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A Wiki-Based Group Project in an Inorganic Chemistry Foundation Course

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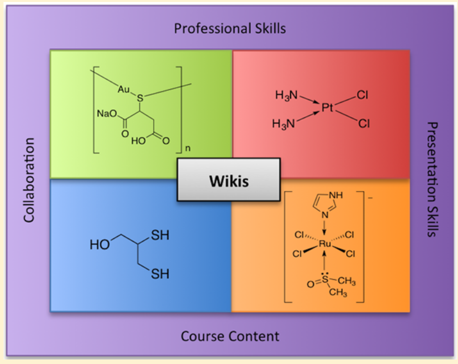
Supporting Information

ABSTRACT: A semester-long group project that utilizes wiki sites to enhance collaboration was developed for a foundation course in inorganic chemistry. Through structured assignments, student groups use metal-based or metal-combating therapeutic agents as a model for applying and understanding course concepts; they also gain proficiency with scientific- and web-based software. Each group displays their assignment products on a cohesive wiki, which serves as a study guide about the assigned therapeutic agent. Students periodically peer review other groups' wikis to learn how ongoing constructive feedback can improve a final product and to practice effective collaboration. Group presentations covering the wiki content and the therapeutic action of the drug are delivered at the end of the semester. This project could be utilized in other chemistry courses with appropriate topic selection.



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INTRODUCTION

Wikis are recognized as useful web-based technology[1] for a wide variety of educational activities in chemistry. Recently published applications of wikis include: professional development of chemistry teachers;[2] libraries of chemical, physical, and spectroscopic data;[3] online chemistry texts;[4] electronic laboratory notebooks and laboratory reporting;[5] platforms for problem-based learning (PBL) activities;[6] and several in-class projects for major and nonmajor, lecture and lab courses.[7] Wikis are also embraced for integrating large collections of data by the professional community of chemists. In addition to wikis dedicated to genomic data for organisms (for example, Ecoliwiki[8] and Zebrafish GenomeWiki[9]), there are wikis for development of NMR pulse sequences,[10] compound design in drug discovery,[11] and other specialized topics of interest to the chemistry community. As the use of web-based materials in both educational and professional contexts expands, students need experience as both users and developers of online content as part of their undergraduate training.[12]

Collaboration through Wikis

In addition to providing familiarity with common web-based technology, wikis can be used in course activities to develop students' collaboration skills. Wikis enable classmates to collect information from many sources, and organize and edit that information as a community of users, with all contributions and changes saved in a permanent record. Students and an instructor can, therefore, work together as both authors and editors using the wiki platform. As many have recognized,[6a,13] collaboration is required for laboratory work in academia and industry, and is a key aspect of every widely accepted communication of scientific results through the peer review process. A wiki-based activity is a useful option to develop collaboration skills in preparation for productive scientific careers.

To teach and assess collaboration skills in science, instructors often rely upon laboratory activities or, in lecture courses, on group activities and projects.[14] Such projects can yield positive learning outcomes for students, but present some common difficulties. Students often have extreme opinions about group work, either resenting or exploiting the possibility of disproportionate contributions from individual group members. Many students tend to experience difficulty meeting as a group, assigning tasks to members, and integrating contributions to produce a coherent final product. Group work also presents challenges for an instructor. In addition to maintaining student engagement with the project, instructors must eventually evaluate students' individual contributions and their level of collaboration. This is often difficult to determine from review of a single, final product.

These instructional challenges are partially addressed by the use of wikis to promote more effective collaboration on group projects.[6,7,15] Students work together remotely through the wiki platform, alleviating some of the difficulty of meeting as a group. They provide feedback to groupmates as the project progresses, resulting in a more coherent end product.[7b] Students are held accountable for their work because every

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Table 1. Learning Outcomes for Wiki-Based Group Project by Category

Course Content	Information Literacy/Communication Skills	Teamwork/Collaboration
Master course concepts by application to the same model complex as they are introduced	Draw chemical structures, orbital diagrams, and reaction schemes using ChemDraw and/or Hyperchem, search the chemical literature using SciFinder	Work effectively as a team
Understand and explain how the structural features of a metal complex affect function in a biological context	Communicate information effectively in writing, in person, and through web-based platforms	Give and receive constructive criticism, and utilize criticism to improve a product

