for their chemical colorants, and a potential link to the utilization of early Bronze age production materials as ingredients for the glasses. Students will conduct stoichiometric calculations based on XRF analyses of the glasses as checks on the validity of the paper's central thesis. Students will come to appreciate more fully that chemical analysis can inform archaeological investigations and our understanding of past civilizations, and that even peer-reviewed scientific publications can be flawed and therefore require a critical eye.

Other example assignment(s):

'Chemical Characterization of Early Iron Age Glass Beads from Central Europe' (case study)

'Chemical Composition and Alteration Processes in Glass from the Cathedral of Leon, Spain' (case study of stained glass degradation)

Glass presentations (students will work in teams to present a slideshow on the chemistry and artistic features of glass pieces from a time period and culture of their choosing)

Resources (assignment-specific URLs and references):

- Rasmussen, S. (2019) A Brief History of Early Silica Glass: Impact on Science and Society, *Substantia*. An International Journal of the History of Chemistry 3(2) Suppl. 5: p125-138.
- https://www.cmog.org/article/chemistry-glass
- https://en.wikipedia.org/wiki/History_of_glass
- https://www.youtube.com/watch?v=dOsXOsb7oz4 (How glass is made)
- Hendersen, J. (2013) Ancient Glass: An Interdisciplinary Exploration, Cambridge University Press, New York, NY, 423 pages.
- https://youtu.be/iBZb2bkn4KU (core formed glass)
- https://www.youtube.com/watch?v=z4XuI2xDx-w (slumped glass)
- https://youtu.be/PMNIEfo6vZY (mold blown glass)
- https://www.youtube.com/watch?v=sqnrJMTp9dc&feature=youtu.be (free blown glass)
- https://www.youtube.com/watch?v=cObJ3P6QyWQ&feature=youtu.be (gold glass)
- https://www.youtube.com/watch?v=5qgtWunYHwQ&feature=youtu.be (mosaic glass)
- https://www.youtube.com/watch?v=FpI2PhJn86s&feature=youtu.be (cameo glass)
- Mass, J., Wypyski, M., and Stone, R. (2002) Malkata and Lisht Glassmaking Technologies: Towards a Specific Link Between Second Millennium BC Metallurgists and Glassmakers,

Archaeometry, v44, p67-82.
- Agua, F., Conde, J., Koblyinska, U., Kobylinski, Z., García-Heras, M., and Villegas, M. (2017) Chemical-Physical Characterization of Early Iron Age Glass Beads from Central Europe, Boletín de la Sociedad Española de Cerámica y Vidio, v56, P119-130.
- https://www.theguardian.com/science/blog/2010/oct/29/science-magic-stained-glass
- https://www.compoundchem.com/2015/03/03/coloured-glass/
- http://www.cvma.ac.uk/index.html (Archive of medieval stained glass in Britain)
- https://www.pbs.org/wgbh/nova/video/building-the-great-cathedrals/
- https://www.youtube.com/watch?v=ExyfPl5z2NY&feature=colike (muff blown glass)
- https://www.youtube.com/watch?v=kzBXU2ovfGo (crown glass)
- https://www.youtube.com/watch?v=aw43nRwZrTw
- https://www.youtube.com/watch?v=T4OAd8S4J0M
- https://www.youtube.com/watch?v=tDyeiePort0 (rolled glass)
- https://www.youtube.com/watch?v=gOeHpqNGrq4
- https://www.youtube.com/watch?v=OVokYKqWRZE (float glass)
- Palomar, T. (2018) Chemical Composition and Alteration Processes of Glasses from the Cathedral of León (Spain) Boletín de la Sociedad Española de Cerámica y Vidio, v57, p101-111.

Lab Activities

For lab activities this unit **students will prepare their own soda lime glass sample** from a mixture of oxides that they select (informed by their reading and research). Students will add a colorant, predict the CIE *L*a*b** values of their resulting glass (based on their understanding of color theory), melt the mixture in a muffle furnace, and then quantify the color of the glass using fiber optic reflectance spectroscopy (FORS). They will also prepare their own small panel of stained glass. Products will include a traditional lab report and one piece of art: their stained glass window panel.

