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Learning with a purpose: a metals chemistry course centered on objects conservation

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Abstract: Corrosion is the visible result of redox reactions on multiple substrates, “rust” being the known, although this term only applies to iron and iron alloy objects. Using corrosion as a relatable example to teach redox eases this concepts’ understanding because its results are visually identifiable; both in everyday objects like door hinges, and in cultural heritage objects like cannons. This article concerns the latter class of objects, as they have the potential to engage people interested in fields that seem unrelated to chemistry. The reality is the opposite, as cultural heritage professionals assess objects used in humanities disciplines like archeology and history through the lens of science. This article discusses how conservators approach corrosion on cultural heritage objects and provides experiments for any base-knowledge and age-level students to learn about the process of corrosion and electrochemistry.

Keywords: art conservation; corrosion; redox; undergraduate.

1 Introduction

Humanities and sciences tend to be taught as completely independent from each other, except for a few notable examples: cultural heritage or science, (art) conservation, technical art history, etc. This arbitrary separation of fields limits the potential for cross- and inter-disciplinary collaborations; and with such limitations come limited understanding of physicochemical aspects that can adversely affect world heritage. Interestingly, the number of publications showing that art makes science more accessible is growing; but science remains a challenge to many of those invested in the care of cultural heritage. Professionals that rely on the study of material culture should have some scientific fluency, ideally. While science education strategies increasingly use artmaking, the efforts in making science more accessible for humanities disciplines remains low. Two examples include separation science (Alcantara-Garcia & Szelewski, 2016) and polymer chemistry (Alcantara-Garcia & Ploeger, 2018), both at the graduate level, when students have already demonstrated the required scientific fluency for admission to art conservation programs in the United States of America.

This article describes an alternative approach to younger audiences, ages 16–21 (upper secondary/sophomore students), from high school to non-STEM undergraduate disciplines. The approach is framed by a metals’ conservation course and internship where objects are at the center, not scientific principles, specifically redox. Using objects lowered the perceived barrier that science was and in doing so, chemistry was approached as necessary for the students’ main aim: caring for cultural heritage.

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2 Metals conservation course

2.1 Course description

The target audience for the described course are college students enrolled in a humanities discipline (art history, art conservation, etc.), with ages ranging from 18 to 21 years old. Course instructor M. Hagerman arranges loans from several cultural institutions every year – all have some historical significance and are ethically treated and housed. Figure 1 shows some of the objects on loan used, which have ranged from archaeological remains to objects from the 1970s.

The course focuses on metals conservation, and it teaches students the basic concepts involved in the preservation of metallic objects: Students document and treat metal objects, each of a different alloy. Figure 1 evidences the steep learning curve that documentation is, as subtle changes in lighting, color scale position, and brightness of objects need to be reproducible and consistent – final evaluations constructively critique images, but are not part of the grade. The documented and treated objects are tangible evidence of the past and presented both technical challenges and learning opportunities to students at the beginning of their conservation careers.

In 2021 students had the rare chance to treat freshly excavated archaeological finds from two sites: The Northampton Furnace project and the Arch Street Project. Under the direction of Dr. Adam Fraccia, copper alloy objects from Northampton Furnace were recovered, in collaboration with both the University of Delaware and the University of Maryland (Anderson, 2019; Fracchia, 2022). The Northampton Furnace project was established to shed light on the lives of both the enslaved and the incarcerated people who worked the furnace from the 1760s through the 1830s.

On the other hand, the Arch Street Project resulted from developers accidently finding the old burial ground of the First Baptist Church at 218 Arch Street (Philadelphia, Pennsylvania, USA). Specifically, they found human remains that had not been relocated to Mount Mariah Cemetery in 1860, as stated in the archives ("Welcome to the Arch Street Project," 2022). Archaeologists from around the Mid-Atlantic region of the USA quickly rushed in to salvage the individuals and their associated burial artifacts, which are currently held at The College of New Jersey. All material from the site, including objects treated by University of Delaware students, will be reburied in Mount Mariah Cemetery in September 2023 (Arch Street Project 2022).

