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Infographics and Iterative Peer/Near-Peer Review as Tools to Improve Chemistry Communication Skills with General Audiences

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ABSTRACT: The ability to communicate scientific concepts to expert and nonexpert audiences is an essential skill for chemistry and STEM students. Current chemistry curricula mainly focus on developing skills to communicate technical information to expert audiences, while relaying the same information to general audiences receives much less attention. Although numerous initiatives work to close this gap, many have logistical or financial barriers that make them difficult to integrate in a large classroom setting. Herein, we present an assignment focused on improving advanced students' (i.e., graduate and advanced undergraduate students) ability to communicate current organometallic chemistry research (i.e., technical information) to a general audience using infographics. Our assignment features a unique, iterative feedback model incorporating instructor, peer, and near-peer (general audience) groups to provide students with multiple opportunities to refine their communication skills. Anonymous student self-assessments of advanced undergraduate/graduate students (infographic creators and peer reviewers) and first year, non-major undergraduate students (near-peer reviewers and general audience) indicate that the assignment led to (i) increased confidence in communication skills (advanced undergraduate/graduate students), (ii) a broadened understanding of advanced chemistry in everyday life (both), and (iii) increased recognition for the importance of scientific communication to different audiences (both). Reflections on student outcomes as well as recommendations and considerations for instructors are discussed.

KEYWORDS: *Upper-Division Undergraduate, Graduate Education/Research, Cheminformatics, Communication/Writing, Organometallics*

■ INTRODUCTION

The ability to communicate complex scientific concepts to specialist and nonspecialist audiences is an essential skill for students studying chemistry and other STEM fields. This has been recognized by several major professional scientific organizations (e.g., National Academy of Sciences, National Science Foundation, American Chemical Society, and the Royal Society of Chemistry), where scientific communication skills have been identified as an essential component of chemical education.[1] Despite the emphasis placed on these skills, there are still key gaps on how to train students to effectively communicate science to *all* audience types (e.g., (i) expert: specialist in the topic; (ii) student: currently learning about the topic/field; (iii) scientific: scientists with backgrounds/expertise outside of the field; (iv) general: little or no training in the sciences).[2] Traditionally, chemistry curricula have focused on training students to communicate technical information (e.g., presentations, posters, manuscripts, and proposals) to other technical audiences (i.e., expert),[2d] while communication of technical information to general audiences has received much less attention.[1b,3] A number of key centers[4] and curricular initiatives,[5] like the *Alan Alda Center for Communicating Science*,[6] are developing resources to communicate technical material with nontechnical audiences.[4,5b] However, financial and logistical barriers can arise in implementing these more broadly, as these can self-select for a small subset of people, involve major curricular redesign(s) (including additional credit requirements),[5a,7] and/or require additional fees or funding for special workshops or seminars.[5a,8] As a result, the development of simple and inexpensive solutions that can be readily integrated into existing upper level undergraduate or graduate courses is highly desirable.

Infographics, media which combine textual and graphical information in a visually appealing and accessible manner,[9] have become increasingly popular as a tool across fields and age groups[9,10] to improve student communication skills and engagement with classroom content.[9,10b,c,11] In chemistry, Andy Brunning's Web site, *Compound Interest*, has received international attention for the simple and appealing nature of

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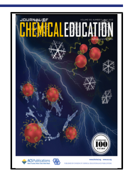

infographics to describe the chemistry behind everyday products and phenomena such as food, sunscreen, and cosmetics.[12] Incorporation of infographics into high school classrooms and out-of-school programs can also help improve learning in STEM.[13] A number of recent publications describe using infographics in classes such as first-year seminars,[14] organic,[15] analytical,[16] and bioinorganic classes,[2a] and they have been used to introduce key concepts in green chemistry,[17] science in policy,[18] the application of organic chemistry to daily life,[14,15,17] and faculty research areas (i.e., departmental research).[14] Although these exciting examples can spark initial student interest in these fields, none of these focus on engaging/educating the public (i.e., general audience) regarding the outcomes of *current* scientific research,[1d,19] which has been recognized as essential for the growth and sustainment of science and an overall benefit to society.[20,21] Outside of infographics, several alternative media types have been implemented to address this critical curricular gap, including Wikipedia pages,[22] blogs,[23] photography,[24] and videos,[14,22b,24,25] with topics ranging from the importance of molecular "strain" in organic chemistry[22b] to laminar flow[26] and the chemistry behind influenza[25a] to nanotechnologies and sustainability.[23] With this in mind, we envisioned that an assignment focused on describing current organometallic or inorganic chemistry research to a general audience using infographics could serve as an effective and easily deployable assignment to improve communication skills in graduate/advanced undergraduate chemistry students.

