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RESERVE THIS SPACE

Building Data and Information Literacy in the Undergraduate Chemistry Curriculum

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The Literature and Seminar sequence at James Madison University has been used to develop the chemistry information literacy skills of chemistry majors for over four decades. These courses have been continually updated to emphasize information literacy skills for the twenty-first century. This chapter describes the methods that have been developed to improve chemical, data and general information literacy at a large, public, primarily undergraduate institution. The focus of the first semester course, described in this chapter, is on skill building rather than teaching specific resources. It is a model of integration and collaboration between chemistry faculty and chemistry librarians. Changes in information resources, disciplinary standards, and assessment are used to inform and refine course instruction. While implementation of a course is always unique because of the size, curricular structure, culture, and students associated with an institution, we think that the approach described herein will be applicable to other programs.

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Introduction

Chemistry is a discipline that requires knowledge of a diverse range of skills and content. Much of the focus of undergraduate preparation is on the development of content knowledge and laboratory skills. However, chemistry graduates need to master many more skills. A critical competence is the mastery of chemical literature and information management skills, which are outlined in the 2015 American Chemical Society Committee on Professional Training (ACS CPT) Guidelines for undergraduate chemistry programs (Student Skills).

> *Essential student skills include the ability to retrieve information efficiently and effectively by searching the chemical literature, evaluate technical articles critically, and manage many types of chemical information. Students must be instructed in effective methods for performing and assessing the quality of searches using keywords, authors, abstracts, citations, patents, and structures/substructures…. Students' ability to read, analyze, interpret, and cite the chemical literature as applied to answering chemical questions should be assessed throughout the curriculum. Instruction should also be provided in data management and archiving, record keeping (electronic and otherwise), and managing citations and related information (1).*

Chemical information is highly structured and organized, and encompasses diverse materials ranging from property information, protocols, and analyses to articles in the primary, patent, and review literature. Increasingly, the definition of scholarly information is expanding beyond the traditional scientific literature to include nontraditional products, such as data. The guidelines developed by the ACS CPT and the Information Competencies for Chemistry Undergraduates *(2)*, developed by the Special Libraries Association Chemistry Division (SLA DCHE) and the ACS Division of Chemical Information (ACS CINF), help to ensure that bachelor's level students have the basic skills needed to find and use the chemical literature effectively. The Information Competencies for Chemistry Undergraduates that are a major focus of the course described in this chapter are summarized below; other competencies can be found online *(2)*.

Competency 1.1 - Library Use. Students should…

- understand the organization of the library and know how to use library tools and library services to obtain desired information and references;
- understand the purpose and characteristics of different information-finding tools, e.g. catalogs, indexing and abstracting databases, subject guides, and web search engines, and choose appropriate tools for a particular information need; and
- request help from librarians, faculty, and teaching assistants when needed and consult online training materials when available.

Competency 1.2 - Scientific Literature. Students should…

- understand the flow of scientific information, and how information is communicated among scientists, both formally and informally;
- understand the nature and purpose of different types of scientific literature, including journals, magazines, patents, proceedings, dissertations, monographs, handbooks, encyclopedias and dictionaries, grey literature, and technical reports;
- be able to read and interpret citations for the different types of scientific literature;
- understand and apply criteria for evaluating the authority and appropriateness of a document or information source;
- demonstrate critical thinking by evaluating information, drawing conclusions from the literature, and following a logical path of inquiry;
- understand the general nature of the peer review process; and
- understand scientific ethics and accountability and have an awareness of intellectual property issues and developments in scholarly communications including those affecting author's rights, the use of copyrighted materials in research and instruction, and open-access initiatives related to the scientific literature.

Competency 2.1 - Background Information. Students should…

- know how to find chemistry-specific sources of background information such as encyclopedias, treatises, compiled works, and review articles.

Competency 2.2 - Articles and Other Chemical Literature. Students should…

- be able to identify and obtain various types of scientific literature.

Competency 2.4 - Chemical Substances, Reactions and Syntheses. Students should…

- have an understanding of the unique features of chemical literature, and be able to use these unique features to find needed information.

Competency 4.1 - Scientific Communication. Students should…

- be aware of the different methods for presenting research;
- understand the reasons for citing the literature in one's own writing;
- demonstrate the ability to cite using appropriate formatting and standard abbreviations; and
- be familiar with software that allows for storing, managing, and formatting bibliographic references or citations.

