Assessing the Impact and Efficacy of the Open-Access ChemWiki Textbook Project

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- **The ChemWiki is constructing a virtually and horizontally integrated resource that addresses STEM education at multiple levels of sophistication and context.**
- **Flexibility is central to driving the success of the ChemWiki.**
- **Existing Wikitexts and Textbook Maps are available to enable instructors to repurpose content.**
- **A data-driven pilot confirms that the open-access Wikitexts have the efficacy to replace costly commercial textbooks.**

Introduction to ChemWiki

New and innovative educational efforts will be necessary to facilitate the increases in creativity, flexibility, and learning capability desired in postsecondary education. These innovations often involve personalized approaches to address both faculty and student needs. Unfortunately, rapidly rising costs, including the cost of textbooks, impede access to higher education for many students, particularly among underserved and at-risk populations. The importance of inexpensive textbooks was demonstrated when President Obama signed the Higher Education Opportunity Act into law in 2008 to "identify ways to decrease the cost of college textbooks and supplemental materials for students." The amount students are asked to pay for textbooks overburdens governmental and familial financial resources. A 2005 U.S. Government Accountability Office study estimated that the average annual cost of textbooks for a student in 2003–4 was $898 at four-year institutions.[1] Textbook costs continue to rise at twice the rate of inflation; according to the College Board, the average budget for textbooks and supplies in 2012–13 was $1,200.[2]

The STEMWiki Hyperlibrary was initiated by the University of California, Davis (UC Davis) to reduce this growing educational cost in the science, technology, engineering, and mathematics (STEM) fields. The focus of the STEMWikis is to develop and disseminate viable online postsecondary textbook alternatives within a centrally integrated open educational resources (OER) environment. The ChemWiki is the primary and most developed component of the Hyperlibrary project, which includes five other interconnected STEMWikis that operate quasi-independently. When sufficiently developed, the Hyperlibrary will be leveraged as a platform for the dissemination of content and evaluation of emerging education technologies and pedagogies.

Textbook publication has historically followed a simple paradigm in which an expert (or small group of experts) with advanced training and experiences apply their collective education and expertise toward developing the required content. The success of Wikipedia has demonstrated that alternative approaches can be similarly powerful, with crowdsourced development approaches substituting the significant efforts of a small number of experts with the modest efforts of many (at a range of capabilities). A clear benefit of such a parallelized approach is that content can be rapidly developed and updated. The development of the STEMWiki Hyperlibrary follows such an approach and is spearheaded by a consortium of students and faculty across multiple campuses and countries.

Development entails collecting, integrating, vetting, and building open-access content within an extensively hyperlinked infrastructure. That infrastructure consists of independent modules containing well-defined concepts that are typically written, edited, and evaluated by multiple authors. Because the modules are formulated at diverse levels of difficulty, advanced students can receive the complex material needed for intellectual stimulation, while less scientifically oriented students can access the core information they need.[3] The collaborative authorship provides both students and faculty with the opportunity to review, change, and comment on the material and its presentation. Because the ChemWiki modules are hyperlinked both internally and externally to the modules within the other STEMWikis, students are exposed to a wide range of content at varying levels of difficulty, which allows for the simultaneous instruction of students with diverse backgrounds and performance.

Impact

The impact of the Hyperlibrary is quantified in terms of both the number of students using the project to supplement their existing commercial textbook and the number of students who use the textbook in lieu of conventional textbooks. Currently, the ChemWiki is the most visited chemistry website in the world, with visitor traffic extending to the United States (55%) and to every nation of the world. Since its inception seven years ago, the ChemWiki has been exponentially growing and currently reaches more than 4 million students per month (see figure 1); the other STEMWikis exhibit similar growth characteristics.

