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Interdisciplinary Explorations: Promoting Critical Thinking via Problem-Based Learning in an Advanced Biochemistry Class

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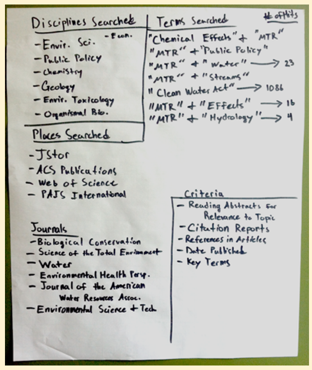
Ⓢ *Supporting Information*

ABSTRACT: Interdisciplinary approaches to research in the sciences have become increasingly important in solving a wide range of pressing problems at both global and local levels. It is imperative then that science majors in higher education understand the need for exploring information from a wide array of disciplines. With this in mind, interdisciplinary instruction has the potential to bring new insights and methods to enhance learning and promote critical thinking skills while itself modeling the benefits of interdisciplinary practice in research. This paper explores an interdisciplinary collaboration between a librarian and a chemist seeking to improve student research and critical thinking skills through the utilization of problem-based learning. A module exploring the interdisciplinary nature of science was implemented for an advanced Biochemistry class and delivered in a library setting. Initial findings of this pilot project suggest that the implementation of a carefully constructed, problem-based curriculum has the potential to improve research skills and multidisciplinary thinking as well as engender a more holistic view of chemical research.



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■ INTRODUCTION

Although there are many examples of the use of problem-based learning in the university Chemistry classroom,[1−5] little has been published on library instruction for Chemistry students using this same pedagogical tool. This paper examines the application of problem-based learning in a library instruction class to improve the critical thinking skills of advanced Biochemistry students. The class arose from a collaboration between a librarian, intent upon forward-thinking, interdisciplinary instruction, and a Chemistry faculty member, looking to improve student literature reviews.

Constructivist learning theories have been firmly rooted in academia for a number of years, with an increasing focus upon experiential learning and critical thinking. These two processes are evident in problem-based learning, a pedagogical technique born out of the medical field in the 1960s,[6] which has steadily gained popularity in the academic classroom. Although problem-based learning has been defined and redefined by scholars, philosophers, and educators, many of the basic tenets have remained relatively unchanged. Roughly 4−5 elements seem to be common to problem-based learning: learning is student-centered, problems are ill-structured and authentic, teachers act as facilitators, and often, students work in small groups.[6−9]

Problem-based learning is not a new concept in information literacy either. Bruce et al. introduced a six-frame model for information literacy education that proposed a "learning-to-learn" frame wherein a constructivist view of information literacy instruction was presented.[10] This frame suggested that the curriculum focus should be on what it means to think like a professional in a given field. The frame also recommends the utilization of real life problems, collaborative learning, and reflective practice to facilitate students' construction of knowledge.[10] All hallmarks of problem-based learning. In a similar vein, Diekema et al. call for information literacy instruction to diverge from a mechanistic focus, intent upon the act of source location, and instead find meaning in information use as an inherent piece of knowledge construction.[11]

Problem-based learning is not without its detractors. Kirshner et al. profess that minimally guided instruction (such as problem-based learning) is less effective than direct, guided approaches. They do, however, note that the advantages of guided instruction techniques diminish when prior knowledge is more substantial,[12] as is evident in students in more advanced courses. Walker and Leary provide a positive meta-analysis of several elements of problem-based learning, but find there is no clear advantage of problem-based learning over direct (lecture-based) instruction.[9] Jonassen asserts, however, that the ambiguity attributed to problem-based learning is no different than the ambiguities and variations of lecture-based instruction. Jonassen's study also suggests that although

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problem-based learners may acquire less knowledge than their lecture-listening counterparts, problem-based learning has a more profound effect upon skill acquisition and the ability to apply the knowledge gained[13] (e.g., critical thinking).