Herein, we present the results of our multiyear study implementing an infographic assignment to communicate technical chemistry advances, including *current* chemical research, to a general audience (Figure 1). This assignment was developed for a graduate/advanced undergraduate-level elective (i.e., nondegree requirement) course (Organometallic Chemistry, CHEM 2310/1560N) and featured a unique, iterative feedback model incorporating instructor, peer, and near-peer (general audience) groups to provide students with multiple opportunities to refine their communication skills. The near-peer component, the pairing of graduate/advanced undergraduate students with first-year undergraduate students, provided direct and real-time feedback from an authentic general audience and an opportunity to further spark interest in STEM research with first-year undergraduates not majoring in chemistry. Anonymous student self-assessments of the first-year undergraduates and graduate/advanced undergraduates from our study revealed that the assignment led to (i) increased confidence in communication skills (advanced undergraduate/graduate students), (ii) a broadened understanding of advanced chemistry in everyday life (both), and (iii) increased recognition for the importance of scientific communication to different audiences (both).

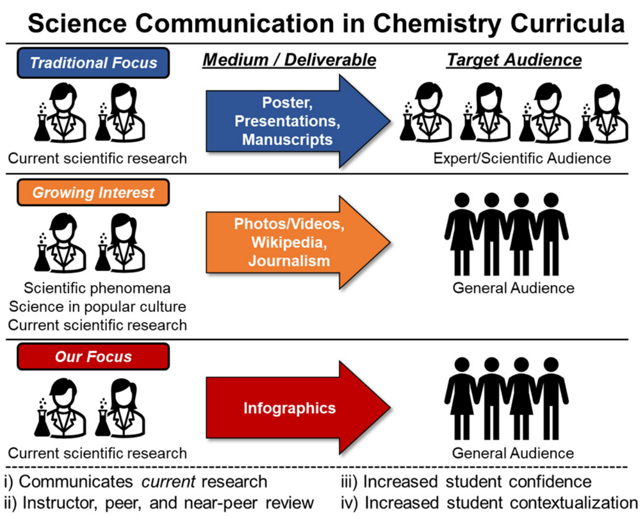

Figure 1. Illustration of common topics a media chemist used to develop science communication in chemistry curricula with a given audience.

■ SETTING AND PARTICIPANTS

This study was conducted at Brown University, a medium-sized, private university in Providence, RI, during the fall semesters of 2017−2021. The infographic assignment involved two different sets of chemistry courses: CHEM 2310/1560N, a graduate/advanced undergraduate-level course, which prepared the infographics, and CHEM 0080 and 0100, first-year undergraduate courses, which served as authentic general audiences for near-peer review.

CHEM 2310/1560N, *Organometallic Chemistry*, is a graduate/advanced undergraduate-level course that covers modern advances and applications of organometallic chemistry. In addition to technical course content, a significant emphasis is placed on effective communication skills (written and oral) with regular instructor and peer feedback on a range of assignments. Course enrollment during this study ranged from 6 to 14 students, with an average class size of 10 students per semester.

CHEM 0080 courses (capped at 19 students), special topic first-year seminars, are first-year undergraduate chemistry offerings comprised of nonmajors that do not count toward a chemistry degree. The first-year seminar offerings covered a range of subjects, including the scientific foundation of energy and fundamental physical, chemical, and thermodynamic aspects of common and novel energy sources (CHEM 0080A), a survey of historical developments and concepts of three-dimensional structures and molecules (CHEM 0080B), and renewable energy with an emphasis on written communication (CHEM 0080E). Chem 0100 (ranging from 50 to 200 students), *Introductory Chemistry*, comprises predominantly first-year students with minimal or no chemistry experience from high school who are considering a STEM major but are less prepared to take the "standard" introductory sequence. CHEM 0100 covers topics from chemistry that enable computational analysis across all STEM disciplines, including dimensional analysis, atomic and molecular structure, phases of matter, and energy balances.