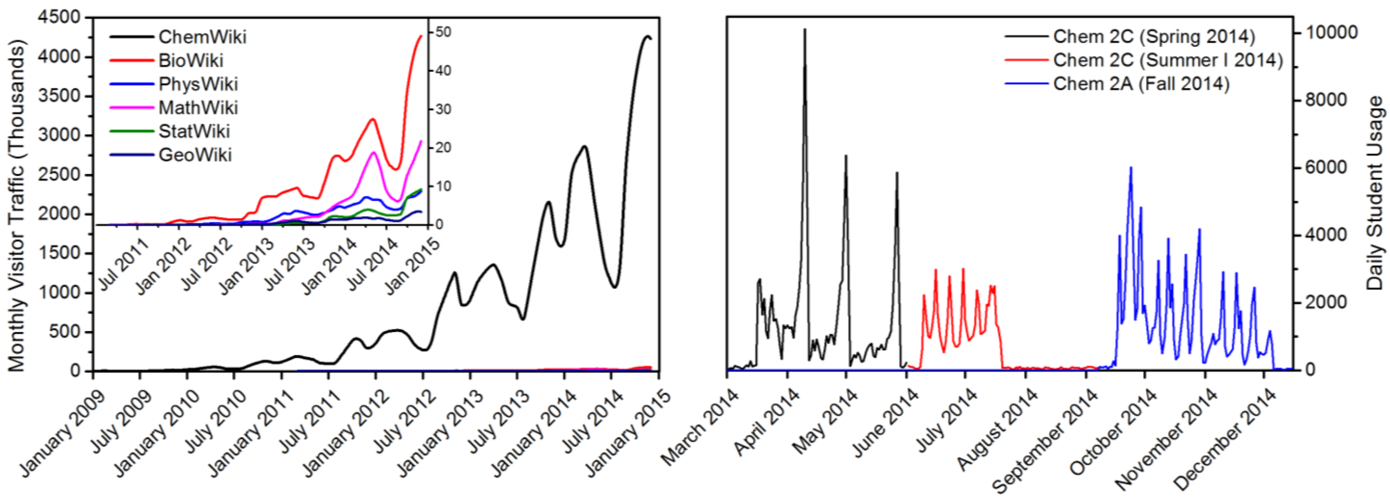

Figure 1. Usage statistics for STEMWikis. (Left) Monthly visitor traffic profiles for the ChemWiki (black curve) and five other STEMWikis (colored curves) since project initiation in 2008. (Right) Daily traffic for student usage of student Wikitexts for ChemWiki pilot; spikes originate from students cramming before exams and quizzes.

The central goal of the Hyperlibrary project is not simply to *supplement* conventional textbooks but to *supplant* them. The Hyperlibrary is being optimized to address a range classes at two- and four-year institutions. Since spring 2014, the ChemWiki has been used as the exclusive textbook in seven classes involving six instructors over four campuses (UC Davis, Purdue University, Sacramento City College, and Howard University), with many more in discussion. From these initial applications, approximately $500,000 has been saved in textbook expenditures to date from the ChemWiki.

The Importance of Flexibility

The impact of the ChemWiki primarily stems from the project's flexibility. Textbook publishers have long provided a suite of textbooks in a single field that address faculty and students of different levels, styles, and pedagogies. The OER project with the greatest flexibility is likely to establish the greatest market share because a simple repository, using a one-size-fits-all approach, is too narrowly focused. Consequentially, the STEMWikis were constructed with practitioner-developed, practitioner-adopted, and practitioner-evaluated approaches that infuse the project with an end-user mentality.

The Hyperlibrary's collaborative developmental approach combines flexibility, adaptability, and applicability, allowing it to address a range of classes. This model enables faculty to adopt and adapt Hyperlibrary materials to suit their specific purposes. In addition, Hyperlibrary content is part of a dynamic network extending both horizontally (across multiple fields) and vertically (across multiple levels of complexity). This structure offers students and faculty not just a single hypertextbook, as with repositories, but a large hyperlibrary of interconnected textbooks. This integration allows the STEMWikis to be exceptionally flexible in addressing both current and future educational needs and new approaches.

Navigating the ChemWiki Corpus

The ChemWiki contains approximately 15,000 modules, with another 2,000 modules in the other STEMWikis. Navigating the corpus of the STEMWikis is enabled by the Core/Wikitext approach as an internalized repurposing scheme (see figure 2). All modules are maintained within the core, and Wikitexts are individually constructed for specific classes by creating a hyperlink structure to the core modules. A well-functioning textbook (whether hypertext or conventional) is much more than just a series of reference topics found in Wikipedia and must address additional aspects including an established continuity between previously discussed, current, and future content.[4]

Each module contains metadata that outlines the recommended modules necessary for students to read prior to the module to receive a full understanding of the content contained therein. For example, an instructor can construct a Wikitext by generating a list of hyperlinks to core modules in the order that best fits the class flow or pedagogical approach. If existing core modules are insufficient for a specific course goals, new ones can be generated from existing vetted ones via the ChemWiki's graphical editor. This approach provides powerful flexibility in introducing and removing content without affecting other concurrently operating classes, and it provides the flexibility for instructors to construct Wikitexts that best suit their needs and the needs of their students. By simply reviewing existing Wikitexts, the Core/Wikitext approach provides faculty the opportunity to easily repurpose existing content when generating instructor-specific Wikitexts. To further facilitate easy adoption of the ChemWiki, independent Textbook Maps have been constructed that reflect the order and organization of the traditional textbooks by following the same table of contents and section titles.