■ BACKGROUND

In the sciences, as with other fields, the research literature provides an archive of published works and a means of sharing of information. Articles are readily and easily accessible through online databases providing electronic versions for future review. With volumes of data available at the stroke of a key, however, locating relevant review literature can present the user with a virtual maze. Despite this challenge, it is uncommon that an intensive course in literature review and information evaluation is required in upper-division courses. At the University of Tennessee at Chattanooga, a foundational Chemical Literature class is taken by all Chemistry majors and minors after the Freshman year. Chemical Literature includes one library instruction session that provides coverage of the most frequently accessed Chemistry-related databases. Other Chemistry-related resources are covered over the course of the Chemical Literature class by teaching faculty in the Chemistry department. The faculty demonstrate the importance of identifying both print and digital resources and their differences that could be used in support of their work. It is also possible that Chemistry students may be exposed to information literacy concepts through two required English Composition courses in which library instruction sessions are embedded. It is likely, however, that students majoring in Chemistry may have either tested out of the foundational English courses or taken them as dual enrollment during their high school years.

The central focus of this article, a senior-level Biochemistry class called Proteins and Nucleic Acids (PNA), was designed for students interested in advanced studies in biochemistry, molecular biology, and related medical sciences. It attracts students with widely varying career aspirations, including chemists, physicians, microbiologists, chemical biologists, and biophysicists. Students from this course, unless going directly into practice, attend graduate programs requiring them to immediately conduct literature reviews for their theses/dissertations and publishable articles. Within these multidisciplinary fields of study, students must be able to clearly express ideas, justifications, and findings in written documents for a vast array of readers.

For several years, it had been observed that the literature reviews required for laboratory reports produced by students in PNA were alarmingly poor, considering the high level of achievement in this group, and only improved very slowly over the duration of a semester. In considering ways to increase quality in a much shorter time frame, a multidisciplinary approach between chemistry department faculty and an external expert was considered. A recent collaboration with a librarian served as the inspiration for moving this exploration into reality via a full-fledged integration into the Spring 2015 PNA class. The Health and Science Librarian was approached to provide an instruction component for the class. It was agreed that she would be fully integrated as a coteacher in the university's course management system (BlackBoard) and would have free reign to address the improvement (broadly defined) of literature reviews and any other information or skills deemed useful to the success of the students.

■ INSTRUCTIONAL DESIGN

Framing Instruction

Providing meaningful library instruction for such advanced students posed a somewhat daunting task. Rehashing the content provided in Chemical Literature would neither prove a good use of the instructor and students' time nor would it help to address the issue of improving literature reviews. It would be beyond the scope of one library instruction session to fully improve literature reviews for an entire class, but elements ripe for improvement could be identified and addressed. For example, improving the quality of sources and citation skills could easily be covered in library instruction. Though improving the literature reviews was a consideration of library instruction, the librarian planning the class felt that instruction should address some broader issues that would serve to foster critical thinking skills designed to serve students beyond the scope of PNA. To provide pedagogical direction, the Association of College and Research Libraries' (ACRL) Framework for Information Literacy for Higher Education[14] and the American Chemical Society's (ACS) Chemical Information Skills document[15] were consulted.

While the ACS publication defines information skills specifically targeting chemical information, the desired skills are easily applicable to other disciplines. One such skill, "identifying key references", aligns perfectly with the spirit of a literature review—a skill that needed improving for the PNA students. The ACS document also prompts teaching faculty to view the "development of chemical information skills as an evolutionary process, beginning with finding specific information and maturing to an ability to critically assess information on broader topics."[15] The PNA students had the foundation and would be primed to tackle the more challenging end of this evolutionary spectrum.

Though the ACRL Framework had not been formally approved when planning for the class began, it still figured heavily into the theoretical underpinnings and practical applications undertaken in the class. Many of the frames played an integral role in determining class elements and appropriate outcomes. In particular, multiple elements from the frames "Searching as Strategic Exploration", "Information has Value", "Research as Inquiry", and "Scholarship as Conversation" would provide pedagogical guidance and mold the class activities and instruction. Using problem-based learning, students would need to exhibit mental flexibility and creativity in problem-solving, use divergent and convergent thinking, understand that research is iterative, seek multiple, diverse perspectives, be able to refine strategies effectively, find research gaps, synthesize ideas from multiple sources, and give appropriate attribution among other skills as described in the Framework.[14] Although these knowledge practices would not all find their way into the learning outcomes for the class, all would play at least a supporting role during class activities and discussions. During the progression of framing instruction, problem-based learning continued to appear the best medium through which to provide the desired results.