Competency 4.2 - Ethical Conduct. Students should…

- learn the professional standards of chemists as articulated in the ACS "Chemist's Code" and in relevant works on scientific ethics;
- understand that science is filled with ethical judgments;
- recognize the ethical component of complex situations; and
- analyze complex ethical problems and design appropriate solutions.

Information literacy has been incorporated into professional standards across many scientific disciplines, and specific guidelines have been adopted in chemistry and engineering *(3)*. Multiple approaches have been used to build information literacy skills in the chemistry curriculum. Increasingly, activities related to chemical information literacy have moved from the resource or tool-based arena towards skill building and application. As recently as 2010, a retrospective of chemical information literacy was focused entirely on resources and collections rather than classroom activities *(4)*. While there are examples in the literature of student engagement and chemical information literacy prior to 2010 *(5-9)*, most of published work occurs after this time *(10-48)*.

Some instructional strategies have focused primarily on tool use and proficiency, such as the effective use of SciFinder, Scopus or patent databases *(12, 16, 22, 30, 41, 49)*. These articles are helpful resources to learn more about exercise design and the impact of scientific literature instruction with respect to student performance. Other articles show how information literacy can be introduced in the laboratory setting *(9, 14, 21, 25, 28)*. Recognizing the quantity of chemical literature available and the difficulty of building the skills required to find and use it effectively, some programs have approached chemical information literacy in a sequenced or scaffolded fashion *(10, 13, 15, 17, 20, 26-28)* or treat information literacy in a stand-alone course *(11, 18, 27, 29, 34, 35)*. Given that the natural “home” for this content straddles two domains, chemistry and library science, it is not unusual to see some level of collaboration between the chemistry faculty and chemistry librarians when developing courses or activities *(10, 12, 14, 15, 18-20, 29, 30, 32, 38)*. While many of these research literature courses can be taught by the chemistry faculty alone, the rapidly changing nature of information sources and data information literacy make the co-teaching model with a chemistry librarian especially attractive.

While faculty have effective strategies for keeping up to date in their field, they are not always aware of the changes in the information landscape, particularly those that are outside of their research and teaching domains. Librarians often become aware of these changes and trends in information science, particularly those that are outside of a faculty member's core discipline, and can educate faculty about emerging trends and changing standards. Recent changes, for example, may require faculty to develop data management plans before submitting grant proposals and to register for unique persistent identifiers provided by communities such as ORCID – Open Researcher and Contributor ID *(50)* before submitting research articles.

Data information literacy (DIL) is an emerging area within librarianship and scientific disciplines. Data information literacy is a relatively new term in librarianship and has not achieved the same penetration in the profession, let alone outside it, as information literacy. Carlson et al. define DIL as merging "the concepts of researcher-as-producer and researcher-as-consumer" *(51)*. While this may seem important only in the research sphere, it is critical that undergraduates have at least some exposure to these ideas because many will have careers in fields where fluency in working with data will be an important skill and asset. In addition to developing chemical information literacy skills students must develop data information literacy skills. Twelve competencies associated with DIL were created by the Data Information Literacy Project, an Institute of Museum and Library Services (IMLS) grant-funded initiative. They investigated the DIL needs of researchers and developed a curriculum to address those needs *(51)*. The competencies include *cultures of practice, data management and organization, data curation and reuse, ethics and attribution, data conversion and interoperability, metadata, data preservation, data processing and analysis, data quality and documentation, data visualization and representation, databases and data formats,* and *discovery and acquisition of data (51).*

Understanding how to manage the data that one produces, while also recognizing how to find and use data effectively and ethically, is an activity that is seldom formally taught *(51)*. Some research communities, like the crystallography community, have a long history of sharing data, and working towards standard formats and filetypes, and training community members to make data easily sharable *(52-55)*. Until recently, this has been the exception rather than the rule. With the increase in collaborative or large-scale projects that require some level of data sharing and mandates from federal funding agencies for data management plans, data management has become a critical skill in chemistry. Data producers need training in data information literacy.

While ACS CPT specifies only data management in its guidelines, a basic awareness of DIL concepts provides a foundation for the students to build upon as they continue their studies or begin their careers. This is clearly a growing area in chemistry. Within ACS, there has been an increased focus on data as evidenced by the ACS Division of Chemical Information technical sessions at the Spring 2016 National Meeting. Session titles include “Chemistry, Data, & the Semantic Web: An Important Triple to Advance Science,” “Driving Change: Impact of Funders on the Research Data & Publications,” and “Global Initiatives in Research Data Management & Discovery” and include cosponsors from the Division of Medicinal Chemistry and the Division of Computers in Chemistry, among others *(56)*.

