Good practice report

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Teaching introductory chemistry through world cultural heritage history

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Abstract:

The present article details a quiz-style lesson for teaching three introductory chemistry concepts: the cleavage of rock salt as well as the oxidation and malleability of metals, through the history of chosen world cultural heritage sites, including the Wieliczka Salt Mine, the Statue of Liberty, and the Golden Pavilion in Kyoto. The described lesson comprises three questions aimed at promoting critical thinking. The responses to the designed questions were made by the students working in groups. While revealing the correct answers, three simple demonstrations were conducted to entice the students and to enhance their understanding of the discussed chemical concepts. The lesson was favorably received by the students and helped them to relate relevant chemical concepts to real-world situations.

Keywords: classroom discourse, science and culture, secondary school

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1 Introduction

Introducing seemingly disparate subjects to a chemistry lesson is an effective way of attracting students to the field of chemistry. A variety of topics, such as movies (Griep & Mikasen, 2009; KostECKA, 2018), art (Esson, Scott, & Hayes, 2018; Wiggins, Heath, & Alcántara-García, 2019), world history (Horikoshi, Yajima, Kobayashi, & Kageyama, 2015; Le Couteur & Bureson, 2003; Pinto, 2017), transportation (Horikoshi, Takeiri, Kobayashi, & Kageyama, 2016; Sanders et al., 2018), heritage sites (Alcantara-Gracia & Ploeger, 2018; Caruso, Wangler, & Flatt, 2018), and sports (McKay, Robbins, & Cole, 2008; Van Natta & Williams, 2008) have been introduced to create more engaging and interesting lessons. To this end, the author of the present article had previously performed lessons, in which the connections between chemistry and topics, such as historical incidents (Horikoshi et al., 2015) or old submarine technologies (Horikoshi et al., 2016) were highlighted. Notably, these lessons were favorably received by the attendees. During the search for additional stimulating lessons, relating chemistry topics to world heritage sites seemed to be a plausible approach to realize thought-provoking teaching.

A world heritage site is defined as a cultural or natural landmark, which due to its significance, is legally protected by international entities and has been inscribed on the UNESCO's World Heritage Sites list (World Heritage List). The history of some world heritage sites can be explained through the chemical properties and reactions of inorganic compounds. For example, it has been determined that three national parks in the United States, i.e. Grand Canyon, Mammoth Cave, and Carlsbad Caverns, were formed by erosion or weathering of minerals. Moreover, the cave art in Lascaux was created with pigments made of metal oxides (Delamare & Guineau, 2000). It is also noteworthy that numerous mining districts have been recognized as world heritage sites. Minerals, metal oxides, and metals are inorganic compounds, some of which have been introduced in high school chemistry textbooks (Davis, Sarquis, Frey, & Sarquis, 2009).

The present article describes a quiz-style lesson for high school students (aged 16–18), in which introductory chemistry concepts are illustrated through the history of three world cultural heritage sites listed in Table 1. The lesson contains three questions aiming to promote critical thinking: (i) "What is the statue in the underground tunnel made of?" (ii) "What was the original color of the Statue of Liberty?" and (iii) "How thick is the gold leaf on the Golden Pavilion in Kyoto?" The reason why these specific three heritage sites were selected was that the cities in which they are located, i.e. Krakow, New York, and Kyoto, were included in the geography and history textbooks for high school students in the country; hence, the majority of students were familiar with them. The chemical concepts investigated in the lesson are not new (DeMeo, 1997; Emsley, 2011; Hughes & Stern, 2014; Moyer & Everett, 2014); however, the methods through which they are examined, using relevant

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demonstrations and related concepts, are innovative. The goal of this lesson was to aid the improvement of the students' understanding and enjoyment of the aforementioned chemical concepts. Due to the time limit and the simplicity of the lesson, the demonstrations did not completely illustrate the chemical reactions concerning the aforementioned world heritage sites. The lesson was performed as a part of extracurricular activities at three high schools and was favorably received by the participants.

Table 1: Quiz-style questionnaire highlighting the connections between introductory chemistry concepts and the history of various world heritage sites.