Constructing Learning Outcomes

With problem-based learning identified as the likely pedagogical method, learning outcomes were constructed. To keep the class focused and avoid a long, unachievable list of learning outcomes, three outcomes were carefully selected and written:

Students will be able to

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1. Explain the multidisciplinary nature of research.
2. Locate scholarly sources to support research and articulate why those sources are necessary.
3. Reflect upon the research process and its relationship to future research endeavors.

As might be expected in a problem-based learning class, the mechanistic elements of library instruction were minimized in favor of forward-thinking, adaptable skills that would serve the student long after undergraduate studies had ended. For example, understanding the multidisciplinary nature of science and research is important for future scientists to understand. The National Science Foundation, among many other funding agencies, recognizes the inherent value of multidisciplinary research in promoting rapid progress in scientific discoveries. The NSF states that "important research ideas often transcend the scope of a single discipline or program" and goes on to express the idea that "the integration of research and education through interdisciplinary training prepares a workforce that undertakes scientific challenges in innovative ways."[16]

This interdisciplinary relationship is not always evident to the undergraduate student, who is largely focused upon single disciplines or topics. Understanding this relationship, however, has the potential to broaden the understanding of the research that should be conducted prior to beginning a project. Real world problems do not often divide strictly along discipline lines and would require the ability to consider both multiple causes and solutions to problems.[17] Considering this, along with the potential variance in future careers for the PNA students, the ability for a student to explain the multidisciplinary nature of research is a skill that contributes to the overall critical thinking skills of the student.

Locating scholarly sources to support research is an imperative skill for all students but was selected as a learning outcome in order to address some of the issues often seen in poor literature reviews. It is not enough, however, for the students to be able to locate these sources, but they must also be able to articulate why specific sources are necessary and why others are not. The ACRL Framework asserts the need for students to be able to evaluate a wide array of information sources and exhibit the "mental flexibility to pursue alternate avenues as new understanding develops."[14] The PNA students would be expected to survey many disciplines and selectively choose sources for literature reviews as well as to critically assess whether such sources were relevant to the assigned problems.

The final learning outcome, requiring students to master reflection upon the research process and its relationship to future research endeavors, would serve as a mechanism for deeper engagement with the class content. A large portion of the lab report homework (discussed later in this article) assigned for this class session would require thoughtful consideration of various parts of the research process, including such activities as brainstorming, search strategies, refinement, evaluation, etc. The students in PNA would likely not continue in the same search patterns and places to which they had become accustomed in Chemistry and Biology but would instead need to easily adapt to whatever real world problems they are required to address. Reflecting upon the intricacies of research would allow them to become more nimble researchers and, hopefully, provide them an edge on the competition in further studies and careers.

Preclass Material

One of the fundamental components of problem-based learning in the classroom is the minimized role of the instructor.[6] Typically, very little instruction takes place in the classroom as the instructor assumes the role of facilitator and prompts metacognitive behaviors in students.[17] It was necessary, then, to devise a preclass component to cover some fundamental information about literature reviews. North Carolina State University offers an excellent YouTube video on literature reviews,[18] which was selected as the preclass component for PNA. In under 10 min, the video gives a complete yet succinct primer on what a literature review is, why it exists, and its various components. Although created for graduate students, it was deemed appropriate due to the high academic achievement of the students in PNA. The video was embedded in the students' BlackBoard course space for viewing prior to attending the library instruction class session.

In-Class Discussions and Demonstrations

Several short discussions were constructed with the intent of stimulating students to think more deeply about the research process, as well as to prime them for the problem-based portion of the class. The first segment posed the question, "Why is surveying the literature important?" The goal of this discussion was to get buy-in to the idea that conducting a well-researched literature review is important. Basically, students understand why a literature review is important but (as evidenced by the results of the discussion in class) often miss the idea that convincing someone to fund research requires a thorough explanation of why an idea is novel and what ground has previously been covered in that area of research. If a researcher cannot express a keen knowledge of the literature, he/she will find it difficult to procure funding.