Chemistry and librarian faculty who have established teaching relationships have an opportunity to weave elements of data information literacy into the curriculum. Recognizing the professional and scholarly value of information, including data as a resource, we have modified our course to include more elements of data information literacy, particularly data management, reuse, and the research lifecycle. Introducing undergraduate students to the concept of data as a scholarly product can be a challenge since not all of them have been involved in a research experience and have not encountered data “in the wild.” In this chapter, we will describe how we weave chemical information literacy and data information literacy into the course that we teach, how we have modified instructional styles to address the skills that our students already have, and the challenges of introducing these ideas to undergraduate students.

Challenges uncovered through course assessment - observations on our information seekers

Information literacy instruction at James Madison University

James Madison University (JMU) is a large, master’s comprehensive public university in Virginia. As of 2015, 91% of the student population of over 20,000 was undergraduate *(57)*. The Chemistry and Biochemistry department at JMU is an undergraduate degree-granting department, which graduates between 30-45 majors each year. For over four decades, the department has required chemistry majors to complete a pair of independent courses that focus on the chemical literature, Literature and Seminar (Lit&Sem) I and II. Each course lasts for one 14-week semester and students are advised to take these courses in consecutive semesters after completing two foundation level chemistry courses *(1)*; students usually take this course during the junior year. Lit&Sem I currently meets for 90 minutes each week and requires that students attend seminar outside of class. Students must take the course for a letter grade. Lit@Sem I is co-taught by a chemistry faculty member and a science librarian; the chemistry faculty member assigned to the course does most of the course grading. Lit&Sem II is taught only by a chemistry faculty member, although students are encouraged to consult with the science librarian. Lit&Sem I focuses on methods of locating, reading, interpreting and organizing specific information from the chemical literature, and Lit&Sem II prepares students to present a literature-based seminar and paper on a topic in the chemical sciences. These courses also address professional ethics, developing a professional online presence, and career readiness. A course outline for Lit&Sem I is provided in Table 1 and a detailed syllabus can be found in the JMU institutional repository, JMU Scholarly Commons *(58)*.

Table 1. Course Outline for Literature and Seminar I

Week	**Class Topic**
1	Introduction to Literature & Seminar
2	Effective reading strategies
3	Identifying key findings
4	Summarizing and article and writing
5	Ethics
6	Finding information: General resources
7	Finding information: Scholarly databases (Scopus)
8	Data management
9	Finding information: Scholarly databases (SciFinder)
10	Finding information: Scholarly databases (PubMed and Patents)
11	Searching in action: Learning about new topics
12	Searching in action: Identifying and choosing resources
13	Searching in action: Identifying and choosing resources
14	Chemistry ILT (Information Literacy Test) and SALG (Student Assessment of Learning Gains)
15	Final exam

The ACS CPT guidelines have always driven instructional content in the Lit&Sem courses. These standards helped to provide guidance in determining outcomes both in Lit&Sem and in other courses in the curriculum. In the most recent guidelines *(1)*, the ACS CPT identified problem solving skills, chemical literature and information management skills, laboratory safety skills, communication skills, team skills, and ethics as critical skills that students need beyond chemistry content knowledge. Lit&Sem I explicitly addresses chemical literature and information management skills, communication skills, team skills, and ethics.

Instruction informed by assessment

James Madison University and the Department of Chemistry and Biochemistry have a robust culture of assessment that helps identify performance trends and determine areas of need. We assess skills associated with information literacy every year using two in-house inventories: the Academic Skills Inventory (ASI) and the Chemistry Information Literacy Test (ILT). We also monitor performance on student assignments and exams and responses on the Student Assessment of Learning Gains (SALG) *(59)* in the Lit&Sem sequence to guide curricular changes. The ASI consists of 90 statements where students self-report whether they have a particular skill by choosing whether a statement that describes that skill applies to them. It asks students about skills that are specifically addressed in Lit&Sem including scientific communication (4 questions), interpersonal/team skills (1 question), ethics (4 questions), and information literacy skills (14 questions). The ASI is administered to all students at the start of their first year, second year, and a few months prior to graduation during a university-wide assessment day. Students show great gains in information literacy skills between their second year and their senior year.

