CHAPTER 9

Know What You Don't Know:

Teaching Chemistry Students to Ask Better Research Questions

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ACRL Information Literacy Frame: Research as Inquiry
Discipline: Science & Engineering
Subject: Chemistry
Learning Theory: Constructivism
Instructional Strategy: Threshold Concepts
Special Population: Undergraduate Students

At California State University, San Marcos (CSUSM),[1] teaching librarians work closely with disciplinary faculty to both develop and deliver information literacy instruction for students in their majors. Oftentimes, this results in long-term partnerships of individual librarians and teaching faculty to rethink and reimagine what information literacy instruction looks like in the classroom. As the STEM librarian, I (T. R. M.) have worked closely with a professor in the Chemistry department (M. S.) on an upper-division course

called The Literature of Chemistry (Chem 300). Chem 300 is a required course for chemistry and biochemistry majors in which they are introduced to the techniques of finding, reading, and writing chemical literature. The centerpiece project is a home chemistry experiment, which requires students to proceed step-by-step through the research process. If I had to describe the main learning objective of Chem 300, it would be "learn how to find, read, and use information like a chemist—and why."

For the last four years, I have been responsible for four sessions (amounting to two weeks in a sixteen-week semester) that cover the broad topics of books, journals, citations and bibliographic managers, and Web of Science. These sessions each include a lecture component, in-class activities, and homework assignments that I am responsible for grading. This past year, the professor came to me before the semester to discuss some possible changes to the content of each of the lessons. In previous semesters, the professor had done an assignment early in the semester to get students looking at general reference works, typically encyclopedias and online references,[2] to get some background information for their project proposals. Although the lesson was focused on the usefulness of these reference works, it was often the case that the most useful information for the students at this stage of their research was not in these works but on the open web. I would give a lesson later in the semester on books and the library catalog, which, while ensuring that students had basic information on these topics, did not always result in students advancing their research project. This exercise ended up feeling inauthentic because many times we would tell them to find a book that was only tangentially related to their research topic just so they could complete the assignment. Students felt frustrated that, in both of these lessons, the in-class work and homework assignments required them to focus their background research on print sources. We decided to abandon the general reference works lesson and hand over that day in the schedule to me to do a more general introduction to finding information. In light of the new ACRL *Framework for Information Literacy for Higher Education*,[3] this gave me an opportunity to rethink the way Chem 300 students embarked on research for their projects.

ACRL Information Literacy Frame: Research as Inquiry

During our initial planning meeting prior to the start of the semester, I asked the professor what he wanted students to understand and to be able

to do after the session. He told me that he mainly wanted students to get the information they needed to ask better questions in order to drive their research—a goal that matched up perfectly with the ACRL frame Research as Inquiry, which states, "Research is iterative and depends upon asking increasingly complex or new questions whose answers in turn develop additional questions or lines of inquiry in any field."[4] At the core of the lesson, we want students to be able to articulate what they did not yet know and/or understand, formulate questions based on their lack of knowledge and understanding, and try to think about where they would go next to learn the answers to their questions.

Learning Theory: Constructivism

The revised lesson plan draws upon a learning theory and an instructional strategy—constructivism and threshold concepts. In constructivism (a concept which appears extensively in the library instruction literature), the focus is on engaging "students …with information to solve a problem and thereby creating new understanding through *active* investigation and thought, instead of memorizing facts presented in class lectures."[5] The key word here is "active"; rather than the librarian/professor "transmitting" information to the student, students construct knowledge "through the process of trying to make sense of new information in terms of what that individual already knows."[6] In our lesson, students start with their preliminary ideas for "at home" research; this is what they already know. However, they are lacking an understanding of how to take these preliminary ideas and turn them into workable research questions. A lecture-based lesson that tells students how to arrive at better questions would not provide students with the vital practice of actual inquiry.

In the revised lesson, much of the lecture portion (which included information on the difference between primary/secondary/tertiary sources, how to find books using library classification systems, and a demonstration of how to use various book catalogs) is shifted to pre-class reading on some of these topics prepared by the professor. Although there is still a short lecture at the beginning of the session, most of it focuses on the purpose of background information and the different places students might go to learn what they need to know and how this would drive their research process. They are then provided with a large amount of in-class time to complete a worksheet[7] that walks them through the background research as question development

process. Students thus construct their own knowledge both of their research topics and the inquiry process through the activities of the lesson.

This worksheet asks students to

- articulate their research interests;
- learn more about their topic by consulting a variety of sources;
- write down vocabulary terms and definitions, as well as where they found the terms;
- articulate new questions that occur to them while conducting background research and think about where they might look for the answer;
- determine what their "observables" will be in their experimental research project (the project requires quantitative data, and the students often have a hard time specifying just what parameters will be measured; background research can be useful in clarifying this for them);
- write down two new sources they encounter during their background research that they might want to find and consult; and
- locate one book that might be useful for their research.

