

# Improving Information Literacy Skills through Learning To Use and Edit Wikipedia: A Chemistry Perspective

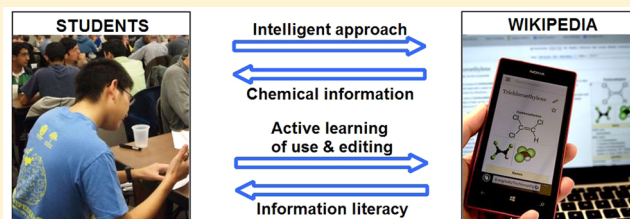
Martin A. Walker<sup>\*,†</sup> and Ye Li<sup>\*,‡</sup>

<sup>†</sup>Department of Chemistry, State University of New York at Potsdam, Potsdam, New York 13676, United States

<sup>‡</sup>Shapiro Science Library, University of Michigan, Ann Arbor, Michigan 48109, United States

**ABSTRACT:** Our students rely on Wikipedia on their mobile devices or laptops, since it is an extremely rich and broad resource. This article overviews the Chemistry content on Wikipedia and how students can learn to use it effectively as an information resource, critically evaluating content, and learning key information literacy skills. We also discuss how students' information literacy skills can be improved through a class project where students edit Wikipedia articles. Through such projects, students may begin to appreciate where and how chemical information is generated, gathered, developed, and shared in the real world.

**KEYWORDS:** *First-Year Undergraduate, Second-Year Undergraduate, Upper-Division Undergraduate, Graduate Education, Chemoinformatics, Collaborative/Cooperative Learning, Internet/Web-Based Learning, Student-Centered Learning, Descriptive Chemistry*



Wikipedia is a hugely popular resource for information on the Web—but should it be embraced by academia, or rejected? Its unconventional approach to gathering information has allowed it to grow into the world's largest single body of information, or perhaps of knowledge, and gain extraordinary reach—but it does not rely on accredited experts or formal peer review. It would be a mistake to completely rely on Wikipedia for learning and research, but we would also short-change our students if we ignored such a deep, rich resource.<sup>1</sup>

Wikipedia can meet a variety of needs, ranging from a quick piece of data to a thorough understanding of a difficult concept. This article describes how students can be trained to use the site effectively for their day-to-day work, while developing specific skills in information literacy. The latter part of the article describes how students can be shown how to collaborate and edit a Wikipedia article correctly, leading to an even deeper understanding of how chemical information is created and disseminated.

## WIKIPEDIA AS AN INFORMATION RESOURCE

Wikipedia accrues information by allowing anyone to submit or change content via a Web browser, while simply requesting that any substantive contribution be based on a neutral point of view with reliable sources, and not break copyright laws. This approach only works because there is a large, active community of volunteers who then check contributions and revert or edit those which violate the rules—often within minutes—although some edits may “slip through the cracks” for prolonged periods of time.<sup>2</sup> Unlike in traditional encyclopedias, factual assertions must be supported by inline references, leading to a very rigorous standard for content; however, a vandal may change the word “black” into “white” and completely reverse the

meaning given in the supporting reference! Regular users earn the respect and trust of the community based on the quality of their edits, not on claims of traditional academic qualifications.<sup>3</sup> It is not unusual to see an established scientist's work being edited by a smart student, especially if the latter is known as a well-trusted member of the community.<sup>4</sup>

With such an unusual approach, it is not surprising that many academics have shied away from Wikipedia, and some may actively discourage their students from using it as a resource. This situation is exacerbated by the tendency of some students to plagiarize Wikipedia, or for them to rely on it uncritically. Neither of these provides a valid reason for outright rejection of Wikipedia, but they do mean we should educate our students to read Wikipedia like a newspaper story, with a critical eye! As scientists, we should understand and guide students to understand the difference between perception and reality, or between credibility and reliability; we should apply that understanding when using information resources, just as we might with laboratory data.

Over time, we learn to treat certain information sources as reliable, “good enough”, or unreliable. But we know that even our most reliable sources are imperfect, and that scientific peer review can be superficial or even biased (just like Wikipedia!). Since we need to get our information from somewhere, we often tend to use resources that are *useful* to use and easy to access, as long as they are considered “good enough” in terms of reliability. In an educational context, “good enough”,<sup>5</sup> i.e., what can be considered adequate in the context of the problem

**Special Issue:** Chemical Information

to be solved, in terms of content and reliability, may also provide an opportunity to teach students about information literacy.

A good way to judge reliability is to look at the actual content in Wikipedia, rather than worrying about perceived flaws in the process that created it. An early example involved a famous 2006 study by *Nature*,<sup>6</sup> which concluded that Wikipedia was almost as reliable as a traditional premium encyclopedia; this was from a time when referencing in Wikipedia was much less rigorous than today. In more recent studies, one 2009 survey of expert toxicologists found Wikipedia to be one of the most balanced sources of toxicology information, compared to traditional media.<sup>7</sup> In contrast, a 2011 study on information used by pharmacy students<sup>8</sup> showed that content was often incomplete and/or inaccurate, and concluded that “faculty should actively recommend against our students’ use of Wikipedia for medication information”, though they acknowledge that “Wikipedia articles may have been deemed complete when additional information could be found in other resources.” However, a 2014 study<sup>9</sup> came to the opposite conclusion; after comparing the German Wikipedia with standard textbooks, the authors concluded that “Wikipedia is an accurate and comprehensive source of drug-related information for undergraduate medical education.” Clearly, the academic community remains divided.

