Bridging the Worlds of Art and Science

How General Chemistry Empowers Cultural Heritage Preservation

Adrian Villalta-Cerdas[1]

[1]Sam Houston State University (axv067@shsu.edu)

Abstract

This article presents a novel pedagogical approach, integrating theoretical chemistry concepts into practical art conservation applications to enhance learning and skill development in students. This strategic assignment focuses on cultural heritage conservation, emphasizing the practical application of chemistry concepts. Students recognized the importance of chemistry in analyzing artifact composition and developing tailored conservation methods, appreciating its role in maintaining historical authenticity and promoting cultural pride.

Introduction

In the continuously evolving landscape of chemistry education, there has been an increasing emphasis on integrating innovative pedagogical techniques to enhance students' conceptual understanding and real-world application of course materials. Among these methodologies, incorporating writing assignments has become valuable in fostering a more profound, reflective engagement with course concepts.

Chemistry, inherently abstract and complex, presents significant challenges in the pedagogical realm, often leading to lower student engagement and understanding (Johnstone, 2006). These issues emphasize the necessity of innovative teaching strategies to enhance students' comprehension and application of chemical concepts (Bodner, 1986). One such approach is incorporating writing assignments, posited to encourage deeper engagement, analytical thinking, and practical application of scientific knowledge (Rivard, 1994; Robinson et al., 2009; Smith et al., 2018). Despite noted challenges such as time-consuming grading and potential disconnect with traditional exam performance (Hand et al., 2004), this pedagogical tool presents an intriguing opportunity to enrich learning outcomes in chemistry education. The current paper dives into this topic, proposing an innovative writing assignment centered around the intersection of chemistry and cultural heritage conservation, aiming to address some of these challenges while enhancing student learning.

The existing body of literature on writing assignments in chemistry education has indicated its pivotal role in enhancing student engagement and comprehension of complex scientific concepts. One prevalent approach, as illuminated by Visser et al. (2018), involves writing tasks to encourage a deeper exploration of theoretical concepts, ultimately facilitating the translation of these ideas into practice. However, the effectiveness of writing assignments is often contingent on their design and execution.

While the value of writing assignments in promoting scientific literacy and understanding has been affirmed, certain studies have also shed light on their limitations in chemistry education. For instance, grading such projects can be significantly time-consuming, presenting an issue for educators managing large classes (Hand et al., 2004). Further, students might find it challenging to articulate intricate scientific concepts through writing, potentially leading

prompt
a journal of academic writing assignments

Volume 8, Issue 1 (2024), pages 9–18.

DOI: 10.31719/pjaw.v8i1.178
Submitted June 26, 2023; accepted November 29, 2023; published February 15, 2024.

to misunderstandings or oversimplifications (Reynolds et al., 2012). Moreover, while writing assignments stimulate critical thinking and conceptual understanding, evidence suggests they may not directly correlate with improved scores on conventional examinations (Nurnberg, 2017). This potential disparity underscores the necessity of implementing diverse assessment methods to evaluate a student's competency in chemistry holistically. Therefore, while writing assignments hold considerable educational value, these limitations must be acknowledged to refine their implementation for optimized learning outcomes.

Indeed, even with the recognized challenges, a growing body of literature supports the integration of writing assignments into chemistry education, underscoring their significant benefits in enhancing students' comprehension, critical thinking, and application of scientific concepts. For example, Rivard (1994) found that writing exercises in science education could dramatically improve the comprehension of scientific concepts. Similarly, studies found that students who participated in writing-to-learn activities showed increased engagement and a more profound understanding of chemistry concepts (Burke et al., 2006; Greenbowe et al., 2007). Nurnberg (2017) observed that writing assignments enhanced conceptual understanding and facilitated the development of critical thinking skills. Moreover, work by Cooper (1993) emphasized the role of writing in helping students connect theoretical chemistry knowledge with real-world applications. Writing assignments thus represent a powerful pedagogical tool, nurturing students' abilities to assimilate, articulate, and apply chemistry knowledge, despite the acknowledged limitations.