■ ASSIGNMENT DESIGN

The infographic assignment in CHEM 2310/1560N was developed for students to improve their abilities to communicate technical information with general audiences. This was one of several assignments aimed at improving communication skills with specific audience types (e.g., expert, student, scientific, and general)[2d] throughout this course. Students in CHEM 2310/1560N were asked to develop an infographic to communicate key concepts in inorganic/organometallic chemistry (2017, pilot year) or recently published inorganic/organometallic chemistry research (2018−2021) to a general audience. In addition to

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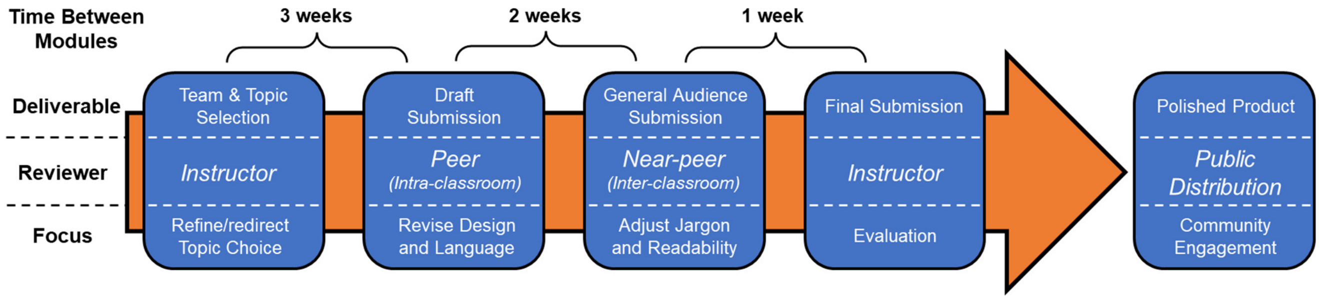

Figure 2. Overview of the infographic assignment and associated timelines used in CHEM 2310/1560N.

instructor-developed assignment descriptions and rubrics, students refined their infographic based on an iterative and delocalized feedback model involving instructor, peer, and near-peer feedback (Figure 2). This model was selected to further hone students' abilities to engage in productive and meaningful peer-review and as a sustainable model for enhanced feedback through iterative dialogic cycles.[28] Although feedback effectiveness can be challenging to measure,[29] feedback provided by multiple peers and instructors can lead to improved clarity and more complex revisions than that of instructors alone.[30] The assignment was carried out over a six week period to accommodate other deliverables within the course; however, this could easily be adapted to shorter timelines and/or other audience types.

Team and Topic Selection

Students paired up to form their teams and selected a topic. Students were free to select any topic of interest to them within the areas of organometallic or inorganic chemistry (broadly defined) and encouraged to meet with the instructor briefly (before/after class, office hours) if they were having difficulties selecting a topic or team. Team and topic selections were reviewed by the instructor, and feedback was provided to help refine/redirect their choice of topic. Although feedback was infrequently needed, the most commonly given feedback redirected students to consider topics where they would ultimately highlight organometallic or inorganic chemistry. The timing of the topic selection coincided with completing the introduction of general organometallic concepts (e.g., electron-counting, back-bonding, ligand types, ligand substitution, and emerging applications) but could be introduced earlier or later in the semester.

Draft Submission

Students were provided examples of chemistry infographics from compoundchem.com/infographics. In class, the instructor briefly introduced freely available infographic design websites (e.g., Piktochart,[31] Canva,[32] and Venngage[33]) along with free or university-supported graphics editing software (e.g., GIMP, Photoshop, and PowerPoint). Students were largely self-guided in the use of these websites and software, where specific questions were fielded during office hours. After the draft was prepared and submitted, the infographics underwent intraclassroom peer review by at least two other students outside of their team. Peer reviewers commented on the choice of topic, relevance/appropriateness of content for a general audience, inclusion of references, and writing mechanics.