Work by Lim<sup>10</sup> has shown that many Internet users, including students, base their judgment of reliability on *apparent* reliability (such as numbers of references for an article, or the professionalism of the writing or Web site graphics), rather than on more formal methods such as a rigorous check of each reference and whether or not it matches the assertion in the article. Therefore, it is very plausible that both students and educators may use Wikipedia inappropriately as long as it “feels” correct.

## ■ CHEMISTRY CONTENT ON WIKIPEDIA

### Types of Content

Chemistry is a much broader topic than drug information; errors are not usually life-critical, and there is no perfect source of free but reliable information. The largest body of information is in substance articles,<sup>11</sup> which are normally a combination of encyclopedic text (physical and chemical properties, synthesis, reactions, applications, etc.) side-by-side with a ChemBox summarizing key data (structure, InChI, melting/boiling points, solubility, etc.). The ChemBoxes have a feature which may be unique within Wikipedia: validated content that is patrolled by a bot (CheMoBot)<sup>12</sup> to ensure that certain data fields remain accurate. A green check mark indicates a checked datum, while a red X indicates one that has been changed and may be wrong. Validated CAS registry numbers have been checked against a data file provided by CAS, and these are linked to the relevant CAS Common Chemistry page.<sup>13</sup> However, much of the ChemBox remains unvalidated at present. Some further chemical data (such as thermodynamic and spectral data) may be available on supplementary data pages, linked from the ChemBox.<sup>14</sup>

Other chemistry pages mostly follow the standard Wikipedia article format. There are good sets of articles on chemical elements and on named reactions. Articles are available for industrial processes, as well as concepts such as thermodynamic or polymer chemistry terms. There are thought to be fewer

biographical articles about scientists than there are about people in some other fields.<sup>15</sup>

### Organization of Content

The articles are overseen and maintained by a community of editors who mainly collaborate through WikiProjects such as WikiProject Chemistry, Chemicals (for substances), Elements, Pharmacology (for drug articles), Molecular and Cellular Biology, Spectroscopy and Polymers (on the English language Wikipedia).<sup>16</sup> Articles are tagged and assessed<sup>17</sup> (on the discussion pages) by these groups, and a bot, an automatic algorithm running behind the scenes, then provides tables of information to the WikiProjects so they can track which articles need work, which have been improved, etc. Editors may collaborate to turn an article into a “Good Article”<sup>18</sup> or (even higher) a “Featured Article”,<sup>19</sup> which require a fairly intense review process by people from outside the WikiProject. These articles are usually very extensive and well-referenced, though the outside reviewers cannot usually judge the quality of the chemistry content. For a detailed look at the provenance of information in the article, and reasons why the article contains or excludes certain information, the article’s history tab and the discussion page are very useful.

In 2012, the Wikimedia Foundation and Wikimedia Deutschland began a database project, Wikidata,<sup>20</sup> in order to centralize data across all Wikipedias with validated content; the birth date of Marie Curie or the boiling point of methanol is the same in any language! There is a Wikidata project for chemistry,<sup>21</sup> the information collected in Wikidata has yet to be fully integrated into the articles and the ChemBoxes, but this is likely to occur in the coming years.

### How To Use Wikipedia Effectively for Chemical Information

In order to gather information, one must learn to critically evaluate references for both relevance and reliability, yet many students lack this skill, even after training.<sup>22</sup> Wikipedia provides an excellent place for them to begin asking questions, such as Has the text been changed, devaluing the original citation? Why were certain references chosen: Because they appear high in a Google search, or because they are the most relevant? Is there an inherent bias in Wikipedia references toward recent and online sources? In order to answer these questions students must find their own in-depth ways to evaluate information critically.

One aspect where Wikipedia is often exemplary in its practice is in its handling of copyright. It is critical for the site to use a clear, open “copyleft” license (Creative Commons CC-BY-SA)<sup>23</sup> for its materials, since that material is designed for reuse. Students may believe it is perfectly acceptable to use a copyrighted picture or diagram from a Web site or Google image search; they should be taught about copyright, fair use, public domain, and Creative Commons licenses,<sup>24</sup> as well as the importance of citing the source for an image file. This lesson is well learned (often the hard way—after deletion!) when students upload images into Wikipedia in class projects (*vide infra*). For citing the Wikipedia article itself, students should be shown the “Cite this page” link on the left side toolbar of each page.

We would recommend the use of Wikipedia in the following ways:

**To Provide Context for a Topic.** Many concepts are understood as part of a wider “landscape” by practicing scientists, who appreciate the connections with other topics.