The next discussion was constructed to explore the nature of multidisciplinary research. The students in PNA were largely not Chemistry majors, but instead represented a wide array of disciplines including Biology, Pre-Med, Pre-Dental, Environmental Science, and so forth. The work that many of them will go on to do after graduation will be informed by multiple disciplines. For example, the field of medicine will require the practitioner to be informed by the principles of medicine, biology, chemistry, psychology, sociology, and so forth. To illuminate the multidisciplinary nature of research, the students would be prompted to consider a research topic and which disciplines might be interested in the topic. This would also prove important for the problem-based learning activity as students would need to assess which disciplines could be viewed as stakeholders in each problem and use this knowledge to guide searching.

It would also be important for students to understand seminal research and how to locate it. As the majority of the students in PNA would have used Thomson Reuters Web of Science in a Scientific Writing course or in previous Chemistry or Biology courses, it would not be necessary to provide a full demonstration of the database. Instead, a very brief review of Web of Science and its citation analysis tools via a student-led demonstration using the sample topic was planned. There is very little research on the use of student-led demonstrations in the classroom but they have, anecdotally, been shown to be more engaging than instructor led demonstrations, provoke the curiosity of classmates, and promote attention while alleviating the monotony of a lecture-heavy class.[19,20]

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For a truly forward-thinking lesson plan, it is critical to consider the needs of the students after they have graduated and have entered their intended fields. It is unlikely that the students will have access to a database like Web of Science after their academic careers are complete unless they continue on as professors or research affiliates at a university. Therefore, introducing the question of how to find seminal research when no longer at the University would be important in stimulating the students to think about the research process and searching for information in the "real world". This concept dovetails nicely with a class developed primarily to promote learning through the problem-based paradigm, which requires real world problems to encourage authenticity in the learning process.[17]

Problem-Based Learning Activity

The problem-based learning component of the library instruction session for PNA was intended to be the central focus of the class and was designed to comprise about three-fourths of the class time. All of the learning outcomes needed to coalesce in the problem-based portion of the class and the subsequent lab report homework. When creating the problem-based component the new ideas in the ACRL Framework were heavily utilized as inspiration, including many of the components in the frames Searching as Strategic Exploration and Research as Inquiry.[14]

During the course design planning, the Chemistry professor requested that the problems be unrelated to the discipline of Chemistry. The PNA students would already be well aware of how to locate information and references related to Chemistry or Biochemistry topics. By requiring students to investigate topics unrelated to their discipline, they would need to exhibit mental flexibility and creativity[14] by widening their scope and using databases and search methods uncommon to them. It was this request, along with a solid understanding of problem-based elements, that spurred the librarian to construct broad, open-ended, ill-defined problems. All problems did, however, include elements connected to the field of Chemistry while also requiring the need for multidisciplinary approaches to each problem. The broadness of each problem would require the students to engage in discussion and brainstorming (divergent thinking) in order to determine a strategy for approaching the research process. For example, the problem "Do antioxidants have any effect upon cancer?" might require narrowing, exploring the definition of an antioxidant, selecting a particular cancer, and so forth. While promoting critical thinking, negotiating meaning with peers also forces students to work on their individual roles within a group.

With inspiration from the Framework, the activity was structured into a series of interconnected components. First, the problems were to be presented to the students (working in groups) and each group would then be instructed to spend 10 min brainstorming the problem assigned. During the brainstorming time, students would not be allowed to utilize the computers in the classroom. Instead, they were to consider, as a group, the elements and implications of the problem while using divergent thinking skills to generate ideas about potential causes, solutions, and research strategies. The separation of the brainstorming component from the search process would require the students to collaborate and negotiate the problem and its implications as a group.

After brainstorming, the groups would be allowed to begin searching. They would be instructed to use any database or search engine desired but that, when the lab report homework was written, at least four of the sources used were required to be peer-reviewed. During the search process, students would need to put into practice the idea that searching is iterative and nonlinear, be able to refine search strategies, assess research gaps, and synthesize information from multiple places, as described in the ACRL Framework.[14] At this point, students would also be informed that they would be required to give a group presentation at the end of the search period, detailing each phase of their brainstorming and research process. They would be given a set of questions and asked to consider these questions during the process. Approximately 30 min would be designated for search time, during which both instructors (Chemistry professor and librarian) would circulate and answer questions. In keeping with Jonassen's spectrum of ill-structured problems,[13] the instructor would emphasize that the process (or chain of reasoning), not so much the answer to the problem, is the most important part of the experience for the student.