5) Methods of Scientific Analysis (2 weeks)

What are the various instrumental analytical methods employed by research scientists and art conservators to characterize and understand works of art and cultural heritage objects? What are the physical and chemical principles that form the basis for how they work? What kinds of chemical information does each analytical method provide?

Assignments

Sample assignment: **Analytical method videos**

Students will work in groups to research, create, and present to the school a 5-minute video that discusses an instrumental analytical method, explains how it works and the chemical information it supplies, and provides an example of its application to the understanding, restoration, and/or conservation of a specific piece of art. Students will come to more fully appreciate the physical and chemical principles behind quantitative instrumental analytical methods and how they can be harnessed to inform our understanding of artistic and archaeological objects.

Other example assignment(s):

There are no other assignments for this short unit.

Resources (assignment-specific URLs and references):

- Doménech-Carbó, M., Osete-Cortina, L. (2016) Another beauty of analytical chemistry: chemical analysis
- of inorganic pigments of art and archaeological objects, Chem Texts, v2, n14, 50 pages. (overview)
- http://www.webexhibits.org/pigments/intro/look.html (overview)
- https://www.youtube.com/watch?v=cAKcOyrt5Vc (XRF)
- https://en.wikipedia.org/wiki/X-ray_fluorescence
- https://www.youtube.com/watch?v=QHMzFUo0NL8 (XRD)
- https://www.sciencedirect.com/topics/materials-science/x-ray-diffraction
- https://www.youtube.com/watch?v=VWxYsZPtTsI (SEM: discusses secondary, back-scattered, and X-ray electrons)
- https://www.youtube.com/watch?v=GY9lfO-tVfE
- https://en.wikipedia.org/wiki/Scanning_electron_microscope
- https://www.youtube.com/watch?v=1FQPXtN7MeI
- https://www.youtube.com/watch?v=mZ-U7Qpkz8Y (IR)
- https://en.wikipedia.org/wiki/Infrared_spectroscopy
- https://www.youtube.com/watch?v=1FQPXtN7MeI (UV-VIS)
- https://en.wikipedia.org/wiki/Ultraviolet%E2%80%93visible_spectroscopy
- https://www.youtube.com/watch?v=vdwZbshe77o (FORS)
- https://chsopensource.org/fors-fiber-optics-reflectance-spectroscopy/
- Kakoulli, I., Radpour, R., Lin, Y., Svoboda, M., Fischer, C., (2017) Application of forensic photography for the detection and mapping of Egyptian blue and madder lake in Hellenistic polychrome terracottas based on their photophysical properties, Dyes and Pigments, v136, p104-115. (photoluminescence imaging)
- Vyhnal, C., Mahoney, E., Lin, Y., Radpour, R., Wadsworth, H., (2020) Pigment Synthesis and Analysis of Color in Art: An Example of Applied Science for High School and College Chemistry Students, Journal of Chemical Education, *accepted, in press*, 11 pages.

Lab Activities

For lab activities this unit **students will travel to the Conservation Laboratories at the Getty Museum** to tour their facilities and see various analytical instruments and their applications in art restoration and conservation. The product of this field trip will be a written journal reflection of the students' experience.

6) Principles of Art Restoration and Conservation (3 weeks)

What are the various techniques employed by conservators to restore works of art and cultural heritage objects? How can the various instrumental analytical methods available to conservators be used to help characterize alterations (both naturally occurring and anthropogenic) in a work of art and inform its restoration and conservation? What are the physical and chemical principles that

underlie the restoration and conservation of art?

Assignments

Sample assignment: **Case study of the National Gallery's restoration of Artemisia Gentileschi's *Self-Portrait as St. Catherine of Alexandria***

Students will watch a series of videos that document the restoration of a Baroque classic and answer questions about the various considerations (both scientific and artistic) related to its restoration in preparation for a broader class discussion.