In advancing the field of chemistry education, this paper presents a unique pedagogical approach that strategically addresses prevailing limitations and gaps identified within the existing body of research. Our novel pedagogical proposition aims to circumvent the frequently cited challenges while concurrently bolstering student engagement and strengthening the bridge between theoretical and applied chemistry, with a particular focus on art conservation science. In this assignment, students are tasked to analyze culturally significant artwork related to the university critically, applying fundamental chemistry concepts from the course to the processes involved in art conservation. Their analysis culminates in comprehensive reports, which, in turn, constitute a valuable educational resource for future course participants, thereby encouraging a learning continuum within the academic community. This method offers an immersive learning environment by vividly demonstrating the practical relevance of course content within art conservation science. Simultaneously, it fosters a sense of communal continuity and shared academic journey among successive student cohorts. This work, therefore, presents a unique and impactful contribution that seeks to effectively bridge the worlds of art and science and introduce an enriching dimension to chemistry education.

Designing the Activity

The conception of the writing assignment was informed by the author's experiences from the "Writing-in-the-Disciplines" workshop led by Dr. Carroll Ferguson Nardone and Dr. Todd P. Primm at Sam Houston State University, and a summer fellowship at the Indianapolis Museum of Art under the supervision of Dr. Gregory Dale Smith, both undertaken in 2022. Following these engagements, the preliminary draft of the learning activity was developed during the summer and subsequently incorporated into the curriculum in the fall of the same year.

The workshop introduced the author to three principal writing strategies from Bean and Melzer's (2021) publication on classroom writing integration, adapted for the General Chemistry I course. These strategies encompass exploratory writing (informal, unedited writing used to generate, extend, deepen, and clarify thinking), microthemes (concise, formal, closed-form writing, typically under 250 words), and thesis statement writing (a one-sentence summary of

an essay's argument). The initial draft of the writing assignment thus incorporated these three strategies to cultivate students' writing skills. Constructive feedback from workshop facilitators and participants led to several revisions, primarily focused on optimally introducing first-year college students to art conservation techniques and content knowledge commensurate with their educational level. The writing strategies were incorporated into the writing assignment and during in-class activities related to the chemistry topics covered in the activity.

Upon completing the workshop, the author engaged in a summer fellowship at the Indianapolis Museum of Art, a commitment that entailed a three-month residency within the museum campus. The fellowship exposed the author to the domain of art conservation science through participation in various field research projects. This intensive learning process equipped the author with the pedagogical content knowledge essential for adequately introducing students to the field of art conservation under principles delineated by Bucat (2004) and Rodriguez and Towns (2019). In essence, the author's experiential learning approach to art conservation research was effectively translated and adapted for implementation within the context of introductory-level college science courses.

Previous endeavors that bridge art conservation and chemistry have been reported (McBurnett, 2021; Wells & Haaf, 2013), often accentuating advanced analytical chemistry techniques. Although insightful, explorations traverse beyond the grasp of introductory chemistry courses due to their emphasis on intricate data analysis and technical writing within chemistry-oriented frameworks. Conversely, the venture delineated in this manuscript endeavors to entwine central chemistry notions with exploring culturally significant artwork, aligning more harmoniously with the foundational skill set acquired by students in their first year of college. The learning activity seeks to equip science majors with the requisite knowledge to elucidate the pragmatic application of chemistry in preserving artistic heritage while ensuring a mindful engagement with the ethical obligations inherent to the handling and analysis of valuable artifacts.