In creating the worksheet, I found it extremely helpful to consult the ACRL frame Research as Inquiry and its knowledge practices that state, "Learners who are developing their information literate abilities formulate questions for research based on information gaps or on reexamination of existing, possibly conflicting, information" and "… deal with complex research by breaking complex questions into simple ones, limiting the scope of investigations."[8] This worksheet helped students to do all of these things: take a seemingly large research topic, determine what they do not yet know, and ask simpler questions that will ultimately help them develop and answer their "big" question.

Instructional Strategy: Threshold Concepts

In addition to constructivism, this lesson is also based on the instructional strategy threshold concepts. In their extensive writing on the subject, Meyer and Land have described threshold concepts as transformative, irreversible, integrative, bounded, and possibly troublesome, and as concepts which "…can be considered as akin to a portal, opening up a new and

previously inaccessible way of thinking about something."[9] Talanquer considers the idea of threshold concepts within the field of chemistry, stating that threshold concepts are, "…in very general terms, the types of disciplinary practices that learners have to master to comprehend how knowledge is established …within a discipline."[10] As stated previously, the informal learning objective of Chem 300 is that students will "learn how to find, read, and use information like a chemist—and why." The threshold concept we want students to understand after this lesson is how chemists conduct background research as their first step in the research process. Not only will students need to research and learn about fundamental chemistry concepts, they will also need to gain an understanding of the scope and breadth of sources in which they can learn about these chemistry concepts.

In prior semesters, the professor and I had seen students struggle when conducting their background research—they always wanted to jump right into primary research articles before they understood much (if anything) about their proposed research topic. Based on observed student reactions, it seemed that the students considered non-scholarly web sources as antithetical (and "troublesome") to their preconceived notions of what scientists do. This attitude may be reinforced in other classes where the professor specifies that a project must ultimately be based on peer-reviewed scholarly articles—while failing to mention that the student must often do more basic background research to understand these sources. The new lesson plan emphasizes the importance of "approaching a high peak by choosing the gentle slope"[11]—basically, start by learning the easy concepts first before progressing to the harder stuff. The first time I taught this lesson, one of the students told me she was worried she was not able to find any scholarly articles that included an anatomical diagram of the human eye, so I asked her what kind of source might have the information she was looking for. She said, "Well, I know that I can go to places like Wikipedia or Khan Academy, but those aren't good." When I told her that those kinds of sources were indeed "good enough" for this kind of information and that it was likely she would not even be able to find them in the more specific scholarly articles, I saw a light bulb go off for her—she was crossing the threshold. Although for professional chemists, the background research they have to conduct starts at a more advanced level, the concept remains the same: first, learn about what you do not know before trying to understand more difficult information. And for students, understanding this concept transforms how they conduct research.

The previously described anecdote, in which the student comes to the realization about how to best address the gaps in their knowledge, is the "best case" scenario. By figuring out what she did not yet understand and then locating answers to her basic questions, she was then able to ask more sophisticated (and relevant) questions that drove her research.

This past semester, the "worst cases" tended to fall into two different categories, both of which were related to the question portion of the in-class assignment. In the first category, students asked questions that were too advanced or complicated during the background research portion of the in-class work because, at this point, they did not have the background knowledge necessary to ask appropriate questions. An example of a question that is too complex at this point would be "What are the effects of sulfate-free shampoo on color-treated hair?" as the student first needs to ask something more fundamental like "How do shampoos and dyes interact?" or even "How does shampoo work?" In the second category, students continued to ask very closed-ended questions that did not get them any closer to good experimental questions. Although closed-ended questions are not necessarily inappropriate to ask at this point in their research process, students were not conducting true inquiry in which their questions became more and more nuanced/complex; instead, it was more like they were "spinning their wheels" and not progressing in their research. An example of this "worst case" would be a student starting out with a research topic of the effect of different yeast types on the hardness of bread. Questions like "What are different types of yeast?" and "What types of bread are there?" are closed-ended, while questions like "What is the function of yeast in baking bread?" or "What do I mean by hardness and how do I measure it?" could yield further insights and improve their experimental research plans.

According to the American Chemical Society's *Guidelines and Evaluation Procedures for Bachelor's Degree Programs*, students graduating from an undergraduate chemistry program should be able to "…retrieve information efficiently and effectively by searching the chemical literature…" and they "…must be instructed in effective methods for performing and assessing the quality of searches using keywords, authors, abstracts, citations, patents, and structures/substructures…."[12] The professor and I do provide such instruction for students enrolled in Chem 300: The Literature of Chemistry; however, before they are prepared to engage in this level of research, we first try to set them up with a good solid foundation in question formulation and background research.