Number	Question	World cultural heritage site	Chemistry concept	Choices	Correct answer
(i)	What is the statue in the underground tunnel made of? (Figure 1)	The Wieliczka Salt Mine	Cleavage of salt	1. Lime Stone 2. Rock Salt 3. Coal 4. Iron Ore	2
(ii)	What was the original color of the Statue of Liberty? (Figure 4)	The Statue of Liberty	Oxidation of metal	1. Golden 2. Silvery 3. Coppery 4. White	3
(iii)	How thick is the gold leaf on the pavilion? (Figure 6)	The Golden Pavilion in Kyoto	Malleability of metal	1. 0.05 mm (as thick as a copy paper) 2. 0.005 mm (1/10 as thick as a copy paper) 3. 0.0005 mm (1/100 as thick as a copy paper) 4. 0.00005 mm (1/1000 as thick as a copy paper)	3

2 Demonstration

The total lesson time required, including questions, simple demonstrations, and a brief explanation of the relevant concepts, was approximately 50 min. Questions, answer choices, and correct answers, which were presented using a PowerPoint slide during the lesson, are listed in Table 1. Students worked in groups of two to five people, and were required to answer all questions. Prior to conducting the lesson, familiarizing the students with the concepts of ionic and metallic bonding and the oxidation of metals was necessary. In Japan, these chemical concepts are generally taught in first grade of high school. Thus, the lesson facilitated the students' understanding of the classroom syllabus. The students' comprehension of the taught concepts was determined using a questionnaire, which was carried out a week after the lesson had been conducted. Relevant information relating to the questionnaire is summarized in the following section. Detailed instructions for constructing appropriate teaching aids for the demonstration are described in the Supplementary material.

3 Question (i): "What is the statue in the underground tunnel made of?" (The Wieliczka Salt Mine, Cleavage of Salt Crystals)

In antiquity, the sea covered the inland area of what is presently Poland. Crustal movements subsequently transformed the inland sea into an enclosed saltwater lake (Földvary, 2009). As the water of the saltwater lake gradually evaporated, rock salt layers were formed, eventually leading to the creation of in the world famous Wieliczka Salt Mine. In the 11th century, intense salt mining began at the mine (Földvary, 2009). Since then,

miners have excavated more than 300 km of tunnels, which connect more than 2000 chambers. Furthermore, dozens of life-sized statues made from the layers of rock salt have been carved (Figure 1) (Gordon, 1927; Salmon et al., 1996). The salt statue of Pope John Paul II is depicted in Figure 1. Pope John Paul II, born in Poland, was renowned for advocating against war, fascism, and dictatorship (New World Encyclopedia). The Wieliczka Salt Mine was added to the UNESCO's World Heritage Sites list in 1978 under the official name of the Wieliczka and Bochnia Royal Salt Mines.

Figure 1: A statue in the Wieliczka Salt Mine to demonstrate the concept of salt cleavage and the related question “What is the statue in the underground tunnel made of?” The photograph was taken by Prof. H. Kageyama (Kyoto University).

For the salt crystals cleavage demonstrations, samples of rock salt were purchased from a science shop and placed on a rubber sheet before being crushed with a flathead screwdriver and a hammer (Figure 2). This was done to emphasize the point that rock salt, which consist of sodium and chloride ions, exhibits a remarkably strong structure held together by ionic bonds (Davis et al., 2009). The concept of salt cleavage is characteristic of rock salt, and the mechanism through which it occurs can be explained using a simple ionic crystal teaching aid made with magnets glued to hemispheric plastic cases, as demonstrated in Figure 3. Generally, when stress is applied to a piece of rock salt, a layer of ions is forced to move from its original position (Figure 3a and b). Consequently, ions bearing the same charge tend to come within a close distance of each other (Figure 3c), and the subsequent repulsive forces between similarly charged ions cause the rock salt to cleave along a smooth plane (Figure 3d). This explains both the hardness and brittleness of rock salt. Consequently, rock salt can be easily chipped or cracked, making it difficult for miners to sculpt elaborate statues. Using the aforementioned teaching aid, created by combining magnets and plastic balls, proved remarkably helpful during demonstrations related to the motions of particles (Horikoshi, 2016).

Figure 2: A piece of rock salt crushed to demonstrate the concept of salt cleavage: (a) Before and (b) After being crushed.

Figure 3: Mechanism through which the cleavage of rock salt occurs. Red and yellow plastic cases indicate the sodium and chloride ions, respectively. The blue arrows indicate the directions of applied stress. (Top) Photographs of an ionic crystal model. (a) Former state, (b and c) Applied stress, and (d) Repulsion. The letters in parentheses correspond to those used in the bottom. (Bottom) Diagrams of magnets within the hemispheric plastic cases.