Table 2. Typical Group Project Assignment Sequence and Related Skills

Number/ Week	*Assignment Topic*	*Related Skills*
0	Introduction to Therapeutic Agent	✓Add pages in the wiki and displaying/editing text ✓Display graphics, videos, and links ✓Search for data with SciFinder Scholar and pubs.acs.org ✓Request articles by interlibrary loan ✓Cite sources in ACS style ✓ Provide useful, objective commentary
1	General Properties of the Metal	
2	Electronic Structure of the Metal	
3	*Peer Review of Assignments 0-2*	
4	Electron counting, IUPAC naming, ligand classification	✓ Construct understanding of coordination compound structures and properties ✓ Attractively display tabulated, graphic, and written information ✓ Effectively organize a wiki with multiple pages using links and index tools ✓ Use ChemDraw to draw chemical structures and orbital diagrams ✓ Provide useful, objective commentary
5	Geometry, stereo and optical isomerism, symmetry	
6	Crystal Field Theory: orbital energy diagrams	
7	*Peer Review of Assignments 4-6*	
8	Coordination modes and M–L bonding interaction	✓ Continue to develop skills from Assignments 0-7 ✓ Utilize reviewer feedback to make improvements to the wiki prior to final deadline
9	Ligand Field Theory: spectrochemical series, colors and spectra, magnetism	
10	Substitution reactions: kinetic lability, mechanisms	
11	*Peer Review of Assignments 8-10*	
12	In-class Group Presentation	✓ Design effective presentation slides ✓ Practice oral communication skills

change to the wiki is tracked in a permanent record; both students and an instructor can see the quality and frequency of each group member's contributions. Peer review by classmates through the wiki also increases accountability to their groupmates and the class.[6a] The wiki can facilitate participation by students with weaker skills or disparate learning and communication styles[15a] by enabling students to examine their groupmates' work in advance of face-to-face meetings. For an instructor, the record of revisions and comments on the wiki provides a glimpse into how student groups work together to construct a final product. The wiki also enables an instructor to be a participant in the project alongside students through reviews and comments.

Group Projects and the Inorganic Chemistry Curriculum

The subdiscipline of inorganic chemistry encompasses a huge array of topics and concepts. A recent study[16] demonstrated that the choice of topics to include and exclude in a given foundation course in inorganic chemistry have varied greatly from one institution to the next, and even from year to year at the same institution. The ACS CPT guidelines[17] require ACS-accredited departments to offer a foundation course in inorganic chemistry yearly. While the guidelines for inorganic chemistry curricula include comprehensive lists of suggested topics, they are not prescriptive. Four different types of foundation inorganic chemistry courses that are currently taught in the U.S. were identified through a survey of inorganic chemistry professors:[16] Descriptive Chemistry, Fundamentals and Selected Topics, Foundation Survey: Fundamentals, and Foundation Survey: Comprehensive. A large majority of survey respondents reported teaching electronic structure of atoms and molecules, covalent bonding, and coordination chemistry; their curricula varied by which additional topics or fundamental inorganic chemistry concepts were covered, and to what extent.

Inorganic chemistry instructors must, therefore, select and prioritize lecture topics from the large scope of potential course material and have flexibility in choosing how to deliver content. The conflict between limited class time and the large amount of course material can be alleviated somewhat by requiring students (or groups of students) to tackle selected topics outside of class time. This approach also helps students become comfortable with independent learning, which is a skill required for in-depth coursework in any area of chemistry.