More chemistry educators are interested in expanding the traditional approach to teaching redox, for example using at home kits (Wong & Sim, 2022), demos using ships (Furlan, Jaravata, Furlan, & Kahl, 2023), raising awareness of lead water pipes (Schnoor, 2016), and even synthesizing historical pigments (Wiggins, Heath, & Alcántara-García, 2018). This course, in contrast, assesses real-world examples of corrosion on objects with cultural, historical, and research significance. The course goal is to treat the assigned object, but students need to first assess and document it: this work forces them to consider the object's burial environment and helps them identify spots of different corrosion. Students reflect on the value and significance of objects and submit a statement of significance.

The set of observations is referred to as condition report. It outlines the current preservation state, (likely) manufacturing processes, and history of each object. The report also includes a treatment proposal, which lays out a step-by-step plan for treatment – the treatment unfailingly needs in-depth knowledge of redox chemistry. As a result, students apply redox chemistry to the potential consequences of treatment. Therefore, the discussed cultural meaning of these objects and how they were manufactured is embedded in the scientific process of deterioration, corrosion, and treatment. The perceived learning barrier was bridged by the interest in the preservation of these objects: Learning and applying fundamental chemistry turned into a powerful tool.

2.2 Material culture as a teaching tool

Each object examined in the internship is affected by one of the most challenging condition issues in metals conservation: corrosion. Students were interested in learning what leads to metals' corrosion because it is destructive in three ways:

Figure 1: Above: silver coffee pot before (left) and after treatment (right), by Miriam-Helene Rudd – the black tarnish on the surface results from metallic silver reacting with pollutants in the air like sulfides. Middle: tinned-iron-alloy coffin fitting before (left) and after treatment (right), by Brooke Curwin. Bottom: Hoe from the Wye House Plantation (University of Maryland/University of Delaware excavation) before (left) and after (right), by Hannah Covel.

(1) It alters metals' appearance, misrepresenting the esthetic intentions of the original maker or artist.
(2) It obscures surface detail, rendering relevant information invisible, e.g., making coins impossible to date or decorations hard to see (Figure 1, middle).
(3) It hides the object's original shape, especially on iron objects where corrosion is expansive.

Figure 2: Copper-alloy brooch with mineral preserved textile, 600 CE, Isle of White (2006,0305.137), Shorwell site on the Isle of Wight, Image by Madeline Hagerman, by Trustees of the British Museum.

(4) It can completely eat through objects, damaging them permanently, unless professionals intervene (Figure 1, bottom).

Metals corrosion can also preserve material culture. The so-called "mineral-preserved" or "mineralized" organic pseudomorphs are corrosion products that form in contact with organic materials, such as archaeological textiles, skin, or leather, acquiring the shape of the organic material (Gleba, 2008). Even if the organic matter degrades in the buria environment, experts can still study the human evidence. Figure 2 shows a mineralized copper alloy brooch where weave and s-spin are still visible. Without the mineral-preserved textile, it would be impossible to study the textile technology of this 600 CE Anglo-Saxon textile cloak, the majority of which has disintegrated over time.

Corrosion slowly "wears away" a metal through a "chemical action" ("Corrosion." Merriam-Webster.com Dictionary). Those aiming to preserve a metal, intuitively, would like to slow down the rate of corrosion, ideally completely stopping it; to then reverse or remove corrosion products. This idea has two broad learning opportunities: First, corroded objects are relatable examples that illustrate concepts of thermodynamics and (electro)chemistry, e.g., activation energy, redox, etc. Second, corroded objects enable key discussions around conservation ethics of, e.g., the relationship between corrosion reduction and stability,

It is worth remembering that corrosion products were originally part of the surface of objects-formed from reactions with the environment. Most cultural heritage objects are made from alloys of four different metals: iron, copper, silver, and lead. Each metal corrodes in a different way. Iron-alloy objects corrode expansively, forming thick crusts of akaganeite (chloride-containing iron oxide-hydroxide mineral) (Selwyn, Sirois, & Argyropoulos, 1999). Green copper-alloy corrosion tends to stay close to the original surface topography of an object (Scott, 2000). Silver tarnish is the thinnest type of corrosion and forms very quickly in response to environmental conditions (Bradley, 2005). Lead forms a powder-like, white corrosion product (Bart Ankersmit, Selwyn, & Sutherland, 2023). Therefore, the removal of any type of corrosion also removes part of the original surface of artifacts and the pros and cons of treatment should be carefully considered.