General Audience Submission

Students were given 2 weeks to revise the infographic based on peer feedback before submitting it for near-peer review by an authentic general audience. In partnership with collaborating faculty members in the Department of Chemistry at Brown University, the instructor distributed the revised infographics and rubrics for near-peer review to students in CHEM 0080 or 0100. In the pilot year, 2017, the infographics were distributed electronically, and near-peer review occurred asynchronously. In this year, students from CHEM 0080 provided written feedback on the infographic without the opportunity for further questions or real-time discussion. Based on anonymous student feedback from CHEM 2310/1560N in the pilot year, near-peer review in subsequent years (2018−2021) included an additional, real-time discussion component. In 2018, 2019, and 2021, the near-peer review sessions were carried out in-person, while in 2020, near-peer review was carried out remotely using video conferencing software (e.g., Zoom) due to public health considerations associated with COVID-19. Students in CHEM 0080/0100 were offered a small amount of extra-credit to incentivize participation in the ∼20 min near-peer review session and were asked to complete an anonymous postactivity survey.

Final Submission

Students enrolled in CHEM 2310/1560N were given 1 week to further revise their infographics based on feedback from an authentic general audience. Upon completion of the assignment, students were asked to complete a postactivity survey, and the completed infographics were then published, with student permission, on the instructors' research Web site and VIPER (***V***irtual ***I***norganic ***P***edagogical ***E***lectronic ***R***esources, https://www.ionicviper.org/problem-set/moment-organometallic-chemistry-infographics).[34] In later iterations, the final infographics were to be posted in rooms during STEM outreach activities (e.g., Brown Chemistry's *STEM Day*); however, these large, in-person outreach activities were suspended during the 2020−2021 and 2021−2022 school years.

Grading Criteria

The first three parts of the assignment (i.e., team/topic selection, draft submissions, general audience submission) and peer review were graded on completion. The final submission from CHEM 2310/1560N students was evaluated by the instructor employing the same rubric used in the peer review process. Each section was assigned a one-point value, totaling ten points for the final assignment. The assignment comprised 10% of the students' total grade, but percentages could easily be adjusted based on other coursework. CHEM 0080/0100 students were incentivized to fill out the surveys accompanying the assignment by offering a small amount of extra credit.

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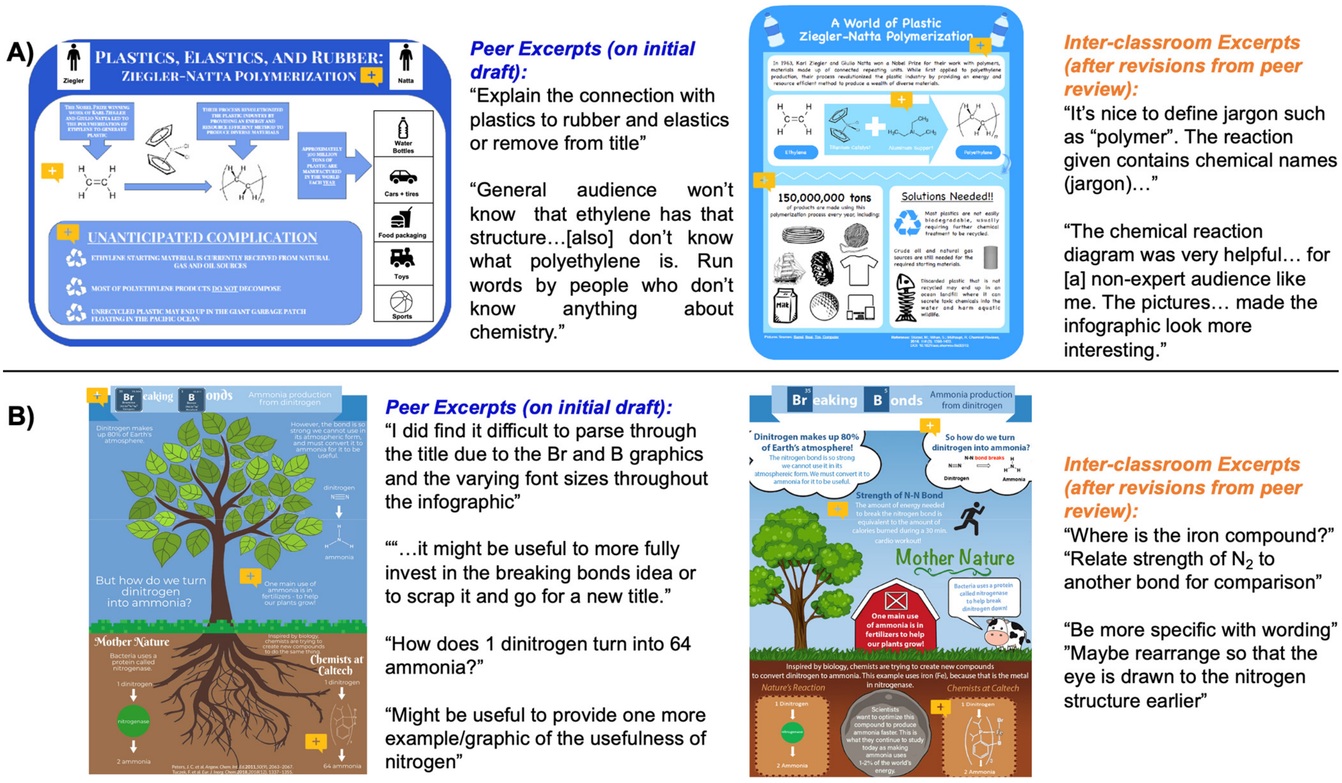

