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The Stepping Stone Approach to Teaching Chemical Information Skills

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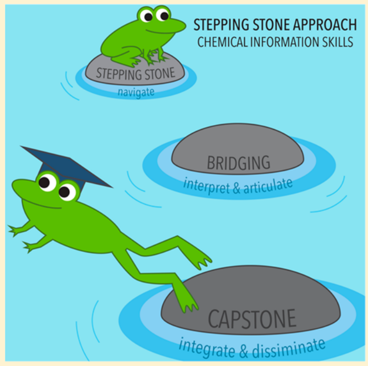
S *Supporting Information*

ABSTRACT: Information literacy is of paramount importance to any successful research program. Information techniques and skills should be infused throughout a student's undergraduate curriculum rather than being the focus of a single course. To this end, we have created several courses, beginning in the first year, where students review current scientific literature, design experiments, collect and analyze data, and disseminate their findings in both written and oral formats. At the completion of this sequence of courses, students have a greater understanding of all aspects of chemical research from identification of reliable sources through articulation of their findings. Details about the creation and implementation of the Stepping Stone Approach to chemical information literacy are discussed within.



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■ INTRODUCTION

The educational system is constantly adjusting to how students access and interpret an ever-increasing amount of information. As early as 1974, Paul Zurkowski recognized the change that computers were bringing to the informational landscape and a need to improve our understanding of informational handling thus beginning a foundation of what he coined "informational literacy". From its inception, informational literacy included what Paul called the "techniques and skills" used by "information literates" to "mold information solutions to their problems."[1] In 1989, an American Library Association Presidential Committee finalized their report on information literacy and at this time defined information literate as being "able to recognize when information is needed and have the ability to locate, evaluate, and use effectively the needed information."[2] Following this, the term information skills was further developed, which later was best summarized by Eisenburg and Berkowitz as the Big6 skills.[3] Here, information skills were similarly defined as "the information problem-solving process of task identification, information-seeking strategies, location and access, information use, synthesis, and evaluation." It has become clear that information literacy contains multiple components that help an individual handle the new flow of information. However, the original terms, techniques and skills, seem to have lost their original identities.

While this definition of information literacy has been revisited over the years and its applications evolve with changing available information, the content has remained consistent. More recent descriptions expand on the definition to delineate specific standards and outcomes that would apply to an information literate undergraduate student.[4] These general standards have been applied to the sciences, and in chemistry, a joint document by the American Chemical Society's Chemical Information Division and the Special Library Associations Chemistry Division offers a comprehensive set of standards that includes techniques and skills.[5,6] Within our program, we envision the teaching or dissemination of information practices as being twofold. Leaning on Paul's initial segregation of techniques and skills, techniques are those used to obtain and evaluate information, whereas skills are required to apply the information extracted. Transitioning from an informational illiterate to a literate citizen requires a curriculum that introduces, allows for practice, and hones these techniques and skills. Thus, the process must elaborate on the techniques long before requiring a student to apply the skills.

This approach is born from a belief that conveying information literacy requires a cumulative knowledge base and in undergraduate institutions will span the entirety of a student's experience.[7,8] Too often it is assumed that learners can make connections between what they know and should know. For instance, at the college level it is safe to assume these students are literate, meaning they can read and write, even if their proficiency in doing so is questioned.[9] However, it is not then safe to conclude that literate individuals necessarily possess information literacy. This is something that is very often overlooked when requiring students to produce written

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work. Within the sciences, we spend an unprecedented amount of time within the primary literature. By contrast, very little, if any, time is spent teaching students to interact with such documents in secondary education. Only recently has secondary education begun to integrate primary literature sources.[10−13] We must consider these foundations when building an undergraduate curriculum that incorporates scientific information literacy.