2.3 Blending conservation ethics and chemistry

Interventive conservation treatments that remove corrosion are irreversible. Without taking extreme care, the reduction of corrosion products on objects can cause permanent damage to surfaces. As a result, past and present treatments are discussed both from the scientific and the ethical perspectives. These discussions allow students to critically think about if, how, and how much corrosion products should be reduced. For the purposes of discussion, corrosion reduction can be divided into three categories:

1. Full removal. Not currently used, this method quickly stripped all corrosion layers using an acid vat. The aim was to fully reveal the metallic remains, frequently with disastrous consequences (Cronyn, 1990), e.g., Figure 3 shows a Viking iron sword that was soaked in acid.
2. Corrosion reduction. The most common interventive practice today, reducing corrosion can be electrochemical, or mechanical.
    - 2.a. Electrochemical – local reduction of the powder-like white lead corrosion (hydrocerussite, $2PbCO_3$-$Pb(OH)_2$). Figure 4 shows a potentiostat being used on lead Roman ingots from the British Museum. The process made lead objects the cathode, and graphite rods the anode, while an electrolyte solution is applied to the surface with cotton wool swabs held with plastic tweezers. This procedure prevents the creation of dangerous lead dust particles within a lab setting. The electrochemical removal of corrosion uses a controlled redox reaction: placing an anode and a cathode at the opposite ends of the area requiring corrosion reduction.
    - 2.b. Mechanical – using either a scalpel and non-aqueous solvents; an air abrasive cabinet, a closed-loop unit in which the conservator directs small abrasive particles on the corrosion using a fine tool. This method is very effective on *lumpy* bits of iron corrosion.
3. Stabilizing corrosion. Conservators sometimes choose to avoid reducing corrosion because of potential harm to objects or lack of resources. When this happens, objects are placed in a stable environment, e.g., ammonites with pyritic disease are placed in an anoxic environment. This practice is becoming increasingly mainstream, under the umbrella discipline of preventive conservation.

Figure 3: Viking sword, ca. 9th–10th century CE, Newark-on-Trent, UK, (British Museum, 1906,0612.1). Image Courtesy Trustees of the British Museum (Museum, 2023).

Figure 4: Madeline Hagerman with electrolytic reduction set up at the British Museum. Image by Hailey Bullock, Courtesy of the Trustees of the British Museum.

Full corrosion removal using an acid bath is an opportunity to witness a striking redox reaction on a sacrificial object. Iron oxides are common on archaeological objects and are often a characteristic "rust" color, a red-orange hue. When these oxides react with a strong acid, like hydrochloric acid, the red crust reacts forming bubbles resulting in water-soluble green iron chlorides. Iron chlorides can then be rinsed with water, leaving the iron metal exposed, but prone to further reactions with the environment.

When and how to stop this treatment is a problem, and all practitioners run the risk over-cleaning a metal artifact it, i.e., removing part of the iron metal. Even if controlled, reacting metals and their oxides with acids will seed more corrosion, which will continue reacting with oxygen and humidity. This is why understanding the importance of a "stable rust" was a turning point in metals conservation: professionals have since embraced it under the term *patina*. Patina in this context indicates that there is a layer of reacted material that is protecting the original surface.

Acknowledging the importance of this stable corrosion layer led to more controllable interventive methods like electrochemical and mechanical corrosion reduction. The aim is to remove just enough corrosion to enable appreciation for the object and see details, without taking an object back to its metallic layer.

Preventive conservation approaches are becoming mainstream: stable corrosion products are likely to remain stable, as long as environmental factors such as relative humidity, temperature, and oxygen are controlled. After all, rust formation is a thermodynamically spontaneous process.

3 Conclusion

This course helped students realize that a suitable conservation treatment needs a careful consideration of both the object's chemistry and its cultural significance. By making the course about the objects, the science became relatable and accessible, thus facilitating understanding. Given this was a foundational course for pre-professionals, the learned chemistry is expected to be carried over and extrapolated to their future careers.

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