Other example assignment(s):

'Restoration of Vermeer's *Girl Reading a Letter at an Open Window*' (case study with questions)

'Restoration of the Sistine Chapel' (case study with questions related to the chemistry of the fresco lime cycle reactions)

'The *Fake or Fortune?* Flap' (case study with questions related to best practices in art restoration)

'Probiotics for Paintings' (case study with questions related to bacterial remediation of art)

'Lead Soaps in Oil Paintings' (case study with questions related to lead soap formation and restoration)

'Darkening of Cinnabar' (case study with questions related to pigment degradation and restoration)

Resources (assignment-specific URLs and references):

- https://www.invaluable.com/blog/the-science-behind-art-restoration/
- https://www.youtube.com/watch?v=zt7d5Nb5GdE (The art restoration plan for Artemisia Gentileschi's 'Self Portrait', part 1 of 14 video clips, all of which will be viewed.)
- https://www.theartstory.org/artist/gentileschi-artemisia/#nav
- https://www.colourlovers.com/group/Artist_Palette_Challenge/conversations/15960/APC_295_Artem
- https://www.theartnewspaper.com/news/hidden-cupid-resurfaces-in-one-of-vermeer-s-best-known-works
- https://arthive.com/news/2987~Vermeers_Girl_Reading_a_Letter_at_an_Open_Window_is_getting_
- https://www.youtube.com/watch?time_continue=934&v=sFH8vhOI1Ck&feature=emb_logo (Vermeer)
- https://www.scientificamerican.com/article/modern-chemistry-techniques-save-ancient-art/ (Sistine Chapel)
- https://news.artnet.com/art-world/conservation-sistine-chapel-1499899
- https://en.wikipedia.org/wiki/Restoration_of_the_Sistine_Chapel_frescoes
- https://www.davidbcalhoun.com/sistine-chapel-restorations/
- https://www.nytimes.com/1990/05/14/arts/review-art-after-a-much-debated-cleaning-a-richly-hued-sistine-emerges.html
- https://en.wikipedia.org/wiki/Fake_or_Fortune%3F (Fake or Fortune?)
- https://www.telegraph.co.uk/news/2017/11/07/incredible-restoration-removes-200-years-grime-oil-painting/

- https://www.thisiscolossal.com/2017/11/watch-200-years-of-varnish-stripped-from-a-17th-century-painting/
- https://www.livescience.com/60957-dramatic-video-restoration-all-wrong.html
- https://www.pbs.org/wgbh/nova/article/could-microbes-save-masterpieces/ (probiotics for paintings)
- https://www.metmuseum.org/about-the-met/conservation-and-scientific-research/projects/lead-soaps (lead soaps)
- Noller, R., (2013) Cinnabar reviewed: characterization of the red pigment and its reactions, Studies in Conservation, The International Institute for Conservation of Historic and Artistic Works, v0, n0, 9 pages.
- Terrapon, V., Bearat, H. (2010) A study of cinnabar blackening: new approach and treatment perspective, 11 pages.
- Spring, M., Grout, R., (2002) The blackening of vermillion: An analytical study of the process in paintings, National Gallery Technical Bulletin, London, Roy, A. ed., v23, p50-61.

Lab Activities

For lab activities this unit **students will complete a color analysis of Artemisia Gentileschi's *Susanna and the Elders* (1610)**, select appropriate acrylic paints for use during a hypothetical restoration and retouching (based on similar RGB values for acrylic paints and colors present in the painting), and interpret Raman spectra to identify potential pigments used to create the painting. Subsequent lab activities this unit will have students interpret a wide variety of scientific data collected on various works of art and explain how the data both identify the type and severity of alteration present and inform its restoration and conservation. These lab activities will put each student in the role of a scientist in the conservation department of a major museum. Products of the activities will be in the form of typewritten letters to conservation department colleagues that: 1) interpret scientific data obtained from a work of art to be restored, and 2) make recommendations for appropriate restoration and conservation methodologies based on their interpretations.

7) Verification of Provenance and Forgery Detection (5 weeks)

What are some of the most famous art forgeries, the most famous forgers, and the famous artists that have been most commonly targeted for forgery? How have chemical analytical methods been utilized in the detection of art forgeries or, conversely, in the verification of authentic works of art? What is meant by the 'provenance' of a work of art and what are some examples of provenance research that has either identified a forgery or verified an authentic work of art?