5 Question (ii): “What was the original color of the Statue of Liberty?” (The Statue of Liberty, Oxidation of Metals)

The shell of the Statue of Liberty consists of hammered copper sheets (Gayle, Look, & Waite, 1992). Upon exposure to air, sunlight, seawater, and general weather conditions, surface corrosion transforms copper from its original reddish-brown color to a greenish hue (Figure 4) (Nassau, Gallagher, Muller, & McCrory-Joy, 1987; Tétreault et al., 2003). This green hue is called “patina” and its composition differs depending on environmental conditions. In clean areas, the patina is mainly composed of basic copper carbonate ($\text{Cu}_2\text{CO}_3(\text{OH})_2$), while in industrial areas, basic copper sulfate ($\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$) and copper sulfide (CuS) are the primary components. When the Statue of Liberty was unveiled in 1886, it was reddish-brown in color, similar to the new American penny coin (Moyer & Everett, 2014). Moreover, the Statue of Liberty was added to the UNESCO’s World Heritage Sites list in 1984 (World Heritage List).

Figure 4: “What was the original color of the Statue of Liberty?” The photograph was taken by Prof. H. Kageyama (Kyoto University).

For the purpose of the demonstrations, patina was generated on the surface of a copper wire twisted into the shape of the Statue of Liberty (Figure 5a) by exposure to apple cider vinegar vapor for 1 day (Figure 5b). Generally, pure copper does not react with acetic acid; however, a reactive oxide layer is formed upon exposure to air. This layer interacts with non-oxidizing acids to give green copper(II) compounds (DeMeo, 1997; Tétreault et al., 2003), namely copper(II) acetate. This result was confirmed by comparing the infrared (IR) spectrum of the green material with that of a known sample (Figure S1, Supplementary material). A clear glaze was sprayed on the copper wire twisted into the shape of the Statue of Liberty to prevent the patina coating from being easily stripped away. It is important to note that even though their colors are similar, the green hue of the patina on the copper wire differs from the patina found on the real Statue of Liberty in the chemical composition. Instructors subsequently emphasized to the students that, under ordinary atmospheric conditions, a long time is required to form a beautiful patina surface like the one seen on the Statue of Liberty.

Figure 5: Metal oxidation is demonstrated by exposing a sculpture of the Statue of Liberty fashioned from copper wire to apple cider vinegar. (a) Before exposure. (b) After exposure; the patina is copper(II) acetate.

7 Question (iii): “How thick is the gold leaf on the Golden Pavilion in Kyoto?” (The Golden Pavilion in Kyoto, Malleability of Metals)

Gold, silver, and copper are malleable metals (Callister Jr. & Rethwisch, 2014). A mere 1 g of gold can be hammered into a decorative leaf, which is approximately 1 m^2 in size (Emsley, 2011). Even though gold leaf has been used to cover exterior walls of pavilions all over the world, the Golden Pavilion in Kyoto (Figure 6) is one of the most recognized sites. Constructed in 1397 and added to the UNESCO’s World Heritage Sites list in 1994 as one of the Historic Monuments of Ancient Kyoto, the pavilion is entirely covered with gold leaf (with the exception of the roofs and the ground floor). The leaf is approx. $5 \times 10^{-7} \text{ m}$ in thickness (Kajiyama, 2018; Kyoto Travel Guide), which corresponds to approx. $1/100$ of the thickness of ordinary copy paper. Incidentally, the torch of the Statue of Liberty is also covered with gold leaf (Figure 4).

Figure 6: “How thick is the gold leaf on the Golden Pavilion in Kyoto?” A photograph of the Golden Pavilion in Kyoto, which was taken by Prof. T. Mochida (Kobe University).

For the purpose of the demonstrations, scraps of gold leaf (Figure 7), which are typically less expensive than the square-shaped ones, were purchased from a local art supply store. During the lesson, a bottle containing gold leaf was distributed to the students, who were offered a chance to examine the leaf up-close to estimate its thickness based on their sense of touch. Additionally, the instructor distributed a piece of tin wire so that the students could experience the concept of malleability in metals. The tin wire was placed on a small anvil over a rubber sheet and struck with a hammer (Figure 8). Although gold exhibits high malleability, it was found

that manually flattening it to the desired thickness was challenging. Hence, the difficulties associated with flattening gold into a uniformly thin sheet faced by ancient gold beaters can be imagined. There is a certain degree of correlation between the malleability, softness, and ductility of metals (Hughes, 2009). Actually, most ductile metals are malleable. However, no references regarding the direct correlation between the malleability and softness of metals could be found in the available literature.

Figure 7: Scraps of gold leaf.