**Table 1. Analysis of Activities in Wikipedia Editing Projects with Respect to the ACRL Framework for Information Literacy for Higher Education<sup>41</sup>**

Framework <sup>a</sup>	Examples of Relevant Knowledge Practices/Dispositions <sup>a</sup>	Activities in Wikipedia Editing Projects
Authority Is Constructed and Contextual	Recognize that authoritative content may be packaged formally or informally and may include sources of all media types	Required to understand how Wikipedia works as a new type of media
	Develop awareness of the importance of assessing content with a skeptical stance and with a self-awareness of their own biases and worldview	Required to learn how everyone could modify Wikipedia thus developing awareness of assessing what is to be trusted on Wikipedia
Information Creation as a Process	Develop, in their own creation processes, an understanding that their choices impact the purposes for which the information product will be used and the message it conveys	Required to create information/knowledge for general public and use a writing style appropriate for a broad audience
	Accept the ambiguity surrounding the potential value of information creation expressed in emerging formats or modes	Required to keep neutral point of view when writing Wikipedia articles but also recognize neutral point of view is a vague standard to apply
Information Has Value	Articulate the purpose and distinguishing characteristics of copyright, fair use, open access, and the public domain	Required to identify the copyright status of media files to be posted on Wikipedia and use them in appropriate manners, which is monitored by the community
	See themselves as contributors to the information marketplace rather than only consumers of it	Required to contribute to a resource they use on a daily basis
Research as inquiry	Synthesize ideas gathered from multiple sources	Required to consult primary, secondary, and tertiary resources and then report a cohesive story about the given topic
	Appreciate that a question may appear to be simple but still disruptive and important to research	Required to overcome the challenge of articulating a complicated chemistry topic to general public as a simple introduction through comprehensive literature research
Scholarship as Conversation	Contribute to scholarly conversation at an appropriate level	Required to contribute to the public knowledge base by “translating” expert opinions to stories general public can understand and find useful
	Value user-generated content and evaluate contributions made by others	Required to review peer editors’ contribution to Wikipedia and respect each others’ contributions
Searching as Strategic Exploration	Utilize divergent and convergent thinking when searching	Required to seek for information to illustrate the big picture but also highlight perspective most commonly accepted for writing an encyclopedia style article
	Understand the first attempts at searching do not always produce adequate results	Required to recognize that the reason why Wikipedia entries are used as starting point while writing their entries

<sup>a</sup>All Framework items and Examples of Relevant Knowledge Practices/Dispositions in the two columns were excerpted from the ACRL Framework for Information Literacy for Higher Education.<sup>41</sup>

For a student of chemistry, these connections are less obvious, and judgments of relevance and importance can be difficult. Unless the article is very flawed, Wikipedia is often an excellent way for a beginner to quickly see connections and the bigger picture—which may not be obvious from the lab manual or the textbook. In some cases the description may be very brief, but internal links to related topics allow the student to explore the subject in detail, more fully than is possible in a flat web page or book. External links and “further reading” usually enrich the subject even more.

**To Provide a Quick Definition and Key Terms.** The lead paragraph (lede) of a Wikipedia article is often a useful description in lay terms; this is why it is often used by Google, ChemSpider, and other sites to summarize what something is. Some official bodies are even beginning to work with the Wikipedia community to try and make sure that Wikipedia definitions are aligned with official definitions.<sup>25</sup> If the definition is critical, then naturally Wikipedia should be only one of several sources. Related to this is the use of Wikipedia to provide alternative spellings or names, and key terms used when discussing the topic. For example, to search on information for the Julia olefination outside Wikipedia, it may be necessary to look for the terms “Julia-Lythgoe” or “Kocienski.” A useful feature is that Wikipedia often redirects the user to an article automatically when common synonyms for the topic are used.

**As a Quick Source for Chemical Data.** The ChemBox is a concise summary of the key substance data that chemists need, and for most purposes those data are accurate enough, especially those fields that have been validated (green check mark). If verification is needed, links are provided taking the

user directly to the relevant records in PubChem, ChemSpider, CAS Common Chemistry, etc. However, we should still generally encourage students to check the primary research paper that published the data, since this may show the measurement context and conditions, which are often crucial for reuse of the data.

**As a Portal to Useful References.** In one author’s experience, students have often scored poorly on literature assignments because of an inability to extract relevant information from a journal article. With training, the citation of sources within Wikipedia can provide students with key papers, helping them to move beyond Web search engines and into the chemical literature. Often the “key papers” on a topic can be quickly seen in context with a single click of a mouse. However, Wikipedia references should be handled carefully as they may show some bias, or not represent the whole topic.

## ■ OTHER WIKIS

There are many other chemistry resources that use MediaWiki, the wiki platform used for Wikipedia. These include educational resources such as the Chemical Education Digital Library (ChemEdDL),<sup>26</sup> VICEP,<sup>27</sup> for inorganic chemistry educators, ChemWiki for virtual textbooks,<sup>28</sup> and the RSC Learn Chemistry Wiki.<sup>29</sup> Chemical information resources include the Wiki Hyperglossary<sup>30</sup> and the Chemical Information Sources Wikibook.<sup>31</sup> All of these wikis fill niches within chemical education, and the wiki platform makes these also suitable for students to use in similar ways to Wikipedia, either as resources or as examples for studying information literacy.