Although this lesson has only been used in a chemistry class, it could be adapted to work for any subject. The process of articulating unknowns, determining where to learn the answers, and asking more advanced questions is the core of the ACRL frame Research as Inquiry and can be applied to any discipline. Certain aspects of the in-class activity (such as the requirement for noting down "observables"[13]) would need to be modified for non-experimental situations.

Lesson Plan

Learner Analysis

- This lesson is appropriate for an upper-level undergraduate chemistry or biochemistry major (although it could easily be modified for many different student populations). Learners should have completed their lower-division chemistry coursework, including general chemistry, organic chemistry, physical chemistry, and quantitative chemistry.
- This lesson will work best with students who are ready to undertake a semester-long research project with the professor's guidance. Students should have basic disciplinary knowledge (including general laboratory techniques) that will allow them to articulate a research topic of interest and design and execute a simple home chemistry experiment.

Orienting Context and Prerequisites

Prior to the lesson, students should have:

- identified a potential area of research; and
- completed the reading[14] overviewing the different types of literature (primary, secondary, tertiary), library classification schemes, and a general overview of how experts in the field conduct research/inquiry.

Instructional Context

- At the very least, the classroom should provide internet access for each student. Ideally, the class should be held in the library to provide easy access to print reference works relevant to the

course topic. Seventy-five minutes to an hour and a half is the ideal length for this lesson, although it can be completed in fifty minutes if much of the in-class activity is shifted to homework. Prior to delivering the lesson, the librarian should develop the in-class activity and either bring printouts to class for the students to complete or post an electronic copy of the handout online for students to fill out on their computers.

Learning Outcomes and Activities

Learning Outcomes

After the lesson, students will:

1. know how to begin conducting background research on a topic;
2. know the type of information they can find in books and online;
3. be able to ask appropriate questions to drive their background research;
4. be able to access and log in to the library website in order to access proprietary materials;
5. be able to search the library catalog to find books by keyword and subject; and
6. be able to request items through interlibrary loan.

Learning Activities

1. Lecture: Students learn about the research process, the purpose of background research, and searching in library catalogs. *(LO1-6, 30 minutes, essential)*
    a. What are we covering today? (*LO1*)
        i. How to begin conducting background research
        ii. Search strategies (catalog)
        iii. Different library catalogs
        iv. Worksheet—find a book/books on your research topic, begin keeping track of important vocabulary, find similar experiments that have been done online, keep track of questions you are starting to have
    b. Basic intro to library website *(LO4-6)*
        i. How to log in, access materials off-site, the type of materials held in the library (physical and electronic), how to get help from a librarian

c. Beginning your background research—*research as inquiry (LO2)*
    i. Your information need is contextual; the type of source you want to seek out and the kind of information that is useful to you will depend on where you are in your research. At this point, what is your information need and where do you think is the best place to find this information?
    ii. Utility of books in conducting background research
        1. What kind of books have you used in the past?
        2. What *is* a book, exactly? What are they good for?
        3. Brief overview of how books are organized (Library of Congress classification and subject headings)
        4. Tools for finding books (catalogs, interlibrary loan)
    iii. Conducting background research
        1. You've already started thinking about your research questions/possible experiments, but what is your research need *now*, and where will you go to learn more?
            a. Open web and book
            b. Type of info you're looking for:
                i. Vocab and definitions
                ii. What has been done before
            c. What you need to produce:
                i. Questions you have that will drive your research forward
                ii. List of observables
                iii. List of sources for further investigation

2. Worksheet: Students begin their background research and articulate the following questions and unknowns *(LO3, 45 minutes, essential)*

a. In a couple of sentences, write out your possible area of research for your home chemistry assignment.
b. Begin your background research. You may want to visit websites, consult library books, look through book records in the library catalog, and more.
c. Vocabulary. Use this space to note down at least five relevant vocabulary terms, brief definitions, and where you found them.
d. New questions. Use this space to jot down at least four questions that occur to you during your background research that you will need to answer in order to continue on your home chemistry experiment. Write down where you might go to learn the answer.
e. Observables. In doing your home chemistry experiment, what will you need to observe and quantify in order to gather useful data?
f. Other references. In your background research, you will come across citations and/or links to other potentially useful sources. Use this space to write down at least two other sources you will want to investigate further.
g. Find one book (either in our library's collection or interlibrary loan) that might be useful for your research. Write out the **title**, **call number**, and any relevant **subject headings**.