Assignments

Sample assignment: **Introduction to Art Forgery**

Students will read a series of web-based articles that discuss some of the most notorious art forgeries and forgers and the famous artists whose works have been most commonly forged. They will then then answer questions about the various considerations (cultural, scientific, and artistic) related to art forgery in preparation for a broader class discussion.

Sample assignment: **Create your Own Homework**

Working in teams, students will be assigned a web-based article on the science of forgery detection and asked to generate their own focused reading questions for it. The readings and questions will then be shared across teams for completion, editing, and a broader class discussion.

Other example assignment(s):

'The Vinland Map' (case study with questions and class discussion)

'Shakespeare's Flower Portrait' (case study with questions and class discussion)

'Reinhold Vasters' (case study with questions and class discussion)

'Marc Chagall' (case study with questions and class discussion)

Resources (assignment-specific URLs and references):

- https://www.mentalfloss.com/article/597845/art-forgeries-history (introduction to art forgery)
- https://www.artnews.com/art-news/news/the-10-most-faked-artists-119/
- https://www.sleek-mag.com/article/art-forgers/
- http://www.faelschermuseum.com/Pages/Sammlung_englisch.htm
- https://en.wikipedia.org/wiki/Art_forgery
- https://www.chemistryworld.com/news/analytical-techniques-help-uncover-huge-art-forgery-ring/3000344.article (create your own homework assignment)
- Fieberg, J., Smith, D. (2016) Art Forgeries Revealed through Chemistry, www.acs.org
- Nelson, M. R., (2011) Authentic or Not: Chemistry Solves the Mystery, ChemMatters, www.acs.org, p15-17.
- https://www.nytimes.com/2019/06/06/arts/design/art-forgeries-atomic-nuclear-bomb.html?smid=nytcore-ios-share
- https://www.sciencedaily.com/releases/2019/06/190604131221.htm (C-14 dating exposes modern forgeries)
- https://www.theguardian.com/news/2018/jun/15/how-to-spot-a-perfect-fake-the-worlds-top-art-forgery-detective
- https://www.theguardian.com/us-news/2018/aug/06/the-new-tool-in-the-art-of-spotting-forgeries-artificial-intelligence
- Elgammal, A., Kang, Y., Den Leeuw, M., (2018) Picasso, Matisse, or a Fake? Automated Analysis of Drawings at the Stroke Level for Attribution and Authentication, 32nd Annual Conference of the Association for the Advancement of Artificial Intelligence, AAAI-18.
- https://alj.artrepreneur.com/techniques-art-forgery/
- https://www.chemistryviews.org/details/ezine/10843164/Using_Science_to_Detect_Art_Forgery_in_
- https://www.futurelearn.com/courses/art-crime (online extension course offered through Univ. of Glasgow)
- https://www.youtube.com/watch?v=WtHeZlqYNbk (Vinland Map documentary)
- https://www.youtube.com/watch?v=XUCMiJj4VAU (VM incredible discovery)
- https://www.youtube.com/watch?v=cFPqtY6kyPw (VM puzzling mystery)
- https://www.youtube.com/watch?v=T5DV7hS36SQ (VM stunning revelation)