The discourse surrounding the prudent selection of conservation methodologies was seamlessly integrated into the assignment by directing students toward pertinent video resources. The videos present the nuanced interactions among curators, conservators, and scientists, essential for ascertaining the optimal methodologies to maintain and preserve artworks, with a propensity towards non-destructive testing whenever feasible. Moreover, students are ushered into a domain wherein the scientific analysis of art objects is undertaken with judicious discernment, and the selection of analytical techniques is meticulously scrutinized by an interdisciplinary team of professionals, exhaustively contemplating all avenues before settling on a particular methodology, especially in instances where destructive sample analysis is posited as a viable option. Additionally, the museum personnel, comprising the museum director and curator of collections, furnished a concise introduction (5-10 minutes) to students regarding the collection's artworks and artifacts, along with the common strategies employed to preserve these items, taking into consideration the object's material, which included fabrics and textiles, metal objects, paper documents, and paintings. These objects' materials were a fundamental part of the assignment, as described below. In this way, the assignment fosters a deeper understanding and appreciation for the synergy between chemistry and art conservation, akin to the integrated pedagogical frameworks adopted in other institutions like Ithaca College (Esson, 2021), where historical knowledge and empirical investigations are employed to unravel the mysteries veiled within artworks.

Context and Goals

The assignment was conceptualized for implementation in the General Chemistry I course at Sam Houston State University, an introductory science course categorized at the 1000-level

and primarily intended for students majoring in the STEM disciplines of science, technology, engineering, and mathematics. Each section of the course typically accommodates a cohort of approximately 60 students. In its traditional form, this course contains few writing exercises, primarily centered on elaborating and describing laboratory experiments. Evaluations predominantly comprise multiple-choice questions, with minimal emphasis on writing tasks. Each course instructor is responsible for teaching three sections without the assistance of a teaching aide. Upon successful completion of the course, students are expected to:

1. Grasp fundamental chemistry principles encompassing atomic and molecular structure, chemical bonding, stoichiometry, molecular functionality, and the periodic properties of elements.
2. Relate modern chemistry's scope, methodology, and applications to their physical world, enhancing their scientific literacy and appreciation for science's societal impact.
3. Cultivate critical and analytical thinking skills for solving chemical problems, verifying result reasonability, and applying these skills in advanced chemistry or related subjects throughout their academic and professional journey.
4. Develop problem-solving skills in chemical processes, understand the micro-macro level relationships in chemistry, and employ symbolic language to represent physical and chemical processes.
5. Gain a nuanced understanding of chemical phenomena like bonding, molecular geometry, thermodynamics, acids, bases, and the relationship between structure and reactivity.
6. Foster teamwork abilities, effective communication, and the capacity to identify significant resources for continued learning, preparing them to interpret and integrate new chemical knowledge and ideas in future endeavors.

The assignment was designed with two objectives: (1) to enable students to form meaningful correlations between the realms of art conservation science, fundamental chemistry concepts, and chemical analysis methodologies, and (2) to stimulate an interest in scientific disciplines and an appreciation for scientific literacy due to its significant societal implications. Thus, the proposed activity objectives augment the established learning outcomes common to all sections of the general chemistry program, with a specific focus on applications in art conservation. The activity incorporates two reflective essays (i.e., microthemes) to gauge the students' perceptions and attainment of these goals (see section *Impact on Student Learning*).

Assignment Overview

The assignment, formulated with an interdisciplinary approach, is designed to incorporate central chemistry concepts into exploring culturally significant artwork. It invites students to select and analyze various artifacts, culminating in a detailed written report constructed following a provided template.

The assignment involves using Microsoft PowerPoint for report generation, and a structured template is provided to aid in organizing students' work. The undertaking is intended not just to complete tasks but as an enriching learning opportunity to elucidate chemistry concepts from the course. Students are encouraged to solicit guidance from their instructor or leverage other university resources, such as the Sam Houston State University's Academic Success Center, which includes writing support and online resources.

The assignment is structured into several key stages. Initially, students are required to visit the Sam Houston Memorial Museum (located on campus around a five-minute walk from the

chemistry department), where they choose and photograph four distinct artifacts, including a fabric or textile piece, a metal object, a paper object, and a painting. Subsequently, they compile a brief description of each artifact, detailing its historical context and other pertinent information gleaned during the museum visit.

One chosen object must be relevant to the student, prompting a 200-word reflection on its significance. The next step involves watching videos about the conservation of the selected object type and summarizing the videos' content, focusing on the connections with chemistry concepts or techniques addressed in the CHEM1411 course.