■ CONDUCTING THE CLASS SESSION

There were two available lab sessions for PNA; therefore, each class received a separate yet identical library instruction session. Each class session began with an introductory icebreaker activity, designed to allow the library instructor to learn more about the students through self-reporting of their current research skills and interests as well as the provision of a unique fact about themselves. The unique facts are then sprinkled throughout the class sessions a few at a time. Both the library and Chemistry professors also participated in the activity by providing interesting information about themselves, which helped to diminish some of the border that typically exists between student and professor. This simple yet powerful activity set a relaxed and anticipatory tone for the remainder of each class while also providing quickly assessable information (research interests and experience) that served to guide instruction.

Following the icebreaker, students were briefly informed of the structure of the class and what to expect. This was followed by approximately 20 min of discussion on the importance of reviewing literature on a topic, the nature of interdisciplinary research, and how to locate seminal research (including a brief review of Web of Science; though no student-led demo was conducted) as fully outlined in the planning portion of this article. Students in both class sessions seemed to be prepared for the discussions, participated readily, and exhibited a firm grasp on the concepts presented.

After the conclusion of the discussions, students were introduced to the problem-based learning component. First, they were divided into groups of 3−5 students, based upon their pre-existing laboratory partnerships. Next, each group was handed a sheet of paper with a different ill-structured, vague problem in the form of a question. Example questions include, "Do skin peptides provide any defense against chytridiomycosis in amphibians?" and "Do antioxidants have any effect upon cancer?". A set of four uniform tasks was disseminated with each problem. Tasks included (1) Form groups/receive assignment. (2) Brainstorm: evaluate problem and create a research strategy (10 min). (3) Searching: use any database or search engine, but four peer-reviewed articles must be included in your total (40 min). (4) Share answers: Give brief presentation detailing each phase. What was your strategy? Where did you look? What terms did you search (make a chart)? How did you evaluate the results? What questions

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remain after your search? Finally, each group was given a large piece of restickable easel paper and instructed to use it for creating a visualization of the search strategy and terms selected in anticipation of using it during the presentation portion of the class.

Instructors circulated throughout the entire class time, but gave no direction unless requested. A few groups asked for some clarification on the problems; "Can we narrow the problem?" was the most commonly asked question. This modification of problems was allowed, as well as any other modifications that the students chose to make with the understanding that a large component of a problem-based learning activity is the negotiation of the problem. This action requires the students to think more deeply about the problem and its causes as well as how they might go about searching for answers.

At the end of the 10 min brainstorming session, groups were instructed that they could now, if ready, move into the searching phase. Interestingly, groups took very different paths during the search time. A couple of groups took the "divide and conquer" route by assigning one group member each an article to locate. Other groups searched databases and the web together and evaluated each source as a group. The majority of the groups continually discussed and renegotiated the problems during the search process. Often, one group member would work on the chart and promote discussion while the other group members searched.

Following the approximately 30 min of allotted search time, group presentations began. Each group had been instructed to give a brief presentation (4 min or less) to include an explanation of the assigned problem and the steps taken to negotiate the problem and find answers or evidence. Prior to beginning the presentations, the library professor emphasized once again that the conceptualization of the question and the process by which groups searched were more important than whether any answers were found. Almost every group in both classes made charts of some sort and used them as guides during presentations. All group members participated in the presentation. At the end of the presentations, the library professor reminded the class of the lab report that would be due the following week.

POST-CLASS LAB REPORT HOMEWORK: ASSESSING STUDENT LEARNING

Grades for the lab section of PNA are comprised of three elements: formal (lab) reports (100 points), a laboratory notebook (50 points), and a final exam (50 points). Each lab report counts for 20 points, or 10% of the overall lab grade. During the planning phase, it was agreed that the library class session should also require a formal lab report as homework in order to reinforce learning and retention of the class content. Each lab group would be responsible for submitting one unified report.