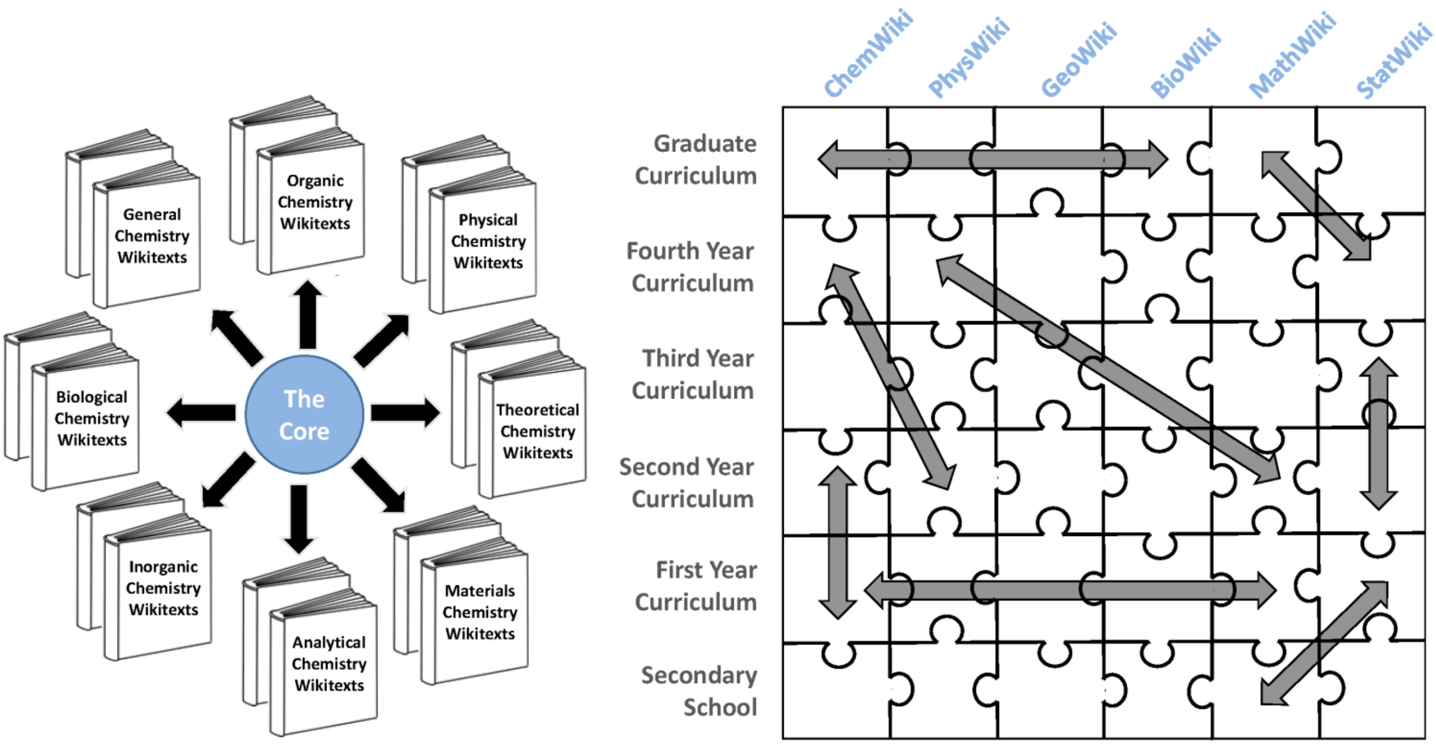

Figure 2. Integration and organization schemes of the Hyperlibrary. (Left) The Core/Wikitext design to enable a flexible textbook for classes at all levels of instruction. (Right) Integration scheme of Hyperlibrary with all content vertically and horizontally integrated.