To deepen their understanding of art conservation and implement the writing strategy of microthemes, students must find an additional, related video online and summarize it, justifying its relevance to the conservation of their chosen artwork. Art conservation videos are abundant online from reputable sources like art institutes, museums, private conservation professionals, and higher education institutions, thus making it easier for students to choose relevant videos for the assignment. The last part of the assignment is to draft two reflective essays, one on how chemistry can promote the conservation of cultural heritage in Texas and another on the importance of preserving artifacts and artwork like those housed at the Sam Houston Memorial Museum and, more broadly, within the state of Texas. Each response should be within a recommended word count.

Implementation and Assessment

The initial implementation of the assignment occurred in the Fall semester of 2022. Instructional materials and guidelines were disseminated to students in the tenth week of the semester, providing a completion timeframe of four weeks. Students had undertaken several other course assessments and completed six out of ten chapters at this juncture. This ensured that students had acquired a sufficient knowledge base in chemistry to comprehend the assignment and the art conservation topics and methodologies highlighted in the assigned activity videos. Moreover, the timeframe allowed students to plan their museum visit and finalize the report with ample opportunity to raise questions and receive feedback from the instructor. It is possible to integrate structured peer review sessions during class hours, wherein students may evaluate each other's work in groups, adhering to established rubrics. However, this approach was not employed during the Fall semester of 2022. Class time was dedicated to discussing the assignment and encouraging students to inquire about chemistry in art conservation science. Overall, the assignment was met with a positive response from the students. They appreciated the integrated approach, which facilitated applying their chemistry understanding through university museum resources.

The grading system consisted of three tiers: 100%, 50%, or 0%. These grades are assigned based on: (1) the student's demonstration of diligence and comprehension of the chemistry content in the presented classwork; (2) the timely submission of the required document via the course management online platform; and (3) the report's completeness and accuracy. The activity accounted for 3% extra credit to the final course grade. All reports were collected in digital format and graded by the instructor.

Impact on Student Learning

Integrating this writing assignment into the chemistry curriculum resulted in various impactful learning outcomes, delineated below.

The outcomes of this assignment elucidate an extensive understanding by students of the crucial role of chemistry in the conservation of cultural heritage artifacts. The ramifications of

chemistry within society and the significance of scientific literacy stand as paramount learning outcomes within the general chemistry program, consistently upheld across all course sections. The course sections that undertook the writing assignment were allowed to directly engage with these learning objectives by establishing a connection between chemistry content knowledge and its practical utility in art conservation science.

Students demonstrated cognizance of the interplay between environmental factors and material interactions in preserving artifacts, reinforcing the notion that understanding chemical principles can aid in formulating restoration techniques and preventative measures against decay. They discerned the application of chemistry in preserving art pieces and documents following solubility principles. Further, students recognized the importance of chemical testing for identifying the composition of artifacts, thereby aiding in the customization of conservation methods and facilitating the removal of contaminants. A notable outcome was their acknowledgment of the role of chemistry in preserving artifacts in a manner that lends credibility to historical narratives, besides serving as an educational tool on conservation processes.

Additionally, students perceived the essentiality of understanding diverse chemical reactions and the requisite specialized knowledge to conserve various artifacts. They highlighted the significance of chemistry-based preservation in promoting cultural pride. Moreover, they underscored the role of chemistry in adapting conservation techniques to local environmental conditions, preserving textiles, handling metals, future-proofing artifacts, and actively engaging students in conservation initiatives. They observed that the chemical preservation of artworks provides valuable insights into the lives of historical figures and societies, thereby highlighting the comprehensive benefits of this integrative pedagogical approach in chemistry education.