Many institutions have sought to eliminate this curricular gap in undergraduate chemistry curriculums. Some have modified traditional chemistry courses to include various aspects of chemical information literacy. This has been done as early as a first-year general chemistry course[14−16] or in subsequent courses.[17,18] Others have developed specific courses or incorporated components of information literacy into upper-level capstone or precapstone courses.[19−23] While each of these and other methods have merit, our department has moved beyond a piecemeal introduction to information literacy to a unified approach.[24] This approach requires early student interaction with the scientific literature and culminates with the preparation and development of original research projects that are carried out and presented in both written and oral formats. This structure can be customized within a program, and thus, the following will describe our general approach, referred to as the Stepping Stone Approach (SSA), to chemical information literacy. This approach is unique in its application to a small school setting using minimal resources and its adaption to fit within an existing earlier curriculum. Most importantly, this approach then culminates in research coursework that frames the student's application of information literacy.

■ INTRODUCING THE STEPPING STONE APPROACH

On the basis of the guidelines placed forth by the ACRL,[4] ACS,[5] and Longwood's expected information literacy outcomes (found on p 32 of the Supporting Information), the faculty in our program have developed a list of what we consider to be key techniques and skills necessary for chemical information literacy. We teach these in a tiered approach, starting with lower level courses (stepping stones) and culminating in the fourth-year courses (capstones). Table 1 summarizes the techniques and skills ideally included within each stage of the Stepping Stone Approach. The initial step in the SSA involves the simple introduction of available chemical information to students. Early introduction to these documents has precedent in other programs.[25] Similar to the ACS guidelines, this introduction can be as simple as finding characteristic data for chemicals or as complex as an article review. The goal of this step is to generally guide students in how to interact with and navigate various sections of the literature. In many cases, these assignments are graded using low stakes, pass/fail assessment methods. As students progress through the SSA courses, assignments are high stakes and assessed using departmentally defined rubrics.

The SSA continues with courses that require students to interact with the literature more independently, including database searching and reading abstracts to determine relevance. Students are also instructed on how to follow a trail of references from one source to another. This second step in the sequence bridges the gap between stepping stone and capstone courses by requiring students to demonstrate their understanding of information techniques through written and oral reports. For instance, writing abstracts in connection with laboratory reports helps students internalize the key components of an effective abstract. Courses must begin to contain presentations on an assigned topic forcing students to become proficient in locating and interpreting relevant information. These final assignments, in the second stage of the SSA, begin the application of information skills.

Table 1. Chemical Information Techniques and Skills Addressed within the SSA

Program Tiers	Chemical Information Techniques	Chemical Information Skills
Stepping Stone	Use source searching techniques	Drawing conclusions from identified literature excerpts
	Locate reliable sources, including from citations	
	Extract pertinent information (chemical information) from sources	
Bridging Stone	Determine when information is required	Articulate source information (written and oral)
	Analyze information from abstracts	
	Determine relevance of information	
	Follow a "reference trail"	
Capstone	—	Organize accumulated information
		Critique written information based on literature findings
		Design laboratory experiments
		Synthesize new information
		Articulate source information (written and oral)

The culminating step in the SSA allows students to integrate their information techniques and skills in a research setting. The main purpose of the capstone is to provide the students with a platform to generate an original or a multitude of original works. For example, in this capstone, students could develop a research proposal to be carried out based on a search of current literature.[26] A course might outline a research-like experience that leads to the writing of an article based on the laboratory findings. Formal laboratory report writing can continue in this capstone, but the emphasis is on the application of information skills to original research, culminating in both written and oral dissemination.

■ LOCAL IMPLEMENTATION OF THE STEPPING STONE APPROACH

The chemistry program at Longwood University (LU) has undergone a number of changes in recent years, and we have recently introduced a new course sequence based on a mapping of our curriculum. Much like the evolution of institutional applications of information literacy, our information literacy coursework evolved from what was solely a research-like course (CHEM 403) built originally to provide a research experience to all graduates. Postgraduate feedback illustrated that students felt unprepared for the literary components of this course and that additional scientific writing was necessary within the curriculum to prepare them for postgraduate experiences. This feedback prompted the creation of a course (CHEM 402) that was used to prepare them for the writing process and was built around generating a proposal for the CHEM 403 research project. Recent mapping of our curriculum's information literacy components prompted a reorganization of coursework and the creation of a bridging CHEM 302 course. This course focuses on applying the students' information literacy techniques and includes a traditional literature review assign-