The ILT is a major-specific information literacy test, developed with the chemistry librarian, to assess chemical information literacy knowledge at a more granular level. The ILT aligns with both the Association of College & Research Libraries Information Literacy Competency Standards for Higher Education *(60)* and the Information Competencies for Chemistry Undergraduates and includes questions about citations, appropriate sources of information, plagiarism, and information types. Each year, the results of the ILT undergo statistical analysis to identify areas of growth and need, although this can be a challenge with the relatively small sample size year after year *(18)*. The ILT also includes a section on student-reported comfort levels with various search tools and information types. This section of the test is administered to first semester sophomores and then as a pre- and post-test in the Literature & Seminar sequence. From this data, we can localize where in the curriculum students are developing comfort with different search tools and we can determine learning trends as they relate to information literacy. The ILT and student results have been described previously *(18)*.

The SALG *(59)* focuses on the degree to which a course has enabled student learning. Students assess and report on their own learning and on the degree to which specific aspects of the course have contributed to that learning. This instrument was customized to match Lit&Sem I and allows the instructors to ask about class-specific learning objectives and content delivery. The version of the SALG used in Lit&Sem I is freely available on the SALG site to registered users. To access the instrument, create a course, reuse a public SALG, and search for the instructor, course and semester (Reisner, CHEM 481, Fall 2015).

Changes in course delivery and instruction methods

For many of the past 15 years, Lit&Sem I was presented in lecture format. The instructors would *tell* students about the information competencies as defined by SLA DCHE/ACS CINF then have them complete activities that reinforced these competencies *(18)*. By assessing student performance on the chemistry ILT and search assignments, we found that students developed the mechanics of searching via the tools (usually databases) but did not develop comprehensive and efficient information search strategies. Students did not think about how ideas relate to one another and what the purpose of a particular publication may be. Students also were not developing the skills to manage the information that they acquired, be it in the form of references, data, or annotations.

Course instructors observed that students could choose a tool to use, but did not necessarily choose the best tool. They were focused on task completion and defined success as obtaining a result, not necessarily a high quality result. They had a tendency to fall back to general information seeking skills, using Google or Wikipedia, with little attention to the reliability or quality of the resource. Even though they had seen research database resources in prior classes, they defaulted to strategies that they had been using since before college. They also tended not to question whether their search produced a reliable result or the best result. For many students, the search itself was superficial and success was defined as finding *something*. In this age of easy information access, students need to build the skills to search, filter and refine effectively. To do this, they need to develop critical reading and evaluation skills.

To address the apparent lack of both skill retention (from their earlier courses) and skill development, we shifted our approach to focus on developing critical reading, searching, evaluation, and data management skills. First, students must become critical and deep readers. They must be able to identify the components of a journal article and the key points from the paper so they can understand how research fits into the broader context. This is a key step to the development of effective and efficient search strategies. By developing critical reading skills the students can develop a framework from which to search. Once students recognize the depth of content in an article, with consideration to supplemental information and associated data, they are more inclined to switch to a specialized research database, away from general search tools like Google. With the large amounts of information to which they have access and are asked to process, students are receptive to adopt tools that help them manage the data, but it is still not a workflow that is ingrained in their default processes. These observations helped the instructors recognize that a different emphasis was needed in this course. To break poor research habits of students, the instructors changed the structure of the Lit&Sem class to emphasize the skill development rather than search tools use.

(Re)Designing a course to improve information literacy in chemistry

Changes in the structure of information resources and easier access to information resources had already had a major impact on how chemical information has been taught at JMU. Using several years of assessment data and personal experience, the Lit&Sem instructors decided that the course needed a radical revision. Lecture-based instruction was too didactic and hybrid or online deliveries did not perform well and were not embraced by the students *(18)*. We came to the decision that more in-class time would allow for group activities and guided practice. Overcoming the disconnect between tool use and research and communication skill-building was not feasible in a 60 minute class. Upon consultation with the department head, the instructors secured 90 minutes of curricular time per week and moved the class into a flexible learning environment. This classroom was equipped with movable tables and chairs, multiple projection points, and dry-erase walls. Once the space and time were set, the instructors took a backwards design approach to the course redesign.