The students developed a comprehensive understanding of the importance of preserving artifacts and artwork, particularly those housed at the Sam Houston Memorial Museum and within the broader context of Texas. They underscored the indispensable role of such preservation in facilitating historical comprehension, sustaining cultural diversity, and averting the recurrence of historical errors. They appreciated the significant pedagogical value of artifacts and acknowledged their potential to inspire innovation. Furthermore, they recognized how artifacts serve as tangible commemorations of historical accomplishments and as carriers of personal and familial legacies. Economically, students identified the significant implications of artifact preservation and emphasized the need for preserving the technical skills associated with restoration efforts. Their insights also pointed towards the potential of artifacts in unveiling historical enigmas, underlining the essential role of document restoration in maintaining societal records and the value of artifacts in providing an authentic glimpse into the past. These holistic insights elucidate the transformative capacity of this writing assignment. This pedagogical approach significantly enriches chemistry education by adopting a practical, immersive, and integrative learning experience.

Limitations

The successful completion of this activity hinges on students having a foundational understanding of chemistry principles to effectively interpret the online videos concerning art conservation science and their intersection with chemistry. Consequently, the activity had to be scheduled towards the latter part of the semester and could not be executed earlier. The conclusion of the course concurrently aligns with other assessment components in General Chemistry, such as examinations and laboratory reports, as well as additional coursework in students' other classes. Despite the four-week completion period, this coincidence posed a challenge to a subset of students in fully engaging with the activity. One potential remedy to this issue may be organizing the museum visit and associated activities earlier in the term, and subsequently integrating the

art conservation connections later in the semester.

It is also crucial to consider the writing proficiency of first-year college students, as additional resources might be necessary for them to complete their assignment. Our institution is equipped with the Sam Houston State University's Academic Success Center, designed to assist students with such tasks. It is essential to highlight the availability of these resources to students, encouraging them to utilize them effectively. In the pursuit of enhancing the writing abilities of students, particularly those in their first year, a meticulous approach is required beyond merely directing them to online resources. It is advised to hone in on the primary objectives of the educational endeavor at hand, allowing for a targeted instructional and evaluative approach. For instance, if the crux of the exercise lies in synthesizing scientific principles or concepts with museum artifacts, a pedagogical pathway should be laid out: beginning with smaller, informal assignments, gradually progressing towards more refined and formal expositions, as exemplified in the current assignment structure. It's imperative to provide a scaffolded learning experience that aids in meticulously developing the necessary writing skills. Establishing a clear and achievable set of expectations alongside a supportive learning environment will likely foster improved writing competency, particularly in articulating complex interdisciplinary connections between chemistry and art conservation science.

Conclusions

This interdisciplinary assignment, crafted to weave fundamental chemistry principles into investigating culturally significant artwork, successfully encouraged an enriching and integrative learning experience for students. It permitted students to apply their academic knowledge practically, facilitating a more comprehensive understanding of chemistry's role in art conservation science. The assignment alignment towards the end of the course, when students had acquired adequate chemistry knowledge, proved to be a strategic decision, albeit posing potential challenges due to concurrent academic assessments.

The execution of the assignment did present some limitations. The timing of the activity towards the end of the semester, although necessary due to the foundational chemistry knowledge required, did coincide with other course assessments, causing some students to struggle with complete engagement in the activity. A potential solution may involve scheduling certain components of the assignment, such as the museum visit, earlier in the semester.

Overall, this innovative assignment was a valuable pedagogical tool, encouraging students to forge meaningful connections between theoretical chemistry concepts and their practical applications in art conservation. It created an engaging learning environment, inviting students to explore their cultural heritage through a scientific lens, enriching their educational experience. The insights gleaned from this assignment underscore its potential as a transformative approach in chemistry education that fosters a practical, immersive, and integrative learning journey.

Acknowledgments

The author recognizes the Sam Houston Memorial Museum's and Republic of Texas Presidential Library's support for this work. The author is grateful for the guidance provided by by Dr. Carroll Ferguson Nardone and Dr. Todd P. Primm at Sam Houston State University, and Dr. Gregory Dale Smith at the Conservation Science Laboratory in the Indianapolis Museum of Art at Newfields. This work was supported by the National Endowment for the Humanities (grant no. PE-268864-20), the Welch Foundation (grant no. X-0011), and the National Science Foundation (grant no. 1725674). Any opinions, findings, conclusions, or recommendations expressed in this

paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

ASSIGNMENT

Integration of Art Conservation Science and Cultural Heritage Preservation in General Chemistry

Vision Statement

To promote the application of chemistry content and students' skills within the chemistry education community, your work will be available to future students to learn relevant course concepts applied to art conservation science.