## ■ EDITING WIKIPEDIA AS A LEARNING TOOL

### Developing Information Literacy by Editing Wikipedia

To help students develop a deep understanding of these recommended practices in using Wikipedia, one very effective approach is to involve students in editing Wikipedia themselves and guide them to better their information literacy skills during the process. Many instructors in higher education around the world have explored using Wikipedia editing as a class assignment to help students improve their understanding of subject matter, their information literacy skills, critical analysis skills, writing skills, and teamwork competences.<sup>32–35</sup>

In 2010, the Wikimedia Foundation initiated the Wikipedia Education Program to help university instructors to incorporate Wikipedia editing assignments in their classes and also facilitate communications between classroom education and the Wikipedian community.<sup>36</sup> This program has now become the Wiki Education Foundation (Wiki Ed), a spin-off of the Wikimedia Foundation.<sup>37</sup> It has been providing learning materials and collaborative spaces on Wikipedia to instructors and students<sup>38</sup> and also connecting online volunteers and campus volunteers<sup>39</sup> with instructors and students.

As a science librarian, one of the authors started a collaboration with Anne McNeil, a University of Michigan Chemistry professor, to support her classes employing Wikipedia editing projects and has been supporting many other classes across Science, Social Science, and Humanities at the University of Michigan since 2011. Some of the class portals on Wikipedia are linked on the author's Wikipedia user page.<sup>40</sup> After working with a variety of classes, the author clearly recognized how students could improve their information literacy skills through a Wikipedia editing project.

To articulate the potential, we present an analysis of the components of Wikipedia editing with respect to the recently filed Framework for Information Literacy for Higher Education from the Association of College & Research Libraries (ACRL)<sup>41</sup> in Table 1. Instead of giving a static checklist of specific skills like a traditional information literacy standard, this new ACRL Framework focuses on interactively cultivating information literacy skill development through involving students in the actual creation of information collaboratively. Because Wikipedia editing projects allow students to play a creator role for information that is useful for the general public and to experience various aspects of metaliteracy, it is naturally a way for students to grow from novice learners to information literacy experts, and it fits well with the threshold concepts of the ACRL IL framework. Compared to other types of writing assignments such as a traditional course paper, Wikipedia editing provides the following benefits:

- (1) Having a real audience, the general public, and a defined writing style, encyclopedia style;
- (2) Doing public good by converting subject knowledge learned in class into articles more approachable by nonexperts;
- (3) Interacting with classmates and peer editors on Wikipedia around the world during the information creation process;
- (4) Presenting an opportunity to make information they created available to the world instantly.

The last point means making a real-world impact; and if done properly, this impact can last long after the class ends, which is beneficial both for the students and for the general public. The

selected knowledge practices and dispositions relevant to Wikipedia editing projects in Table 1 are examples of how the editing activities can help develop information literacy abilities in these areas.

From the perspective of the chemical education community, a Wikipedia editing assignment also aligns with the requirements for student skill development in the ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs,<sup>42</sup> such as chemical literature and information management skills, communication skills, team skills, and ethics.

### Supporting Classes for Wikipedia Editing

Because of the strong relevance to the development of information literacy, Wikipedia editing projects often require support from librarians or information specialists. The support mainly covers the following components.

**Dynamics of Wikipedia Community.** When contributing to Wikipedia, students are participating in the Wikipedia community as individuals. Other editors may or may not know their student identity and will interact with them the same as with other anonymous editors. Preparing students for responding to a variety of perspectives and communication styles could be the key to creating a constructive experience for them. Starting with overviews of the structure of the Wikipedia community and articulating both advantages and limitations of the structure<sup>43</sup> often attracts their attention and builds up their excitement to get involved. Introducing WikiProjects<sup>44</sup> for the particular discipline not only provides students a channel to connect to the Wikipedia community but also helps them select a topic interesting to the community to edit, for example, the "Things you can do" list on the WikiProject Chemistry page.<sup>45</sup>

**Literature Search and Evaluation Strategies.** Since Wikipedia is a dynamic encyclopedia, the writing style requires authors to consult a broad spectrum of resources, evaluate them, and cite them properly. Search strategies for primary, secondary, and tertiary information resources in given disciplines will need to be articulated for students. For example, students often do not realize that they could consult other encyclopedias or handbooks to get an overview of the topics they need to perform research on. Citing sources such as news articles for the history or application parts of Wikipedia article will ensure that science students have an opportunity to find, evaluate, and use this type of information, which they do not often use in other classes. In addition, besides evaluating the reliability and the relevancy of content that they discover, students also need to identify the neutral point of view based on the resources they find. This skill is essential to develop and can only be improved through interactions among students, instructors, librarians, and peer editors on Wikipedia.

**Encyclopedia Writing Style.** Students' previous writing experiences are mostly course papers with limited audience. Without intervention, they tend to write articles focusing on one particular aspect, oftentimes what they know best about the topic, or only reviewing the recent development of a topic. Explaining the general structure of an encyclopedia article, including a lead section to overview, history, and current focuses etc., will help students see the difference. Meanwhile, the extensive style guides on Wikipedia such as the Manual of Style for Chemistry<sup>46</sup> should be introduced to students for their reference, but students can be easily overwhelmed by the extent and level of details. It is important to encourage students to be bold with editing as long as they respect the fundamental principles of the community with good faith. Featured

Articles<sup>19</sup> can be used as examples, and the tutorials provided by Wiki Ed are customized for students to learn. If students are to work on special types of articles such as biography, ensure they pay close attention to specific requirements of the community.<sup>47</sup>

**Wikipedia Editing Techniques.** The markup language used to edit Wikipedia articles can appear to be intimidating for beginners. A 20 min in-class demonstration of basic editing techniques often helps students overcome the fear to start. A series of video tutorials available on Wikipedia can be provided for students to use after class.<sup>48</sup> Adding references is one of the most important steps in editing and also a good opportunity for students to learn how to cite various types of resources and integrate them in their writing. Make sure sufficient examples are provided for students to avoid confusion. A new WSIWYG type of editing tool called “VisualEditor”<sup>49</sup> is now available in Wikipedia and can lower the technical barrier of editing Wikipedia, but it is still in beta version and may cause unexpected problems.