For continuity, the library lab report overall requirements and structure mirrored the other lab reports completed by students in the class. Instructions for the assignment gave very specific details for how the lab report should be constructed, complete with headings and issues to be addressed within each section. Components included an introduction, literature review, methods, discussion, conclusions, and references (to be completed using APA style). Students would begin by introducing their topic and its relevance, including any modifications or narrowing that they might have decided upon followed by the literature review. The intent of the methods section was to require the students to reflect upon the research process: where did they search for information and why did they search in that location, how did they search and how did they modify their search, and so forth? In addition to fostering reflective practices in the students, these questions provide the librarian a better understanding of how the students are searching through the mental narrative they provide. The discussion section was reserved for commentary on the interdisciplinary nature of each group's question and how this was addressed in the search process. Conclusions were expected to include whether any conclusive evidence could be found and the identification of any research gaps.

All groups submitted reports on time through the university's course management system. Many groups provided more than double the required number of four peer-reviewed sources while some provided charts, graphs, or pictures to accompany the reports. Overall, the students produced excellent lab reports with appropriate literature reviews and narrative descriptions of their research process, which will yield more assessment information for future studies. The weak point of every lab report was evident in the adherence to APA style (the required style, assigned by the Chemistry professor, for the Proteins and Nucleic Acids class). Most reports used a variety of different styles and lacked consistency. [At the time of this writing, the Library has already taken measures to address this weakness through an integrated library instruction session on the citation management tool EndNote for all Chemical Literature students.] Despite this weakness, the average grade for the reports was a respectable 18 out of 20 points.

To this point, only a very cursory analysis of the quality of the lab reports (postlibrary instruction) has been conducted. A preliminary assessment of the laboratory reports submitted after library instruction showed improvement from papers submitted by the previous semester's students (who had no library instruction). An analysis of the reports produced by these two separate groups showed a 2-fold increase in the number of creditable references. Though marginal differences were observed between the two semesters, student papers showed a 1.7-fold increase in citations from refereed journals (a requirement for the library lab report homework). Continued analysis of reports and the addition of control groups in coming semesters should provide a clearer picture of student learning and skill acquisition.

Additionally, all students in the class were required (but anonymous) to take an affective survey on what was presented in the class and how they felt about the class. Over 92% of the class felt that they had a better understanding of the purpose and components of literature reviews and 100% indicated that the Library class was important in their understanding of why surveying the academic literature is important to their work in the lab. In all, the survey overwhelmingly indicated that the students found value in the session and felt that their learning was enhanced. A modified version of this survey will continue to be required in order to maintain an understanding of the students' perspectives on the session.

CONCLUSIONS

The pilot project detailed here is but a humble beginning to what should be a significant longitudinal study as the problem-based learning module is modified and built into multiple parts of the PNA curriculum over the coming semesters. An expansion of topics covered could include a deeper discussion

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of the utility of open access resources (include web resources) and the use of print materials. Both pre- and post-tests will be utilized in future iterations of the course in order to assess prior knowledge and whether specific skills were improved. The minimal amount of assessment data covered in this paper is not intended to serve as any sort of proof but rather to provide further context and understanding of a pedagogical technique not widely utilized in library instruction for the sciences. The findings do, however, suggest that a problem-based learning approach implemented to improve student research skills is a viable pedagogical tool that merits further exploration. The overall success of the collaboration and the module implementation also imply that the use of an external expert, a librarian in particular, can be beneficial to the curriculum and may provide improvements that could not be produced in other ways.

There is much work yet to be done in understanding if and how problem-based learning affects critical thinking and knowledge acquisition across a multitude of disciplines. More studies involving library instruction are also needed in the applied sciences in order to determine whether problem-based learning is a valid tool for the sciences. Another pathway for research might include a more in-depth study of interdisciplinary teaching and learning and how these factors might affect future performance in the workplace. This article simply offers yet another glimpse into the possibilities that problem-based learning and a focus upon interdisciplinary research may present for students in higher education and the benefits to students when professors and librarians collaborate.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00378.

Further explanations of the ACRL Framework. (PDF)
A class plan for the library instruction session. (PDF)
A grading rubric (specific to the library assignment). (XLSX)

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Notes

The authors declare no competing financial interest.

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