ChemWiki Pilot: Design and Results

During the 2014 spring quarter, the efficacy of ChemWiki was evaluated in a multiclass pilot at UC Davis that tested the viability of using the ChemWiki, rather than a traditional text, as the primary textbook resource for a large general chemistry class. The study design involved two classes (groups): an experimental class (*n* = 478) that used the ChemWiki as its primary resource (including reading, homework, and solutions), and a control class (*n* = 448) that used the commercial textbook for the general chemistry sequence. The experiment occurred in the final quarter of a three-quarter sequence in general chemistry. To remove bias among instructors and teaching assistants, both classes were taught back-to-back by the same instructor and teaching assistants. A variety of assessment protocols were developed to compare the effectiveness of the ChemWiki to the traditional textbook. The protocols included in-class assessment, a pre/postcontent exam, a student attitudinal survey, and a study-habit questionnaire. Only students in the ChemWiki class were given authenticated access to the course Wikitext. A weekly resource-usage survey was administered to all students to help verify online versus textbook access that could be correlated with online usage for the ChemWiki group. Assigned readings for either class were targeted to their specific resource.

Midterm and Final Exam Performance

Course grades for both the control and experimental classes were determined using the same two midterms and a final exam. The same rubric and the same teaching assistants were used to remove any bias in grading. Item-level analysis of the midterms and final showed no statistically significant differences in the performance of the students in the two classes with identical questions posed to them. An example of the item-level analysis can be seen in figure 3, which compares the average performance on multiple items from the first midterm and the final exam. These data confirm that there is no statistical difference between the ChemWiki and control class when comparing the overall and item-level performance on the in-class assessments.

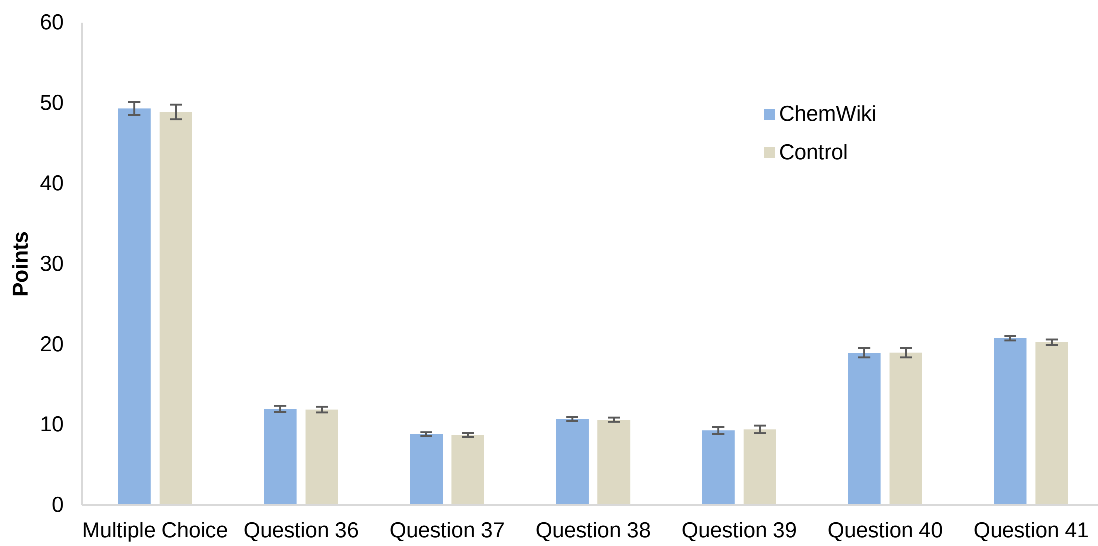

Figure 3. Item-level analysis of the questions on the final exam in pilot comparing the ChemWiki (blue) class to the control (tan) class. Similar statistics result from midterms. Error bars represent a 95% confidence interval.

Individual Learning Gains

A 35-question multiple-choice pre/postexam was constructed to determine the overall learning gains made by the students in both courses. The pretest was given the first week of class to assess the amount of material students knew coming into the course. The posttest questions were embedded into the final exam to measure the amount of material the students understood after completing the course. A student's normalized learning gain was then calculated according to the following formula:[5]

$$NLG = \frac{\%Post - \%Pre}{100 - \%Pre}$$

Measuring individual learning gains allows us to compare and correlate student learning to different student characteristics and performances. For the purpose of this study, we used individual normalized learning gains to correct for incoming student demographics and to generate average normalized learning gains for the two classes. The average normalized learning gains for the ChemWiki and control class were 0.577 ± 0.008 and 0.577 ± 0.009, respectively. The ChemWiki class's normalized leaning gains were therefore not inferior to the gains of students in the control class using noninferiority testing.[6] The similarity of the two classes shows that both the conventional textbook and ChemWiki result in similar learning gains.