Figure 8: Tin wire used to demonstrate the concept of malleability in metals: (a) At the beginning of the demonstration (b) While being beaten with a hammer, (c) After being hammered, and (d) The side view of the wire after being hammered.

9 Hazards

Several precautions should be taken into consideration when conducting the aforementioned demonstrations. Instructors should wear safety glasses and work gloves. Additionally, care should be taken to protect hands when hammering the rock salt or tin wire.

10 Students' comprehension

The quiz-style lesson was presented as a part of extracurricular classes at three high schools (A, B, and C) to students at various stages of education. In School A, the participants included nineteen high school seniors (age 18), most of whom intended to start working after graduating the following year. The group from School B consisted of sixteen sophomores (age 17). Most of the students in this group were majoring in science and all of them were planning to go to college. Lastly, the group in School C included five freshmen (age 16) and three sophomores, most of whom planned to attend college. The students were instructed to work in groups of two to five people and were required to answer all questions in the quiz. Students had already reviewed the relevant chapters and learned the appropriate concepts, including ionic bonding, metallic bonding, and oxidation of metals in their conventional classes during the first year of high school. Hence, the lesson motivated the students to develop a better understanding of the classroom syllabus. Several students had been to the Golden Pavilion in Kyoto, and one student from School B had visited the Statue of Liberty.

The results of the quiz are summarized in Table 2. Students' comprehension of the lesson was tested with a simple questionnaire 1 week later (Table 3). It is difficult to estimate the effectiveness of the quiz-style lesson in comparison to a conventional class, because the author usually teaches at a university, where lectures are structured differently from typical high school classes. It is speculated that it was the low resolution of the salt statue of Pope John Paul II that prompted some of the incorrect answers from the groups in high schools B and C. In addition, the performance of the projector as well as the brightness and size of the screen were significantly different in each high school. Although the questions set in the questionnaire were relatively easy, some of the students in School A chose incorrect answers. This is because, unfortunately, some high school students tend to lose their motivation to learn after they have been assigned a real-world employment. Pleasingly, however, the students in School A chose more correct answers on the quiz than those in Schools B and C, which was applauded. On the other hand, most of the students who were planning to go to college (Schools B and C) tended to answer the questions correctly. The author is unsure how regularly the students discussed the taught chemical concepts a week after the lesson.

Table 2: Quiz and students' answers.

Number	Question	Answers High school A	High school B	High school C
(i)	What is the statue in underground tunnel made of?	Group a incorrect b correct c correct d correct	Group a incorrect b incorrect c correct d incorrect	Group a incorrect b incorrect c incorrect
(ii)	What was the original color of the Statue of Liberty?	Group a correct b correct c correct d correct	Group a correct b incorrect c correct d correct	Group a correct b incorrect c correct
(iii)	How thick is the gold leaf on the pavilion?	Group a incorrect b incorrect c incorrect d correct	Group a incorrect b incorrect c correct d correct	Group a incorrect b incorrect c correct

Table 3: Students' comprehension after the lecture.

Question	Answered correctly High school A	High school B	High school C
1 Which of the following materials can be cleaved easily: copper, sodium chloride, polystyrene, or glass?	63 %	100 %	100 %

2	Which of the following materials corrodes easily: copper, sodium chloride, polystyrene, or glass?	95 %	100 %	100 %
3	Which of the following materials shows a high degree of malleability: copper, sodium chloride, polystyrene, or glass?	63 %	100 %	100 %

11 Conclusions

Introducing chemistry concepts through the lens of real-world experiences excites students and captures their attention. With this in mind, the composition of the three UNESCO World Cultural Heritage Sites was explained in relation to chosen basic chemical concepts. A statue in the Wieliczka Salt Mine was used to demonstrate the cleavage in sodium chloride crystals, whereas the characteristic color of the Statue of Liberty was explained by the oxidation of copper and was used to teach the concept of oxidation. A remarkable luster, high malleability, and superior-corrosion resistance of the gold leaf covering the Golden Pavilion in Kyoto was utilized to explain some of the properties of gold. It should be noted that if necessary, the instructors could opt to use other heritage sites, ones that their students are more familiar with, as familiarity with the site often makes the lesson more engaging for the students. It is hoped that after attending these lessons, high school students will start looking at world heritage sites and their general environment with a fresh set of eyes and will be able to apply their knowledge of chemistry to real-world scenarios. The instructor should emphasize in the lesson that although the objects of cultural heritage are studied with chemical methods, it is by no means allowed to take/collect their samples.

12 Supplementary material

A PDF file containing instructions for the construction of teaching aid as well as copies of the students' questionnaires is available.

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