**Copyright and Ethics Issues.** Students often cannot differentiate copyright issues and ethics issues before editing Wikipedia. Some of them may consider it acceptable to post long excerpts from other publications as long as they cite the source. Those edits often get deleted instantly due to suspected plagiarism detected by Wikipedia algorithms. Case studies can be designed to show that this kind of action potentially leads to both plagiarism and violation of publisher’s copyright. It is then possible to emphasize the importance of paraphrasing and citing properly, as well as verifying the copyright status of material to be reused. The last point is most important for media files, which provide a good opportunity to introduce the differences among copyright, fair use, Creative Commons license, open access, public domain, etc.

**Peer Review Criteria.** The most valuable part of the project is the interaction with peer editors, internal and external to the class, through reviewing each other’s work. Instructors often find it helpful to have students review each other’s draft articles in their Wikipedia “sandboxes” first before posting the article for public view. The internal review criteria may contain more basic indicators like minimum numbers of references and images to include. However, it is also crucial to emphasize the core content policy of Wikipedia in the review criteria—neutral point of view, verifiability, and no original research<sup>50</sup>—because those are what the community will use to evaluate students’ articles when the articles are finally posted for public access. The neutral point of view is a fundamental principle of Wikipedia, but it is also the most difficult standard to define in reality. Instructors sometimes may need to work with individual student teams to help them communicate with the Wikipedia community and may need to speak on their behalf occasionally.

One additional advantage of teaching with Wikipedia editing projects is the scalability of the project. The time that can be dedicated for the Wikipedia project from a particular class may be limited and may not allow students to edit full-length articles. In those cases, the assignment can be downsized to add or edit small portions of existing articles or just correct mistakes in existing articles. The librarian can focus on one or two of the components listed above instead of delivering the full package. Instructors newly involved in Wikipedia editing projects may often underestimate the time and effort students need to spend on apprehending the norms of the Wikipedia community and familiarizing themselves with the techniques and communication channels. We encourage instructors who have the intention

to adopt the project to edit an article themselves or at least try to interact with the community first so that they are fully aware of challenges students could encounter.

The scalability issue should also be considered when choosing an undergraduate classes or a graduate class to use a Wikipedia editing assignment. Graduate students often have a more background knowledge and literature research experience that allow them to accomplish a comparatively thorough improvement of a full Wikipedia article and the associated peer review activities. Undergraduates, especially the first-year or second-year students in classes with hundreds of students, are more limited by time and experience as well as individual attention from the instructor. Correcting grammatical errors or adding references may be better options. Box 1 provides a list of scalable components for Wikipedia assignment.

### Box 1

#### Box 1. Scalable Components of Wikipedia Editing Assignments

- Copy editing
- Adding citation
- Adding images
- Adding small sections
- Adding several sections
- Developing stub articles to full articles
- Creating new articles
- Peer review and responding to peer review
- Interacting with Wikipedia community

Librarians usually act as bridges among parties in our user communities. For Wikipedia editing, librarians can also play an important role in connecting the learning community on campus and the broader Wikipedia community, especially when course instructors have not interacted with the Wikipedia community at all. As to any other types of communication, appropriate transparency is the key to success here. It often can be achieved by creating a course page to include introduction on the course project, summary of training provided to students, links to students’ drafts, and a discussion page for Wikipedians to provide feedback to students. The Talk page of Wikipedia articles being edited by students should provide links back to the course page. All the above features can be achieved by using the course page tool provided by Wiki Ed.<sup>38</sup> Librarians can help maintain such course pages and ensure that the communication goes smoothly both ways. Nominating students’ work for “Did You Know?” articles<sup>51</sup> is also a good way to motivate students and facilitate communications among the learning community, the Wikipedia community, and also the general public.

### Unique Learning Opportunities for Classes in Chemistry

Editing Wikipedia in Chemistry also presents unique learning opportunities for students in classes of Chemistry and related fields. A few examples are listed below.

**Data and Facts Are Not Copyrightable.** Students have the opportunity to learn that data such as chemical/protein structures or properties are not copyrightable. Although they may not be able to directly post the images or graphs from other publications to the Wikipedia article they edit, they can take the structural data, property data, or reaction data to make their own figures, diagrams, graphs, or schemes to share under appropriate licenses on Wikipedia and Wikimedia Commons.

In some cases, they may need to contact original authors to ask for permissions and/or further data to reproduce and share a useful media file.