Figure 3. Examples of infographic development and excerpts from peer and near-peer review processes.

Post-activity Surveys

Changes in self-assessed communication skills and knowledge as well as feedback on the infographic assignment were assessed through anonymous, postactivity surveys for students in CHEM 2310/1560N and CHEM 0080/0100. The brief surveys (see the Supporting Information) included a mixture of questions using a four-point Likert scale and short response and also probed potential emergent outcomes from this assignment, such as increased student contextualization. Student survey participation was optional for both student populations, but strongly encouraged. Response rates were >85%.

■ RESULTS AND DISCUSSION

Refining Communication Skills through Peer and Near-Peer Review

The benefits of peer-assisted learning are well established and include advantages such as (i) providing better cognitive matches, (ii) establishing a sense of community, and (iii) enhancing learning for both parties.[35−38] As such, we incorporated two modes of peer-assisted review, peer and near-peer, which revealed common challenges that advanced students experienced in curating infographics for a general audience. As seen in the pre- and postreview examples (Figure 3), most students initially misgauged their target audience. Before peer review, reviewers were provided with a rubric and reminded of the target audience (i.e., general audience). Prior to review, the infographics included significant amounts of jargon and assumed the audience had a more "advanced" technical base. Some peer reviewers (i.e., students from CHEM 2310/1560N) recognized this and provided constructive feedback on this mismatch in content and audience background. For instance, in the *Ziegler−Natta* example (Figure 3A), peer reviewers commented, "A general audience does not know what polymerization is or does...Run words by people who don't know anything about chemistry. If they can't definite it without looking it up, then you need to expand or simplify." Similar comments were received for infographics that centered around a specific publication, such as the *Breaking Bonds* infographic (Figure 3B). While some peer reviewers keyed in on extensive uses of jargon, others still struggled with recognizing vocabulary and the appropriate level of detail for a general audience. For example, one peer reviewer of the *Breaking Bonds* infographic expressed the desire for more technical explanations and inclusion of the catalyst mechanism of action. Instructors should be aware of potential disconnects within the peer review process and help correct them as needed.

Alternatively, the authentic general audience, CHEM 0080/0100, provided more direct and unified feedback during near-peer review. Students in CHEM 0080/0100 were especially adept at identifying language and graphics that were common-knowledge to upper-level chemistry students, but inappropriate for a general audience. For example, one introductory student noted, "I don't know what a ligand is," while another noted, "More explanation about 'polyethylene production' may be helpful." Perhaps more valuable than the written feedback, students engaged in candid conversations with CHEM 0080/0100 students about the content and its delivery. Both forms of feedback led to significant changes in CHEM 2310/1560N infographics and ultimately led to end products that were appropriate for their target audiences. In addition to improved content delivery, the iterative peer review process helped students in both classrooms improve their ability to engage in peer review and critically assess materials.

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Improved Communication with a General Audience

In the postactivity survey, CHEM 2310/1560N students were asked retrospectively about their preparedness to communicate with a general audience before and after taking the course. Overall, CHEM 2310/1560N students reported a significant increase in their self-assessed ability to communicate technical scientific content with a general audience after completing the course. While 44% of students felt prepared (moderately + well prepared) to communicate science with a general audience prior to taking the course, this rose to 98% after completing this assignment (Figure 4). Short responses from CHEM 2310/1560N students also highlighted how this assignment addressed an unmet gap in our curriculum. One student noted that the infographic "...taught me to recognize the type of audience I am trying to communicate with", while another said, "I learned a lot about presenting to a general audience in an effective way. No course I have taken previously taught me this effectively before".