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Table 2. Courses Included in the Stepping Stone Approach at Longwood University

Course Number	Program Tiers	Course Title (Format)	Year
CHEM 213	Stepping stone	Organic Chemistry I (Lab)	First Year
CHEM 214	Stepping stone	Organic Chemistry II (Lab)	Second Year
CHEM 350	Bridging	Quantitative Analysis (Lecture and Lab)	Third Year
CHEM 351	Bridging	Instrumental Analysis (Lecture)	Third Year
CHEM 302	Bridging	Introduction to Chemical Laboratory Problem Solving (Lab)	Third Year
CHEM 402	Capstone	Advanced Chemical Laboratory Problem Solving I (Lecture)	Fourth/Final Year
CHEM 403	Capstone	Advanced Chemical Laboratory Problem Solving II (Lab)	Fourth/Final Year

ment as well as multiple formal laboratory reports. Table 2 summarizes the courses that are included within each level of the SSA. The Supporting Information contains examples of syllabi and assignments for all courses listed therein. This is not a comprehensive list of courses required for graduation. It is also relevant to note that Longwood is on a two-semester per year system, where each semester runs for 16 weeks. Each course listed is a one-semester course.

"Stepping Stone" Courses

First year students are exposed to information literacy within weeks of arriving. Our LU first year seminar course, taught by either a physics or chemistry faculty, introduces the chemistry and physics students to our library with a focus on scientific databases. In the second semester of their first year, students begin the organic chemistry sequence. The student population in both semesters is approximately 75 students, which consists largely of biology majors and a smaller number of chemistry majors (approximately 10). We consider this a stepping stone course because it is in the organic chemistry laboratory (CHEM 213) where students are first asked to consider the availability of chemical information. The inclusion of biology majors is relevant because they will require many of the same basic information skills in their own major. Students are given pre-experiment assignments that require them to look up basic physical properties and safety information for the compounds they will be using and/or synthesizing in the laboratory. Later in this course students are asked to complete a guided literature interaction. In this assignment, students are given a lead article about a particular synthetic technique or problem. Questions guide the student in determining reliability, scientific reasoning, and extracting pertinent information. This assignment requires the students to find references within the parent article that contain similar issues. This assignment has been met with great feedback in which students often mention being surprised that they "could understand that much of a chemistry article." The assignment is a great substitution to a literature review at this stage because it prompts a deeper interpretation of the article than is typically undertaken by a student left to a written review. Similar assignments follow in organic chemistry II laboratory (CHEM 214) to refine the students' ability to collect information as required by the course.

"Bridging the Gap" Courses

Our bridging courses begin in the students' third year of the chemistry program. The first bridging course is quantitative analysis (CHEM 350). In the laboratory part of this course, students are given their first pass at writing (demonstrating chemical information skills). The experiments for this course are generally presented as cookbook-style experiments, and students are required to write a short abstract for every experiment that is conducted. Typically, 10−12 experiments are completed in a semester. Additionally, students are required to prepare two formal laboratory reports during the semester. The first and second year chemistry courses at Longwood do not require any formal writing, so this class is really their first experience with what we consider to be information skills, as defined in the introduction.

Abstract writing is an important skill for any scientist to develop, as it is an important way to summarize key findings in an experiment. The students at this level typically struggle with this assignment; they have never been required to write a short summary and distill important information into a readable paragraph. The most common problem with students' writing at this stage is figuring out what information is necessary and relevant. Students are instructed that an abstract should contain a brief (one or two sentence) statement of purpose, a brief statement of methods used (without experimental details), and a summary of all qualitative and quantitative results obtained. Some common issues that our students have difficulty overcoming are too much experimental detail, quantitative results not included, units or error on quantitative results not included, and purpose of laboratory misstated or missing. Through the process of writing abstracts and receiving feedback from the instructor every week, students' abstract writing skills are significantly improved by the end of the semester. Proficiency in writing abstracts improves with continued instruction and practice throughout the program. Students are given sample abstracts as part of the first few lab assignments and asked to evaluate them on their merits. This exercise gives the students practice at reading good (and poor) abstracts and helps them to hone their own skills.