**Tools and Standards Are Needed To Handle and Share Chemical Data.** Editing Chemistry entries in Wikipedia often involves handling chemical data, for example, editing data in a ChemBox. Students need to be fluent with using relevant software tools such as ChemBioOffice, PyMol, etc. They also need to identify the appropriate format of the data file for best sharing. For example, saving a drawing in the open format .SVG is the best for sharing and reuse.<sup>52</sup> If they explore further, they may discover the Molfile and SDF formats to share machine readable chemical structures. Students are less likely to encounter these format challenges in a traditional class assignment since they are often given the requirement of a single format.

#### Biochemical and Biomedical Topics Can Be Sensitive.

Many classes in Chemistry involve biochemical and biomedical topics. These topics can be sensitive to edit on Wikipedia due to their strong tie to consumer health. Such articles typically receive more public scrutiny, especially for those involving controversial topics. The neutral point of view for those topics is much harder to justify than those areas purely focusing on chemicals. It may be advisable to avoid these topics for undergraduate classes, especially for first-year and second-year classes. Graduate students working in these areas should be guided carefully to ensure that they focus on verified and trustworthy content.

Compared to other disciplines, many Chemistry topics relevant to everyday life are also topics covered in higher education classes, which are good candidates for Wikipedia articles. Also, it is easier for students to identify the neutral point of view on these topics when they edit a Wikipedia article on a Chemistry topic compared to a controversial social science topic. A mature community of chemists on Wikipedia, such as the Wikiproject:Chemistry, also ensures that Chemistry instructors and students have a group to connect to and seek for help from, in addition to the support through Wiki Education Foundation. Thus, implementing Wikipedia assignments in Chemistry classes holds its unique advantages.

## CONCLUSIONS

Wikipedia is a very useful and convenient resource for chemical information, but it must be used with care. Helping students improve their information literacy skills through using Wikipedia wisely and editing Wikipedia carefully has been proven to be effective,<sup>32–35</sup> and allows them to use this exceptional resource to its full potential. Projects involving student editing of Wikipedia must be carefully designed to avoid common pitfalls, but they can promote active and collaborative learning about chemical information. Furthermore, students gain insights of subject matter and become more efficient learners and researchers through a fun and productive journey.

## AUTHOR INFORMATION

### Corresponding Authors

\*E-mail: [walkerma@potdam.edu](mailto:walkerma@potdam.edu).

\*E-mail: [lye@umich.edu](mailto:lye@umich.edu).

### Notes

The authors declare no competing financial interest.

## ACKNOWLEDGMENTS

Thanks to Robert Buntrock and Grace Baysinger for their kind invitation to contribute this paper. Ye Li thanks Professor Anne McNeil at the University of Michigan and the staff of Wiki Education Foundation for their collaborations and support.

## REFERENCES

- (1) Walker, M. A. Wikipedia as a Resource for Chemistry. In *Enhancing Learning with Online Resources, Social Networking, and Digital Libraries*; Belford, R. E., Moore, J. W., Pence, H. E., Eds.; ACS Symposium Series; American Chemical Society: Washington, DC, 2010; Vol. 1060, Chapter 5, pp 79–92. DOI: 10.1021/bk-2010-1060.ch005.
- (2) Wikipedia contributors, Wikipedia Seigenthaler biography incident. [http://en.wikipedia.org/w/index.php?title=Wikipedia\\_Seigenthaler\\_biography\\_incident&oldid=668929933](http://en.wikipedia.org/w/index.php?title=Wikipedia_Seigenthaler_biography_incident&oldid=668929933) (accessed June 30, 2015).
- (3) Wikipedia contributors, Wikipedia/Community. <https://en.wikipedia.org/w/index.php?title=Wikipedia&oldid=669240419#Community> (accessed June 30, 2015).
- (4) For example, the Talk page of Organocatalysis showed an interesting discussion that included a well-respected student Wikipedian (Rifleman 82) and an established expert in organocatalysis, as well as other Wikipedians. The student was critical to the process of editing the article to bring it into compliance with the Wikipedia norms and helping it avoid problems from possible conflict of interest. See <http://en.wikipedia.org/w/index.php?title=Talk:Organocatalysis&oldid=641322346> (accessed October 16, 2015).
- (5) James, C.; Oplatka, I. An exploration of the notion of the 'good enough school'. *Management in Education* **2015**, *29* (2), 77–82.
- (6) Giles, J. Internet encyclopaedias go head to head. *Nature* **2005**, *438* (7070), 900–901.
- (7) Are Chemicals Killing Us? Toxicologists Say Media Overstate Risks. *BusinessWire*; 2009; <http://www.businesswire.com/news/home/20090521006172/en/Chemicals-Killing-Toxicologists-Media-Overstate-Risks> (accessed December 18, 2015).
- (8) Lavsa, S. M.; Corman, S. L.; Culley, C. M.; Pummer, T. L. Reliability of Wikipedia as a medication information source for pharmacy students. *Currents in Pharmacy Teaching and Learning* **2011**, *3* (2), 154–158.
- (9) Kräenbring, J.; Penza, T. M.; Gutmann, J.; Muehlich, S.; Zolk, O.; Wojnowski, L.; Maas, R.; Engelhardt, S.; Sarikas, A. Accuracy and Completeness of Drug Information in Wikipedia: A Comparison with Standard Textbooks of Pharmacology. *PLoS One* **2014**, *9* (9), e106930.
- (10) Lim, S. College students' credibility judgments and heuristics concerning Wikipedia. *Inf. Process. Manage.* **2013**, *49* (2), 405–419.
- (11) As of June 30, 2015, there were 16,102 articles tagged by WikiProject Chemicals (i.e., on substances), but only 8,382 tagged by WikiProject Chemistry. See <http://tools.wmflabs.org/enwp10/cgi-bin/pindex.fcgi?sec=C> (accessed June 30, 2015).
- (12) Wikipedia contributors, User:CheMoBot. <http://en.wikipedia.org/w/index.php?title=User:CheMoBot&oldid=522462374> (accessed June 30, 2015).
- (13) Common Chemistry. <http://www.commonchemistry.org/> (accessed June 30, 2015).
- (14) For an example, see [http://en.wikipedia.org/wiki/Methanol\\_%28data\\_page%29](http://en.wikipedia.org/wiki/Methanol_%28data_page%29) (accessed June 30, 2015).
- (15) See, for example, a humorous comparison with pornstars at <http://www.chemconnector.com/2011/11/17/why-are-pornstars-more-notable-than-scientists-on-wikipedia/> (accessed June 30, 2015).
- (16) Links for these WikiProjects and other Wikipedia chemistry resources can be found on the Chemistry portal <http://en.wikipedia.org/wiki/Portal:Chemistry> (accessed June 30, 2015).
- (17) Wikipedia contributors, Wikipedia:Version 1.0 Editorial Team/Assessment. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Version\\_1.0\\_Editorial\\_Team/Assessment&oldid=656817370](http://en.wikipedia.org/w/index.php?title=Wikipedia:Version_1.0_Editorial_Team/Assessment&oldid=656817370) (accessed June 30, 2015).