Student Attitudes and Beliefs toward Chemistry

To determine if either class's beliefs toward chemistry changed during the quarter, we used the Colorado Learning Attitudes about Science Survey (CLASS) chemistry survey.[7] The CLASS survey is designed to measure the similarity between a student's thinking to that of a professional by comparing student responses to the answers of experts in the field of chemistry. The closer a student's response is to an expert's, the more favorable score the student receives. The data are then compiled into 10 categories.[8] Both classes took the CLASS survey at the beginning and the end of the quarter. The response rate for students taking both the pretest and posttest was 36% for the wiki section and 19% for the control section, which provided sufficiently large sample sizes to determine that both sets of student responses were statistically representative of both classes.

Both the control and ChemWiki class showed statistically significant increases in thinking like a professional chemist; however, there was no statistically significant difference in the magnitude of this change between the two classes. In some categories, such as Personal Interest and Real World Connections, the ChemWiki class showed a negative change from pretest to posttest, where the control group had a small positive change. Although these differences between the two classes were not statistically significant, these data can be used to immediately target improvements in the ChemWiki material to make it more relevant to the students. Similar improvements to the textbook approach would require a new textbook edition to be published.

Student Study Habits

The final tool we used in our research was a weekly time-on-task survey. The survey was designed to investigate the amount of time each student was spending using resources outside the classroom; it also was designed to identify ChemWiki students who might have also used the traditional textbook and identify textbook students who might have used the ChemWiki. The weekly averages for each class are presented in table 1. The student-reported data were verified by comparing the number of hours each student reported to the total number of ChemWiki page views, where a page view is defined as an instance in which a user loads a new/unique page on the ChemWiki. A moderately positive correlation between page views and student reported hours of use suggested that student self-reports were fairly reliable.

When comparing the average number of hours students spent using the conventional textbook or ChemWiki, we found that students in the ChemWiki class spent an average of approximately 0.4 hours more a week interacting with their primary resource but that both classes spent the same total time per week studying. While none of our measures indicated improved outcomes from the additional time spent by the ChemWiki group with the primary resource, this result may indicate a range of possibilities including lower efficiency using ChemWiki, greater efficiency of ChemWiki (due to less need for external, nonassigned reading), greater ease of use and/or access for ChemWiki, confounds in separating time spent on various tasks, and others.

Table 1. Time-on-task survey results

Measure	ChemWiki (n = 377)	Non-Wiki (n = 348)
Hours Spent Reading Primary Resource	2.03***	1.64***
Hours Spent on Practice Problems	1.53	1.52
Percentage of Time Spent Working with Friends	13.85	14.56
Average Number of Weekly Lectures Attended	2.42**	2.56**
Average Number of Weekly Lectures Attended NOT Registered	0.20	0.15
Hours of Private Tutoring a Week	0.17	0.20
Hours Spent Using Nonassigned Reading	0.74*	0.92*
Time on Task	4.47	4.28

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Conclusions

The ChemWiki is a growing open resource within the STEMWiki Hyperlibrary project, with a widening impact in terms of both student usage and faculty adoption. The ChemWiki's modular concept permits content to be easily repurposed in multiple courses at multiple levels, and the open and dynamic nature of the project allows both straightforward error correction and timely content with nearly instantaneous modification possible. The multiple-author construction approach enhances flexibility. Based on results from the assessment tools implemented in the 2014 spring quarter ChemWiki pilot, no statistical differences existed in either class's performance or in changes in thinking like a professional. Each class performed equally well on the in class exams, had similar normalized learning gains, and showed equivalent changes in thinking like a professional. The similarity between the two classes indicates that student learning (as measured) is not affected by using the ChemWiki rather than a traditional textbook for one quarter of general chemistry at UC Davis. Further work needs to be completed to assess the viability of using the ChemWiki for the entire general chemistry series, but ongoing work shows promising results that can lead to cost savings for students and more timely response in improving the quality and relevance of their reading materials.

Acknowledgments

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Notes

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