In the second semester of their third-year, chemistry majors at Longwood University are enrolled in CHEM 351 and CHEM 302. These bridging courses are designed to complement one another as students learn about instrumental methods of analysis (CHEM 351, approximately 10 students including minors) and the application of analytical techniques in the laboratory (CHEM 302, typically 7 students). The experiments completed in CHEM 302 are inquiry-based and are designed to introduce students to problem solving in the laboratory.[27] For each experiment conducted, students are required to write a formal lab report. In contrast with the experiments conducted in CHEM 350, the formal lab reports in CHEM 302 are subject to a more extensive review and revision process, allowing students to work together to improve their skills. Chemical information literacy becomes very important at this stage, as students are now required to do pre-experiment assignments (as they have previously in CHEM 213 and 214) as well as find scholarly sources relevant to the experiment for their final report.

The culminating project in CHEM 351 is a presentation. We consider oral communication (in poster or lecture presentation format) to be an important chemical information skill, equally as important as written communication. CHEM 351 is the first

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Table 3. Sample Course Schedule for Longwood's CHEM 402, a Capstone Course

Week[a]	Topic	Assignment
1	What is a literature review?	Literature review topic selection due
2	How do I read a scientific paper?; Introduction to research proposals	Abstract #1 due; Outline of literature review
3	Review of scientific databases and library resources: Workshop with Library Liaison (at Greenwood Library)	List of 5 sources for literature review due
4	Resumes, cover letters, and grad school applications: Workshop with Career and Advising Center	Resume and cover letter (draft)
5	Scientific writing in chemical industry	Literature review project—FINAL
6	Scientific writing in chemical education	SOP for bomb calorimeter
7	What is a research proposal?	Lab handout for biodiesel synthesis
8	In class library research: Developing a research question	Topic for proposal due
9	In class writing: Proposal	Abstract #2 due; Proposal introduction (draft)
10	What is an e-portfolio? Peer evaluation of proposal introduction	Resume and cover letter—FINAL
11	Research seminar (Guest)	Proposal methods section (draft)
12	Research seminar (Guest)	Proposal planned experiments section (draft)
13	Peer evaluation of proposal methods and planned experiments sections; In-class writing	Research proposal—FINAL; E-portfolio—FINAL

[a]Schedule is designed to fit into a 16-week semester, leaving flexibility for exams, external speakers, holidays, etc.

course in the chemistry major's curriculum where students are asked to do any kind of oral presenting. For the past several years, the assignment has been a study of an EPA Superfund site.[28] Students are required to apply what they have learned about analytical methods to develop a monitoring plan for a site of their choosing. This project usually involves a good deal of sifting through information that is readily available on the Internet (rather than a thorough search of primary literature), and students must determine what information is reliable and how to best use it. At the bridging level, students are applying their literacy techniques for the first time (in written and oral formats) to filter information and determine its appropriateness.

"Capstone" Courses

We have offered our capstone sequence (CHEM 402/403) for five years. The first course in our capstone sequence, CHEM 402, is offered during the first semester of the students' fourth year. They have completed the organic sequence (stepping stone) and the analytical sequence (bridging the gap), and they have either completed or are taking concurrently the physical chemistry sequence. This part of the capstone sequence is in a lecture or seminar format. Part of the semester is devoted to career and future planning. Students prepare portfolios, work on resumes and graduate school applications, and meet with the career and advising center. The other part of the course is spent preparing a comprehensive written literature review on a provided topic, and preparing a full proposal for a research project that will be completed in CHEM 403. It is in this course that students begin to refine the information skills that they have been learning. The course includes abstract writing exercises, a visit to the library with an interactive seminar on the use of library resources and scientific databases, and peer evaluation of their written work. A sample course schedule is shown in Table 3.

Longwood University has library liaisons in many different areas, an institutional subscription to Web of Science, and an interlibrary loan system that allows us to access holdings at other libraries. Students have been informally exposed to library resources in the bridging courses, so we feel that a formal visit with a librarian at this stage is helpful to solidify what they heard before. We are fortunate to have a liaison in the library that specializes in the sciences, who can give our students targeted help. The application of skills at this level is more advanced than what they have been exposed to in previous courses.