- (18) Wikipedia contributors, Wikipedia:Good articles. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Good\\_articles&oldid=608372225](http://en.wikipedia.org/w/index.php?title=Wikipedia:Good_articles&oldid=608372225) (accessed June 30, 2015).
- (19) Wikipedia contributors, Wikipedia:Featured articles. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Featured\\_articles&oldid=669415236](http://en.wikipedia.org/w/index.php?title=Wikipedia:Featured_articles&oldid=669415236) (accessed June 30, 2015).
- (20) Wikipedia contributors, Wikidata: Main Page. [http://www.wikidata.org/w/index.php?title=Wikidata:Main\\_Page&oldid=206220307](http://www.wikidata.org/w/index.php?title=Wikidata:Main_Page&oldid=206220307) (accessed June 30, 2015).
- (21) Wikipedia contributors, Wikidata:WikiProject Chemistry. [http://www.wikidata.org/w/index.php?title=Wikidata:WikiProject\\_Chemistry&oldid=222727552](http://www.wikidata.org/w/index.php?title=Wikidata:WikiProject_Chemistry&oldid=222727552) (accessed June 30, 2015).
- (22) Hsieh, M. L.; Dawson, P. H.; Hofmann, M. A.; Titus, M. L.; Carlin, M. T. Four Pedagogical Approaches in Helping Students Learn Information Literacy Skills. *Journal of Academic Librarianship* **2014**, *40* (3–4), 234–246.
- (23) Wikipedia contributors, Wikipedia:Copyrights. <http://en.wikipedia.org/w/index.php?title=Wikipedia:Copyrights&oldid=671367227> (accessed October 16, 2015).
- (24) Wikipedia:Text of Creative Commons Attribution-ShareAlike 3.0 Unported License. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Text\\_of\\_Creative\\_Commons\\_Attribution-ShareAlike\\_3.0\\_Unported\\_License&oldid=602355710](http://en.wikipedia.org/w/index.php?title=Wikipedia:Text_of_Creative_Commons_Attribution-ShareAlike_3.0_Unported_License&oldid=602355710) (accessed June 30, 2015).
- (25) Synchronizing Polymer Definitions and Terminology with Wikipedia. *Chem. Int.* **2014**, *36*, 219.10.1515/ci.2014.36.2.19
- (26) ChemEd D. L. <http://www.chemeddl.org/> (accessed June 30, 2015).
- (27) Virtual Inorganic Pedagogical Electronic Resource: A community for teachers and students of inorganic chemistry. <https://www.ionicviper.org/> (accessed June 30, 2015).
- (28) UCDavis: ChemWiki. <http://chemwiki.ucdavis.edu/> (accessed June 30, 2015).
- (29) LearnChemistry: Enhancing learning and teaching. [http://www.rsc.org/learn-chemistry/wiki/Main\\_Page](http://www.rsc.org/learn-chemistry/wiki/Main_Page) (accessed June 30, 2015).
- (30) HyperGlossary. <http://hyperglossary.org/> (accessed June 30, 2015).
- (31) Chemical Information Sources. [http://en.wikibooks.org/w/index.php?title=Chemical\\_Information\\_Sources&oldid=2776539](http://en.wikibooks.org/w/index.php?title=Chemical_Information_Sources&oldid=2776539) (accessed June 30, 2015).
- (32) Moy, C. L.; Locke, J. R.; Coppola, B. P.; McNeil, A. J. Improving Science Education and Understanding through Editing Wikipedia. *J. Chem. Educ.* **2010**, *87* (11), 1159–1162.
- (33) Martineau, E.; Boisvert, L. Using Wikipedia To Develop Students' Critical Analysis Skills in the Undergraduate Chemistry Curriculum. *J. Chem. Educ.* **2011**, *88* (6), 769–771.
- (34) Sormunen, E.; Eriksson, H.; Kurkipaa, T., Wikipedia and Wikis as Forums of Information Literacy Instruction in Schools. In *Road to Information Literacy: Librarians as Facilitators of Learning*; Gwyer, R., Stubbings, R., Walton, G., Eds.; 2012; Vol. 157, pp 311–328.10.1515/9783110281002.311
- (35) Sormunen, E.; Tanni, M.; Alamettala, T.; Heinstrom, J. Students' Group Work Strategies in Source-Based Writing Assignments. *J. Assoc. Inf. Sci. Technol.* **2014**, *65* (6), 1217–1231.
- (36) Wikipedia contributors, Wikipedia:Education program. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Education\\_program&oldid=633427068](http://en.wikipedia.org/w/index.php?title=Wikipedia:Education_program&oldid=633427068) (accessed June 30, 2015).