- https://www.youtube.com/watch?v=pscAavYnYdg (VM dating the map)
- https://en.wikipedia.org/wiki/Vinland_map
- http://vinland-map.brandeis.edu/explore/historical/index.php
- https://www.geographyrealm.com/can-high-tech-analysis-of-the-vinland-map-finally-answer-questions-about-its-authenticity/
- https://news.yale.edu/2018/02/28/yale-putting-high-tech-tests-its-controversial-vinland-map
- https://en.wikipedia.org/wiki/Flower_portrait (Shakespeare's Flower Portrait)
- https://www.nytimes.com/2005/04/23/books/arts/arts-briefly-shakespeares-image-problem.html
- http://news.bbc.co.uk/2/hi/entertainment/4471515.stm
- https://www.nytimes.com/1984/01/12/arts/45-met-museum-artworks-found-to-be-forgeries.html (Vasters)
- https://www.metmuseum.org/art/collection/search/192708 (Rospigliosi Cup)
- https://lostinthelouvre.wordpress.com/2013/04/19/famous-fake-friday-the-rospigliosi-cup/
- Hackenbroch, Y. (1986) Reinhold Vasters, Goldsmith, Metropolitan Museum Journal, v19/20, The Metropolitan Museum of Art, p163-268.
- https://www.washingtonpost.com/archive/lifestyle/style/1994/04/03/the-national-gallerys-great-pretenders/fc634cab-2f3e-4c59-bdb0-3237976bbe4c/
- https://www.youtube.com/watch?v=UCrSga8rQbs (Fake or Fortune-Chagall)
- https://chsopensource.org/pigments-checker/ (XRF, Raman, and FORS spectral database for pigments)
- http://www.webexhibits.org/pigments/intro/pigments.html
- http://www.webexhibits.org/pigments/intro/look.html

Lab Activities

For lab activities this unit **students will conduct an analytical scavenger hunt.** They will be given chemical and spectral information for several unknown pigments and asked to refer to relevant online databases to identify their pigments in preparation for their final term project: authentication of an imaginary work of art proposed to have been created by a known artist. The products of these activities will be short, written statements identifying their pigments and justifying their choices.

Textbooks

Title	Authors	Publisher	Edition	Website
Artists? Pigments: Volume 1: A Handbook of Their History and Characteristics	Robert L. Feller, Editor	National Gallery of Art, Washington Archetype Publications, London	1986	https://www.amazon.com/Artists-Pigments-Handbook-History-Characteristics/dp/0521303745/ref=sr_1_5?crid=2HQ9NR7682GOL&keywords=artists%27+pigments+a+handbook+5
Artists' Pigments: Volume 2: A Handbook of Their History and Characteristics	Ashok Roy, Editor	National Gallery of Art, Washington Archetype Publications, London	1993	https://www.amazon.com/Artists-Pigments-Vol-Handbook-Characteristics/dp/0894681893/ref=sr_1_6?crid=2HQ9NR7682GOL&keywords=artists%27+pigments+a+handbook+6
Artists? Pigments:	Elisabeth West	National Gallery of	1997	https://www.amazon.com/Artists-Pigments-Handbook-Characteristics-Publication/dp/0894682563/ref=sr_1_4?crid=2HQ9NR7682GOL&keywords=artists%27+pigments+a+handbook+of+

Title	Authors	Publisher	Edition	Website
Volume 3: A Handbook of Their History and Characteristics	FitzHugh, Editor	Art, Washington Archetype Publications, London		
The Pigment Compendium: A Dictionary of Historical Pigments	Nicholas Eastaugh, Valentine Walsh, Tracey Chaplin and Ruth Siddall	Elsevier Butterworth-Heinemann	2004	https://www.amazon.com/Pigment-Compendium-Dictionary-Microscopy-Historic/dp/0750689803/ref=sr_1_1?keywo
Chemistry	Stephen S. Zumdahl and Susan A. Zumdahl	Brooks Cole	8th edition, 2008	https://www.amazon.com/Chemistry-AP-8th-Steven-Zumdahl/dp/0547168179/ref=sr_1_3?dchild=1&keywords=zum
Chemistry and Art	Anne Gaquere-Parker, Cass D Parker	Kendall Hunt Publishing	2nd edition, 2014	https://www.amazon.com/Chemistry-Art-GAQUERE-PARKER-ANNE/dp/1465250735/ref=sr_1_1?keywords=Chemi
The Science For Conservators Series : Volume 1: An Introduction to Materials	The Conservation Unit Museums and Galleries Commission	Taylor & Francis Ltd	1992	https://www.bookdepository.com/Science-For-Conservators-Series-Conservation-Unit-Museums-Galleries-Commiss
The Science of Paintings	Taft, W.Stanley Jr., Mayer, James W.	Springer	2000	https://www.springer.com/gp/book/9780387987224