The first major writing assignment in CHEM 402 is a comprehensive written literature review on a topic provided by the instructor. This topic changes from year to year and is usually inspired by an interesting news item in *Chemical and Engineering News* or some other scientific trade publication or popular science item. The assigned issue is broad enough to require students to refine it to a researchable topic; for example, "Food Fraud" was a topic given to one class.[29] Students were required to develop a research question and write a comprehensive literature review.

The second major writing assignment in CHEM 402 is the research proposal. For practicality, students should be given a broad common topic; each individual may then refine the topic to a researchable question. As an example, for the past two years, the proposal has been focused on the production of biofuels (in keeping with the University's theme of sustainability). Ideally, the proposed research project will incorporate some aspects of organic synthesis, instrumental analysis of products, and thermodynamic analysis. The proposal requires students to develop a research question, conduct a comprehensive literature review, and write a set of planned experiments. The proposal is written in stages, with a significant review and revision process as part of each student's grade. Student work is reviewed by the instructor and by their peers before a final written product is produced.

The second course in our capstone sequence, CHEM 403, is a laboratory based course that meets twice a week (6 h total). The semester begins with students completing short (one or two week) inquiry-based experiments and writing formal reports for each one. These activities are very similar to the experiments that are done in CHEM 302. During this part of the capstone sequence, techniques learned and skills introduced in the bridging courses (see Table 1) are honed and continue to be further developed. These assignments are also an opportunity for students to continue to improve their writing skills and assess one another's work. Our learning management system, Canvas, has a very useful feature that allows for students to peer review, either by leaving comments or by completing a rubric provided by the instructor.

The final, and in our opinion the most important, part of the capstone sequence is the completion of the experimental work outlined in the proposal generated in CHEM 402. Articulation

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of source information in both oral and written format is the final goal of the SSA, and it is here at the end of the capstone sequence where we expect our students to apply all of the skills obtained along the way to prepare their final project. To those ends, students begin the project by preparing an oral presentation of the literature review that was a part of their proposal. Following their oral presentation, students work for 6 weeks in the laboratory to carry out the projects outlined in their proposals. Their final task is to analyze and compile the data they have collected into a manuscript (using an ACS journal as a style guide) that includes an extensive literature review, a complete experimental section, and a thorough analysis of their results. In completing this final assignment, our students have independently (or with a very small group of peers) envisioned, proposed, and carried out a research project from start to finish and have a written product that can become part of their portfolio.

■ CONCLUSIONS AND FUTURE WORK

The need for the Stepping Stone Approach arose when we found that we were expecting our fourth-year level students to possess skills that we had not necessarily been teaching them. Through the introduction of several new courses (most notably, the CHEM 302 bridging course and the CHEM 402/403 capstone sequence), we have infused chemical information techniques and skills directly in the curriculum. We realized that while our students possessed the chemistry content knowledge that we desired, they did not necessarily possess the skills to share that knowledge, nor the resources to find and process chemical information.

As the Stepping Stone Approach develops, assessment of the overall effectiveness of the program is necessary. Our current third-year class is the first cohort of students that will complete all of the courses included in the program. These students will be assessed using an Information Literacy Competency rubric provided by the Longwood University's Office of Assessment and Institutional Research. The rubric is based on the Information Literacy VALUE Rubric published by the Association of American Colleges and Universities.[30] However, this rubric measures information literacy as a general topic and is not specific to chemistry. We are currently developing our own departmental rubric, based on prior published works,[4,5,31] for assessing chemical information literacy, which we plan to implement in the spring of 2017 when the first cohort completes the program. We will also continue to implement exit interviews for our students, which include questions about their perceived level of preparedness for employment or graduate study. Our current first year class will be the first cohort of students for whom we have the opportunity to evaluate their chemical information literacy from the beginning of the program. We are working with the Longwood University's Office of Assessment and Institutional Research and our Library Liaison to refine assessment of these students' chemical information literacy at the beginning, middle, and end of the program.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00389.

Course syllabi; example assignments; current Longwood University Information Literacy Competencies (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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