To expose students to the wiki platform, enhance collaboration skills, and promote independent learning of course material, a wiki-based group project about metal-based and metal-combating therapeutic agents was designed for a foundation inorganic chemistry course. The foundation course

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in inorganic chemistry, CHM 327: Inorganic and Bioinorganic Chemistry, covers electronic and molecular structure, bonding theories (crystal field and ligand field theory, molecular orbital theory), history and naming of transition metal compounds, geometry and isomerism, coordination chemistry, and bioinorganic chemistry. After traditional presentations of fundamental concepts, some course topics are taught through the study of metal sites in biology. For example, hard−soft acid base theory is introduced in the context of amino acids as ligands, and UV−vis spectroscopy of transition metal ions is covered by analyzing spectra of blue copper proteins. This approach probably falls into the Fundamentals and Selected Topics category of foundation inorganic courses.[16] The course has been well-received by students and attracted uncertified chemistry majors and minors to enroll in the course as an elective.

The choice to use bioinorganic chemistry as more than just a briefly covered special topic in some ways exacerbates the time crunch in the foundation course. Thus, instead of devoting lecture time to therapeutic agents involving metal centers, students introduce themselves to this topic through group project assignments throughout the semester. Students work in groups to apply each course topic, concurrently with its introduction in lecture, to a specific, biologically relevant example of a transition metal coordination compound. Project assignments also demonstrate the wider applicability and utility of the course material.

■ GROUP PROJECT STRUCTURE

Project Design and Learning Goals

The class is divided into three or four groups of 3 or 4 students, depending on enrollment. Each group is assigned a metal-based or metal-combating therapeutic agent and completes sequential weekly assignments that guide them to build a wiki site about the therapeutic agent. The groups also periodically provide peer review of other groups' sites and make a presentation about their work during the final week of class. The assigned therapeutic agents have included cisplatin and derivatives, ruthenium antitumor agents, auranofin and related compounds, and chelators for copper (see Supporting Information). The final exam for the course contains questions related to content that was emphasized in each group's presentation and wiki.

The desired learning outcomes for the group project are related to course content, information literacy/communication skills, and teamwork/collaboration (Table 1). They are combined into a grading rubric in the assignment sheet distributed to students (Supporting Information).

Project Assignments, Peer Review, and Presentation

The weekly assignments (Table 2) require students to apply newly introduced course concepts to their assigned compound(s) as the course progresses, reinforcing the concepts and building in-depth content knowledge related to metal-based therapeutics. For example, when isomerism in coordination complexes is introduced, students are asked to identify all geometric isomers of their assigned compounds and determine which have optical isomers. Students find UV−vis spectra of their assigned compounds and discuss how the color relates to the electronic structure when applications of crystal field theory are studied. Similar assignments (Supporting Information) help students apply all of the topics shown in Table 2 to their assigned compounds and build a wiki with multiple pages to display the associated content.

In addition to compelling students to engage with new course material on a regular basis, the assignments are designed to build students' skills gradually in using the wiki platform and other relevant software, including ChemDraw and SciFinder. Initial assignments require students to search for peer-reviewed articles using SciFinder, obtain electronic copies, and add a page in their wiki to present sources in ACS style with the DOI or link to full text. Searching skills and wiki formatting skills are further developed through assignments where students compile reference information from reputable sources. For example, when chemical periodicity and features of the d-block metals are covered, students find and attractively display reference data for their assigned metal to gain familiarity with the text editor, table formatting, and other features in the wiki. This assignment also requires students to discriminate among the many sources available online, emphasizing primary literature and reference books. In later assignments, students utilize ChemDraw to draw structures and orbital diagrams. Students also link to useful web content, post helpful videos, or design content using other software with which they are familiar. As others have noticed,[7b] once students become comfortable working within the wiki, they begin to add useful features, such as anchors, page indices, etc. spontaneously, and to produce more effective content.

A final goal of the assignments is for students to engage in a peer review process. Periodically, the group assignment asks students to provide objective and useful commentary on the content of another group's wiki using the wiki's comments feature. The peer review assignments are typically scheduled to coincide with the week of an in-class exam. After students review each others' wikis, the instructor leaves feedback on the sites and/or responds to student comments. The comments are public to all members of the class and contribute to the grade for the project. Each group is expected to edit their wiki based upon the feedback they receive from classmates and the instructor before the final project deadline.