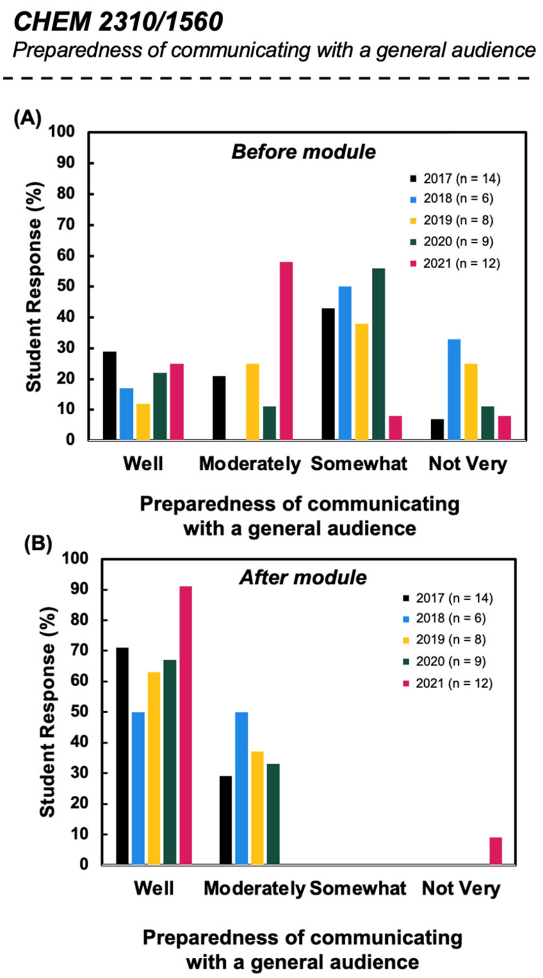

Figure 4. Percentage of CHEM 2310/1560N student responses indicating their preparation level to communicate with a general audience (A) before and (B) after the infographic assignment. Response sample size, *n*, is provided in parentheses next to the year.

Benefits of Interclassroom, Near-Peer Review

One of the major goals of the infographic assignment was for students to hone their ability to communicate technical scientific advances with general audiences. Integration of regular feedback from a *variety* of audiences (i.e., expert: instructor; scientific: peer, intraclassroom; general: near-peer, interclassroom) was crucial to building these skills, where the importance and inherent value of feedback from each audience was reflected in student survey responses. On average, 92% of CHEM 2310/1560N students found feedback from both a scientific and general audience to be informative *and* broadened their understanding of how to communicate scientific concepts with a general audience (Figure 5).

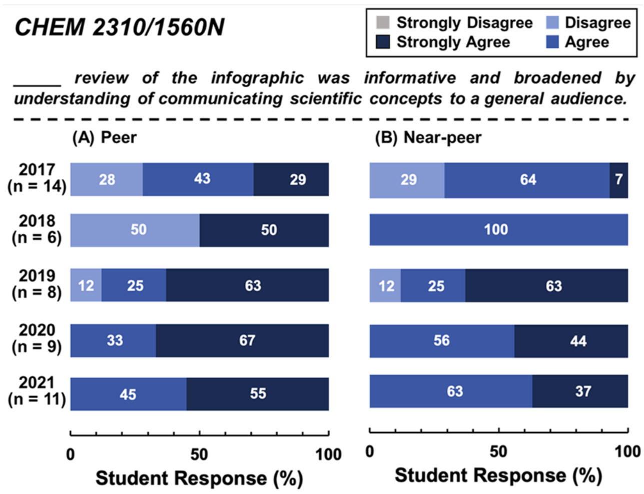

Figure 5. Percent of CHEM 2310/1560N survey responses to whether (A) peer and (B) near-peer review of the infographic was informative and broadened their understanding of communicating scientific concepts with a general audience. Response sample size, *n*, is provided in parenthesis below the year.

CHEM 0080/0100 students also expressed an increased understanding of the (i) importance of science communication (92%) and (ii) challenges of communicating technical information with a general audience (94%) after completing the near-peer review session (Figure 6C,D).

Infographics as an Effective, Stand-Alone Communication Tool

Infographics are intended to convey technical content in a visual and interactive manner *without* the need of supporting audio or an in-person presenter. Although chemistry students have significant experience preparing and giving oral presentations alongside visual aids (e.g., slides, research poster), they have limited experience in developing "stand-alone" materials like infographics. In fact, less than 25% of CHEM 2310/1560N students in the first four years of this assignment (2017−2020) had prepared an infographic prior to this course.