Activity Description

The assignment consists of selecting and analyzing artwork with relevant cultural heritage importance to the students in light of chemistry concepts in the course. Students will prepare a written report following a provided template.

Tools and materials

Students will use *Microsoft PowerPoint* to prepare their reports. A template is available for students to organize their work. To complete the assignment, you should seek help from your instructor or via other university resources (e.g., Sam Houston State University's Academic Success Center, Department of Chemistry Teaching Assistants). *See this assignment as a learning opportunity to clarify chemistry concepts in the course.*

Museum visit

1. Visit the Sam Houston Memorial Museum. The museum is free for university students with their ID.
2. Select one object made of fabric or textile (not paper), and take a photo.
3. Select one object made of metal, and take a photo.
4. Select one object made of paper, and take a photo.
5. Select one painting artwork, and take a photo.
6. Museum information about the artwork: write a brief description of the selected art (i.e., fabric or textile, metal, paper, painting), its history, and relevant information gathered during the museum visit. Do not select an object that has limited information. Your response should be 50 words long. You might find more information about the object on the museum website.

Art conservation science connection

7. Which selected object/artwork is the most relevant to you? Why does this object hold relevance to you? This is a personal type of question. Your response should be 200 words long.
8. Watch all of the videos below for the corresponding type of object/artwork you selected:
    a. Metal Conservation
        - Alamo Cannon Restoration at Texas A&M

- Preserving Texas history at the RELLIS Campus
- Restoring Historic Alamo Cannons at Texas A&M
- The Alamo Battle Cannons Return
- Conservation of iron artifacts at Jamestown

b. Paper Conservation
- Behind the Scenes at NYPL's Conservation Lab
- Conserving Old Master Drawings: A Balancing Act
- The Chemistry of Bathing, "A Harlot's Progress"

c. Fabric and Textile Conservation
- Conserving Textiles - Asian Civilisations Museum
- See behind the scenes at the National Trust's Textile Conservation studio
- Conservation of a 12th-century textile

d. Painting Conservation
- Why are paintings by Reynolds so difficult to clean? Art Restoration - National Gallery
- Examining a Panel Painting
- The Conservation of Nelly O'Brien

9. Write a summary of the videos you watched and the connections you found with chemistry concepts or techniques covered in the CHEM1411 course. Your response should be 200 words long.
10. Browse the internet and find another video with information relevant to art conservation of the type of object/artwork you selected. Write a summary of the video you found and justify its relevance to preserving the object/artwork and how it connects to the CHEM1411 course content. Your response should be 200 words long.

Reflection on the assignment

11. Based on what you learned from the videos, how can understanding the chemistry of the objects/artwork promote the conservation of cultural heritage in Texas? Your response should be 200 words long.
12. Why is it important to preserve objects and artwork like the ones found at the Sam Houston Memorial Museum and, more generally, in Texas? Your response should be 300 words long.

Supplementary Material

For supplementary material accompanying this paper, including a PDF facsimile of the assignment description formatted as the author(s) presented it to students, please visit https://doi.org/10.31719/pjaw.v8i1.178.

References

Bean, J. C., & Melzer, D. (2021). *Engaging ideas: The professor's guide to integrating writing, critical thinking, and active learning in the classroom* (3rd). John Wiley & Sons.