Assessment

Summative Assessment

Following a rubric, the librarian assesses student worksheets and their demonstration of discrete skills (such as the ability to locate a book through the library's catalog) and the following knowledge practices, which state:

- "Learners who are developing their information literate abilities:
  - ▷ formulate questions for research based on information gaps or on reexamination of existing, possibly conflicting, information;
  - ▷ deal with complex research by breaking complex questions into simple ones, limiting the scope of investigations; and

- ▷ use various research methods, based on need, circumstance, and type of inquiry."[15]

Formative Assessment

Throughout the lesson, both the librarian and the professor are available to assist students with their question formulation and source selection.

- Success is measured by student achievement of the learning outcomes. By the end of the lesson, students should have a clearer direction for the necessary steps they should take to progress in their research and should have articulated more complex questions that can possibly be answered through experimentation.

Notes

1. CSUSM is one of twenty-three campuses in the California State University system and has a student population of approximately 14,000. "Fast Facts," CSUSM, accessed September 28, 2016.
2. The classification of "general reference works," while not used by librarians, was preferred by the professor to distinguish works written for a more general scientific audience from those reference works that primarily contained chemical or physical data, which he called "technical reference works."
3. Association of College & Research Libraries, *Framework for Information Literacy for Higher Education*, accessed September 28, 2016, http://www.ala.org/acrl/standards/ilframework.
4. Ibid.
5. Jesús Lau, "Guidelines on Information Literacy for Lifelong Learning," IFLA, 9 (my italics).
6. Alison King, "From Sage on the Stage to Guide on the Side," JSTOR, 6.
7. Talitha Matlin and Michael Schmidt, "Chem 300 Background Research Assignment," California State University San Marcos (see Learning Outcomes and Activities).
8. Association of College & Research Libraries, "Framework."
9. Jan Meyer and Ray Land, "Threshold Concepts and Troublesome Knowledge: Linkages to Ways of Thinking and Practising within the Disciplines," occasional report, Enhancing Teaching-Learning Environments in Undergraduate Courses Project, Edinburgh: School of Education, University of Edinburgh, May 2003, https://kennslumidstod.hi.is/wp-content/uploads/2016/04/meyerandland.pdf, 1.
10. Vicente Talanquer, "Threshold Concepts in Chemistry: The Critical Role of Implicit Schemas," *Journal of Chemical Education* 92, no. 1 (January 13, 2015): 3–9, doi:10.1021/ed500679k.
11. This analogy comes from the unpublished text for Chemistry 300, written by Dr. Michael Schmidt.
12. American Chemical Society, "Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs," 16–17.
13. Matlin and Schmidt, "Chem 300" (see Learning Outcomes and Activities).
14. Unpublished text for Chemistry 300, written by Dr. Michael Schmidt.
15. Association of College & Research Libraries, "Framework."

Bibliography

American Chemical Society. "Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs." ACS (2015). https://www.acs.org/content/dam/acsorg/about/governance/committees/training/2015-acs-guidelines-for-bachelors-degree-programs.pdf.

Association of College & Research Libraries. *Framework for Information Literacy for Higher Education*. Text (2016). http://www.ala.org/acrl/standards/ilframework.

Cooperstein, Susan E., and Elizabeth Kocevar-Weidinger. "Beyond Active Learning: A Constructivist Approach to Learning." *Reference Services Review* 32, no. 2 (June 2004): 141–48. doi:10.1108/00907320410537658.

CSUSM. "Fast Facts." *Fast Facts*. 2015. http://news.csusm.edu/fast-facts.

King, Alison. "From Sage on the Stage to Guide on the Side." *College Teaching* 41, no. 1 (1993): 30–35.

Lau, Jesús. "IFLA—Guidelines on Information Literacy for Lifelong Learning." Accessed September 29, 2016. http://www.ifla.org/publications/guidelines-on-information-literacy-for-lifelong-learning.

Matlin, Talitha R., and Michael Schmidt. "Chem 300 Background Research Assignment." CSU San Marcos (2016).

Meyer, Jan, and Ray Land. "Threshold Concepts and Troublesome Knowledge: Linkages to Ways of Thinking and Practising within the Disciplines." Occasional report. Enhancing Teaching-Learning Environments in Undergraduate Courses Project. Edinburgh: School of Education, University of Edinburgh. May 2003. https://kennslumidstod.hi.is/wp-content/uploads/2016/04/meyerandland.pdf.

Talanquer, Vicente. "Threshold Concepts in Chemistry: The Critical Role of Implicit Schemas." *Journal of Chemical Education* 92, no. 1 (January 13, 2015): 3–9. doi:10.1021/ed500679k.