To assess the efficacy of the prepared infographics in conveying their intended message, we devised a two-stage evaluation process of the infographic by CHEM 0080/0100 students along with several targeted questions in the anonymous exit survey. In the first stage, CHEM 0080/0100 students reviewed the infographic on their own without any supporting explanations from CHEM 2310/1560N students. In the second stage, CHEM 2310/1560N students briefly described the contents of the infographic and fielded student questions. Based on the anonymous survey responses, >95% of CHEM 0100 students found the oral presentation that accompanied the infographic matched their initial impression

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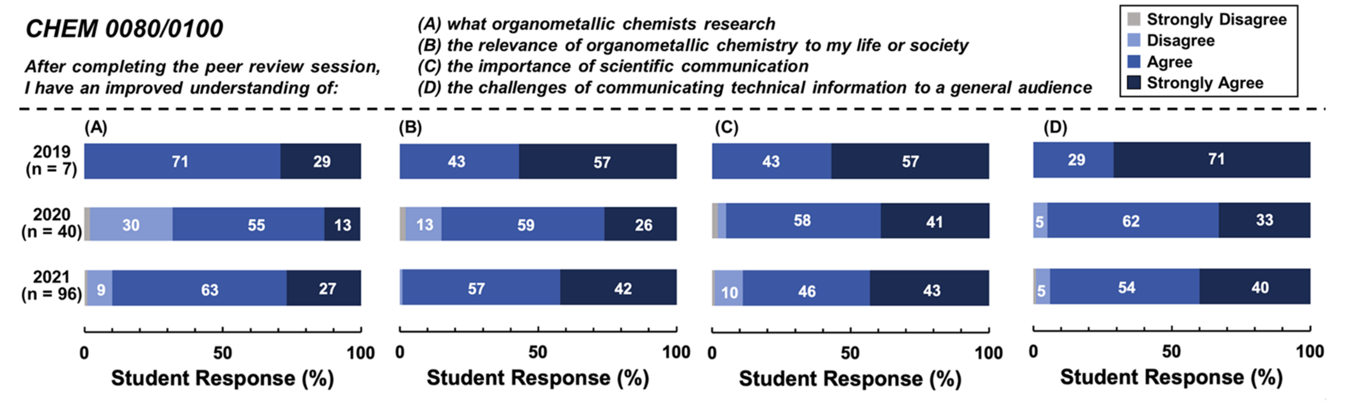

Figure 6. Percent of CHEM 0080/0100 survey responses to whether the peer review session with CHEM 2310/1560N improved their understanding of (A) what organometallic chemists research; (B) the relevance of organometallic chemistry to life or society; (C) the importance of scientific communication; (D) the challenges of communicating technical information with a general audience. Response sample size, *n*, is provided in parenthesis below the year.

from reading the infographic independently. Further support comes from excerpts of short responses collected from CHEM 0080/0100 students: "The infographic was very concise and clear, it was very specific to the research being talked about...I definitely got a good overview of the paper, the research, and its significance".

Student-generated materials and assignments can promote student contextualization,[17,27,39,40] which can in turn lead to significant improvements in student learning outcomes. We reasoned that effective communication of technical content with a general audience would provide context for these results in everyday life, and we hypothesized this could lead to emergent outcomes for students in both CHEM 0080/0100 and 2310/1560N. Although few CHEM 0080/0100 students (~10%) had heard about organometallic chemistry before the review session, after the session, nearly all students had an improved understanding of (i) what organometallic chemists research (84%), (ii) the relevance of organometallic chemistry to their life or society (95%), (iii) the importance of scientific communication (92%), and (iv) the challenges of communicating technical information with a general audience (94%) (Figure 6). Increased contextualization of organometallic and inorganic chemistry was not only limited to the general audience reviewing the infographics (i.e., CHEM 0080/0100). The majority of CHEM 2310/1560N students found that preparing an infographic broadened their understanding of organometallic and inorganic chemistry in the context of their daily lives (Figure 7). As one CHEM 2310/1560N student noted, "As scientists, we should aim to attempt to communicate our advancements in a positive and informative manner to relax the scientific/society information barrier", and the infographic assignment helped to do just that. Both the creators and intended audience of the infographic gained substantial contextualization of organometallics and inorganic chemistry through the assignment.