- (37) Wiki Education Foundation, Wiki Ed: About Us. <http://wikiedu.org/about-us/> (accessed June 30, 2015).
- (38) Wiki Education Foundation, Wiki Ed: For Instructors. <http://wikiedu.org/for-instructors/> (accessed June 30, 2015).
- (39) Wikipedia contributors, Wikipedia:Education program/Ambassadors. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Education\\_program/Ambassadors&oldid=646385792](http://en.wikipedia.org/w/index.php?title=Wikipedia:Education_program/Ambassadors&oldid=646385792) (accessed June 30, 2015).
- (40) Wikipedia contributors, User:ChemLibrarian. <http://en.wikipedia.org/w/index.php?title=User:ChemLibrarian&oldid=644416351> (accessed June 30, 2015).
- (41) Association of College and Research Library, American Library Association. Framework for Information Literacy for Higher Education 2015. <http://www.ala.org/acrl/standards/ilframework> (accessed February 9, 2015).
- (42) Committee on Professional Training, American Chemical Society, Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs. <http://www.acs.org/content/dam/acsorg/about/governance/committees/training/2015-acs-guidelines-for-bachelors-degree-programs.pdf> (accessed November 30, 2015).
- (43) Simonite, T. The Decline of Wikipedia *MIT Technology Review magazine* [Online], 2013. <http://www.technologyreview.com/featuredstory/520446/the-decline-of-wikipedia/> (accessed June 30, 2015).
- (44) Wikipedia contributors, Wikipedia:WikiProject Council/Directory. [http://en.wikipedia.org/w/index.php?title=Wikipedia:WikiProject\\_Council/Directory&oldid=668504058](http://en.wikipedia.org/w/index.php?title=Wikipedia:WikiProject_Council/Directory&oldid=668504058) (accessed 24 June 2015).
- (45) Wikipedia contributors, Wikipedia:WikiProject Chemistry. [http://en.wikipedia.org/w/index.php?title=Wikipedia:WikiProject\\_Chemistry&oldid=665024998](http://en.wikipedia.org/w/index.php?title=Wikipedia:WikiProject_Chemistry&oldid=665024998) (accessed June 30, 2015).
- (46) Wikipedia contributors, Wikipedia:Manual of Style/Chemistry. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Manual\\_of\\_Style/Chemistry&oldid=663118096](http://en.wikipedia.org/w/index.php?title=Wikipedia:Manual_of_Style/Chemistry&oldid=663118096) (accessed June 30, 2015).
- (47) Wikipedia contributors, Wikipedia:Biographies of living persons. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Biographies\\_of\\_living\\_persons&oldid=668299382](http://en.wikipedia.org/w/index.php?title=Wikipedia:Biographies_of_living_persons&oldid=668299382) (accessed June 30, 2015).
- (48) Wikimedia contributors, Education/Materials for Teaching. [http://outreach.wikimedia.org/w/index.php?title=Education/Materials\\_for\\_Teaching&oldid=95198](http://outreach.wikimedia.org/w/index.php?title=Education/Materials_for_Teaching&oldid=95198) (accessed June 30, 2015).
- (49) Wikipedia contributors, Wikipedia:VisualEditor. <http://en.wikipedia.org/w/index.php?title=Wikipedia:VisualEditor&oldid=668495287> (accessed June 30, 2015).
- (50) Wikipedia contributors, Wikipedia:Five pillars. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Five\\_pillars&oldid=666498559](http://en.wikipedia.org/w/index.php?title=Wikipedia:Five_pillars&oldid=666498559) (accessed June 30, 2015).
- (51) Wikipedia contributors, Wikipedia:Recent addition. [http://en.wikipedia.org/w/index.php?title=Wikipedia:Recent\\_additions&oldid=669477158](http://en.wikipedia.org/w/index.php?title=Wikipedia:Recent_additions&oldid=669477158) (accessed June 30, 2015).
- (52) Wikipedia contributors, Help:Contents/Browse/Images and media. [http://en.wikipedia.org/w/index.php?title=Help:Contents/Browse/Images\\_and\\_media&oldid=643541816](http://en.wikipedia.org/w/index.php?title=Help:Contents/Browse/Images_and_media&oldid=643541816) (accessed June 30, 2015).