Project assignments, thus, develop the course material, enhance the students' familiarity with useful software, and provide experience with a peer review process. The oral presentations to the class require the groups to integrate the materials they have produced and consider how best to present it to an audience of peers. The success of this approach to covering a large amount of material in a semi-independent way hinges on sustained student effort and collaboration over an entire semester. The use of wikis contributes to the quality of learning by compelling students to participate, increasing the stakes of the outcome through its public (to the class) nature, and providing solutions to some logistical issues associated with working as a group.

■ IMPLEMENTATION

Structure and Wiki Platform

A class Web site is organized using the free wiki classroom offered by Wikispaces.com.[18] Wikispaces has a "Project" feature that allows students to be assigned to different groups and for each group to maintain an individual wiki. Using the wiki classroom as the course Web site, not just for the group project, is crucial for engaged participation. Requiring students to visit the wiki classroom constantly (rather than the institution-wide course management system, such as Blackboard or Moodle) to access homework assignments, answer keys, slides, and other course materials helps them become more comfortable with the

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wiki platform as a whole, and encourages them to access their project wiki more often.

A schedule of deadlines for project assignments is distributed at the beginning of the semester, and each project assignment is posted to the wiki classroom on a weekly basis to ensure that the topic correlates with the lecture material. In the week following each deadline, the project assignment consists of peer review of other groups' wikis. On the final project deadline (usually the last day of class), the instructor locks the wiki sites to prevent further changes. Students may edit their wiki based upon classmate and instructor feedback until that final deadline, after which the instructor reviews the wiki sites and assigns final grades for the project.

Students may encounter some minor technical problems in developing their project wikis in the Wikispaces environment. For instance, sometimes changes are lost when two students attempt to edit a page simultaneously. Another common problem initially is preparing graphics that have appropriate resolution and display as desired on the wiki site. However, as others have noted,[7b] these minor issues are usually resolved using the Wikispaces Help wiki and do not outweigh the advantages of the wiki platform for this project.

Training and Resources

One, 50-min class period in a computer lab is devoted to introduce students to the group project assignment and expectations, the Wikispaces environment, and SciFinder Scholar as a search tool. Students are required to register for Wikispaces and are added as members to their groups in advance. They complete a training activity (provided by Wikispaces) for homework to ensure that they can perform basic functions within the wiki, such as editing text, adding pictures, videos, links, etc. As the project progresses, some additional class time is devoted to demonstrate the use of ChemDraw or to address class questions about using Wikispaces or SciFinder. The class maintains a "Project Resources" page within the wiki classroom that serves as a repository of useful links and information to help each group prepare content for their wiki.

■ PROJECT OUTCOMES

Student Response and Project Evolution

The first implementation of the project involved four groups of 3 or 4 students and was assessed using both an anonymous survey attached to the online course evaluation and a nonanonymous survey about group collaboration and participation attached to the final exam (see Supporting Information). Across both implementations, the project received overall positive feedback on goals related to course content. Students wrote "applying the information to something we did not discuss in class showed us a variety of ways the material could be utilized" and "the wiki assignments forced me to reiterate what was taught in class," among similar comments. One unexpected complaint that arose in the project evaluations was that some assigned therapeutic agents were easier to study than others because they correlated more closely with the course material. This criticism originated from a group assigned auranofin and other linear gold complexes as their project topic. Octahedral, tetrahedral, and square planar geometries were studied in detail during class, but linear complexes were only briefly discussed.

The first implementation of the project was unsuccessful in encouraging students to use the wiki as a mode of communication among group members. Students tended to default to in-person meetings where they completed the assignment tasks, and then posted the result to the wiki site. Thus, the first time the project was assigned, students largely completed it as they would have *without* the wiki site as a venue for dissemination. Related to this shortfall was the lack of substantive peer review. Students posted comments by the deadline, but they were often vague, overly positive, or otherwise reflected a lack of meaningful engagement with the other groups' work (despite the guidelines provided for peer review).

Several changes were made to the project to address these problems in the second implementation. Enrollment allowed the class to divide into three groups rather than four. Each group was assigned a therapeutic agent with a geometry covered extensively in class to remove the sense of inequality of project topics. In student feedback, this eliminated the criticism that one particular topic required a greater input of outside research than others.