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, *63*(10), 873–878. https://doi.org/10.1021/ed063p873

Bucat, R. (2004). Pedagogical content knowledge as a way forward: Applied research in chemistry education. *Chemistry Education Research and Practice*, *5*(3), 215–228. https://doi.org/10.1039/B4RP90025A

Burke, K. A., Greenbowe, T. J., & Hand, B. M. (2006). Implementing the science writing heuristic in the chemistry laboratory. *Journal of Chemical Education*, *83*(7), 1032–1038. https://doi.org/10.1021/ed083p1032

Cooper, M. M. (1993). Writing: An approach for large-enrollment chemistry courses. *Journal of Chemical Education*, *70*(6), 476. https://doi.org/10.1021/ed070p476

Esson, J. M. (2021). Incorporating conservation science into the general education curriculum. In Kevin. L. Braun & K. J. Labby (Eds.), *Contextualizing chemistry in art and archaeology: Inspiration for instructors* (pp. 3–17). American Chemical Society. DOI:10.1021/bk-2021-1386.ch001

Greenbowe, T. J., Poock, J. R., Burke, K. A., & Hand, B. M. (2007). Using the science writing heuristic in the general chemistry laboratory to improve students' academic performance. *Journal of Chemical Education*, *84*(8), 1371–1379. https://doi.org/10.1021/ed084p1371

Hand, B., Wallace, C. W., & Yang, E.-M. (2004). Using a Science Writing Heuristic to enhance learning outcomes from laboratory activities in seventh-grade science: Quantitative and qualitative aspects. *International Journal of Science Education*, *26*(2), 131–149. https://doi.org/10.1080/0950069032000070252

Johnstone, A. H. (2006). Chemical education research in Glasgow in perspective. *Chemistry Education Research and Practice*, *7*(2), 49–63. https://doi.org/10.1039/B5RP90021B

McBurnett, B. (2021). Using the history of technology to connect art and chemistry in a science of art course for nonscience majors. In Kevin. L. Braun & K. J. Labby (Eds.), *Contextualizing chemistry in art and archaeology: Inspiration for instructors* (pp. 87–95). American Chemical Society. DOI:10.1021/bk-2021-1386.ch005

Nurnberg, D. (2017). *Writing-to-learn in high-school chemistry: The effects of using the science writing heuristic to increase scientific literacy*. [Doctoral dissertation, University of San Francisco]. https://repository.usfca.edu/diss/342

Reynolds, J. A., Thaiss, C., Katkin, W., & Thompson, R. J. (2012). Writing-to-learn in undergraduate science education: A community-based, conceptually driven approach. *CBE—Life Sciences Education*, *11*(1), 17–25. https://doi.org/10.1187/cbe.11-08-0064

Rivard, L. O. P. (1994). A review of writing to learn in science: Implications for practice and research. *Journal of Research in Science Teaching*, *31*(9), 969–983. https://doi.org/10.1002/tea.3660310910

Robinson, M. S., Stoller, F. L., Horn, B., & Grabe. (2009). Teaching and applying chemistry-specific writing skills using a simple, adaptable exercise. *Journal of Chemical Education*, *86*(1), 45–49. https://doi.org/10.1021/ed086p45

Rodriguez, J.-M. G., & Towns, M. H. (2019). Alternative use for the refined consensus model of pedagogical content knowledge: Suggestions for contextualizing chemistry education research. *Journal of Chemical Education*, *96*(9), 1797–1803. https://doi.org/10.1021/acs.jchemed.9b00415

Smith, S. M., Warnes, S., & Vanhoestenberghe, A. (2018). Scenario-based learning. In J. P. Davies & N. Pachler (Eds.), *Teaching and learning in higher education: Perspectives from UCL* (pp. 144–156). UCL IOC Press.

Visser, T., Maaswinkel, T., Coenders, F., & McKenney, S. (2018). Writing prompts help improve expression of conceptual understanding in chemistry. *Journal of Chemical Education*, *95*(8), 1331–1335. https://doi.org/10.1021/acs.jchemed.7b00798

Wells, G., & Haaf, M. (2013). Investigating art objects through collaborative student research projects in an undergraduate chemistry and art course. *Journal of Chemical Education*, *90*(12), 1616–1621. https://doi.org/10.1021/ed400145g