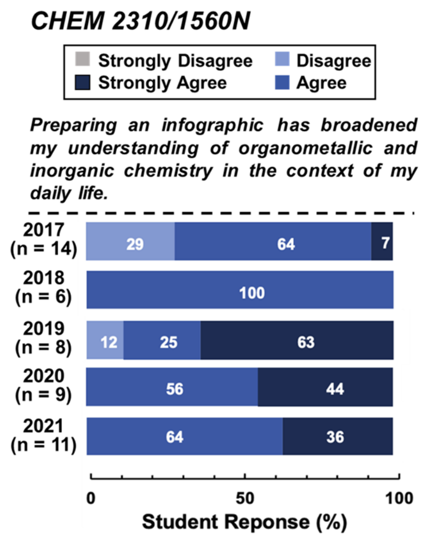

Figure 7. Percent of CHEM 2310/1560N survey responses to whether preparing an infographic broadened their understanding of chemistry in everyday life. Response sample size, *n*, is provided in parenthesis below the year.

FUTURE DIRECTIONS AND CONSIDERATIONS

Overall, the reception of the infographic assignment and peer-review activities by CHEM 2310/1560N and 0080/0100 were overwhelmingly positive. Students from both courses agreed that the assignment should be offered in future offerings (CHEM 2310/1560N: 94%; CHEM 0800/0100: 90%). Based on instructor observations and student feedback over the five-year period, we suggest the following recommendations with this assignment:

- Ensure opportunities for real-time feedback and interaction during peer and near-peer review with advanced and general audiences.
- Devote additional class time or a guest lecturer (e.g., Library, Visual Arts) to integrate STEAM (STEM + Arts) initiatives.[41]
- Initiate collaborations with introductory chemistry or STEM classes as an authentic general audience for near-peer review.
- Include a short assignment on peer review and share a descriptive/targeted rubric preceding the intra- and interclassroom sessions to elicit substantive and meaningful peer feedback.
- Build in short guest lectures from professionals across campus, including visual arts, communication, or library sciences to build additional, foundational multimedia knowledge within the classroom.

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We also want to offer additional considerations for how this assignment might be extended to address curricular needs or department/institutional goals:

- Leverage newly developed interclassroom collaborations as entry points to long-lasting near-peer partnerships, including mentoring networks between advanced and early stage students.
- Given the efficacy of infographics as standalone educational materials, integrate the finished materials into public outreach efforts.
- Consider implementing infographics into special topics, capstone, or colloquium/cohort classes as a means to build student expertise in preparing publication-quality scientific graphics with professional graphic editing software.

CONCLUSION

In summary, we have described our multiyear study using an infographic assignment in an upper-level chemistry course (CHEM 2310/1560N, *Organometallic Chemistry*) as an effective assignment to improve communication of technical scientific advances with general audiences. After completing the infographic assignment, students in CHEM 2310/1560N reported increased confidence in their ability to effectively communicate technical information with general audiences and an increased contextualization of organometallic and inorganic chemistry within their daily lives. Notably, authentic general audiences found that oral-guided presentations matched impressions formed during their self-guided reading of the infographics and support their use as standalone materials to communicate technical information to general audiences. Prior work has demonstrated the educational benefits of including infographics in primary[42] to university level[43] classrooms, and we envision that infographics could be leveraged in similar ways in public outreach efforts.

Collaborative peer (intraclassroom) and near-peer (interclassroom) review sessions were also critical components of this assignment. Students in CHEM 2310/1560N found both peer and near-peer review sessions provided informative feedback and broadened their understanding of how to communicate scientific concepts with a general audience. Students in CHEM 0080/0100 walked away with an improved contextualization of organometallic chemistry (i.e., understanding of organometallic chemistry research and its relevance to their daily lives) as well as the importance and challenges associated with communicating technical scientific advances to general audiences. Although not fully explored in this study, these informal, interclassroom interactions could also serve as a springboard for inclusive educational initiatives like near-peer mentoring. Similar to other studies,[2a,14−17] the assignment was well-received by participating students and further supports the integration of infographics and near-peer review into undergraduate and graduate chemistry curricula.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c00044.

Breakdown of survey responses, example rubrics, surveys, and infographics (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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