In the first implementation, Blackboard was used as the course Web site where students found homework assignments, answer keys, and other course materials. Moving these materials to Wikispaces for the second implementation required students to visit the site frequently and encouraged participation.

To improve the quality of peer reviews, each group was assigned to review one other group's wiki for the peer review assignments (in a rotating schedule). In the original implementation, groups were required to review all other groups' sites for all of the peer review assignments. Focusing the task to one other group's wiki allowed students to spend more time closely reviewing the relevant material.

The changes to the pattern of use of Wikispaces and the peer review structure resulted in much more fruitful online collaboration in the second implementation. The increased emphasis on the wiki site, as a class Web site and through frequent instructor feedback, led to more intragroup comments and reviews, and to higher-quality intergroup reviewer feedback. Students still met in person, but spent more time dividing tasks or combining individual content than actually producing new content during in-person meetings. Some survey comments about working together included "[c]omparing from when we first started to now, our group has gotten better at working together" and "...we each had our own way of doing things. I think I personally learned a lot from working with my team." One unexpected outcome of the increased engagement was the use of communication tools outside of Wikispaces, i.e., message groups through students' personal Facebook accounts, to discuss project assignments. The level of engagement with the project surpassed expectations during the second implementation, and the high quality of the resulting wikis reflects the very successful collaboration.

One comment that has persisted and has been resisted through both implementations of the project is the students' desire to choose their own groups. An instructor can assign groups that contain a distribution of skill levels, past course experience, and personalities that lead to positive learning outcomes. Additionally, in the workplace, employees rarely choose their own work groups. The assigned groups may not be the students' first choice, but they contribute to the goals of the project.

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Learning Outcomes

After the final project deadline, grades were assigned for the assessment areas in the grading rubric (see Supporting Information). The overall quality of students' work improved in the second implementation. This is reflected in the increase in students who met or exceeded the learning outcomes for the project overall, from about 70% to 100%. In the areas of chemistry content and professional presentation, the majority (78−100%) of students met or exceeded expectations in both years. However, there was a drastic change in the quality of intergroup collaboration through peer review from the first to second year. A majority (64%) of students failed to meet the learning outcomes in the first year of the project, and all of the students met the learning outcomes for this criterion in the second year.

Students' assessment of their intragroup collaboration largely correlated with the instructor's assessment gleaned from activity on the wiki sites and observations in class. In the first year, students reported that they mostly worked on assignments individually or in person as a group, then posted the content to the wikis. This pattern was observed in the revision log of the wiki site, which frequently showed an entry for one group member posting the majority of content, with very few subsequent additions or changes. Overall, members of the same group provided similar estimates of the relative contributions from other group members. From observations in class and the revision log, these estimates of the relative contributions appeared accurate to the instructor. In the second year, there was also general agreement about the relative contributions of group members, but intragroup collaboration through the wiki site increased. The enhanced collaboration was apparent in the revision log of the wiki, the public interaction (comments, editing) within each group's wiki, and the overall higher quality of the final products.

■ CONCLUSION

With some modifications after the first implementation, the wiki-based group project was successful in providing experience as a wiki user and as a peer reviewer, as well as offering another way to approach the course material. In addition to gaining professional skills, the students learned content about metal-based and metal-combating therapeutic agents. The general structure of the project could allow for variation of the project topic to cover other areas of inorganic chemistry, such as metalloprotein active sites. Other types of inorganic chemistry courses could utilize the project structure with different topics, such as historically important organometallic compounds (e.g., ferrocene, cobalamin, Zeise's salt) or transition metal and main group poisons. The project structure could, likewise, be used in courses covering other areas of chemistry given an appropriate choice of topic.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00507.

> Project assignment sheet and assignment schedule, individual project assignments, and assessment criteria (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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(18) A wiki classroom includes a home page, calendar function with announcements, and discussion function that can be used by the instructor to organize a course. Pages may be added to the wiki classroom for slides, homework, etc. Instructors control the permissions for the pages and can allow students to edit them if desired. The wiki classroom on Wikispaces also has the "Project" feature that enables assigned groups of students to work together on their own wiki.

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