The first step in a backwards design approach is to determine the learning outcomes for the class *(61)*. By consulting the SLA DCHE/ACS CINF competencies, the instructors developed a list of broad goals and associated specific outcomes (Table 2). Some of these concepts are covered in other chemistry courses. For example, ethics is covered in Biochemistry (CHEM 361) and preliminary literature searching is covered in the second semester of the sophomore lab, Integrated Inorganic/Organic Laboratory II (CHEM 288L). Rather than frame the instruction from prior coursework as redundant, the instructors recognized the value of repetition and of scaffolding the content, so that students could build upon previous knowledge and reinforce appropriate knowledge structures. The instructors were able to plan each week of class time to align with specific objectives and then determine the evidence and activities that the students would need to demonstrate and complete to help achieve those goals *(58)*. Early on, we decided that one strategy to help meet those goals would be repetition. Students would use resources multiple times, to help create both comfort and habit. With repeated experience, we felt that students would be more likely to turn to these resources in the future. We also made a stronger effort to compare and contrast the tools throughout the semester, so that students could differentiate between and identify when to use each resource. The structure of the course, a summary of the assignment and how these assignments map onto specific learning objects can be found in JMU's Institutional Repository *(58)*.

Table 2. Course Goals for a Student Completing Literature and Seminar I

Course Learning Goals A student should be able to…	**Specific Learning Objectives**
… discuss the structure of the chemical literature	• find an article from a citation in the chemical literature • recognize the purpose of a DOI • explain how information is communicated among scientists • explain the process, strengths, and limitations of peer review
... identify appropriate information sources	• identify the difference between peer-reviewed and non peer-reviewed articles • select high quality information sources
… use resources to find chemical information	• know the major chemistry databases & texts for finding chemical information • identify the best resources for starting a search • perform a comprehensive search on an author, molecule or topic • refine searches to target information • examine the relevance and importance of resources • find additional resources by following citations (in and to an article)
... manage chemical information	• recognize ethical practices for managing information • identify best practices for data management • develop strategies to keep current in chemistry

Course Learning Goals A student should be able to…	**Specific Learning Objectives**
… understand technical articles	• list and define unknown vocabulary and ideas in a scientific article • restate the purpose and key findings of a scientific article • interpret data (what it says and what it does) • analyze a scientific article for the most important outcomes of the research study • create a short summary in clear and concise language • evaluate the quality of the research study
... communicate effectively using written language	• identify the relevance and application of the research • use formal written English • construct effective paragraphs • distill the most important ideas from a research article • distinguish between plagiarism, patchwork plagiarism and effective summarizing • construct an effective summary from research ideas and background • integrate content to tell an effective story • revise writing to improve structure, clarity, and story • evaluate the quality of written work (yours and your peers)

The course was built around new instructional space on campus which allowed us incorporate more group activities and peer instruction. The classrooms facilitate this teaching style because they feature flexible furniture, wall-to-wall writeable surfaces, multiple projection points and movable teaching stations. The classroom was laid out so there was no “front of the room” which shifted the focus from the instructors to the students. Instead, groups of four students faced each other. This focus on group activities and peer instruction meant that group dynamics became a part of both the physical and organizational (grading) structure of the class.

Because group work became an important element in the course, the instructors turned to the "CATME Smarter Teamwork" system (CATME) to implement best practices in building and implementing teams *(62)*. CATME allows the students to input their schedules, preferred leadership style, language comfort levels, and any other information that would be helpful to know for group work and then groups the students together based on those inputs and any instructor criteria (group size, gender balance, etc…) *(63)*. Using this software to group the students had two benefits: 1) the students felt that the groupings were intentional and there was less potential for schedule conflict and 2) the students were able to provide peer feedback to their groupmates regarding work contribution. We hoped that this would help the students feel more empowered by their membership and more motivated to be an equal contributor. CATME also provided students with accountability for and feedback on their performance as group members *(64, 65)*. Students assessed and received feedback from their peers near the midpoint and end of the semester.

To capitalize on the student-centered environment, we designed in-class activities and assignments that were in line with each week's objectives *(58)*. Lecture was kept to a minimum. While some activities could be completed at home, much of the coursework was completed in class. We started each day with administrivia then moved to a warm-up activity exercise where students used the writable walls to note their opinions or knowledge about the topic of instruction. This helped students to activate their prior knowledge, identify content strengths and weaknesses, and allowed for some real-time tailoring of lecture instruction. After a detailed treatment of the subject, the groups then worked through 1-2 exercises, with time for discussion and debriefing after each exercise. At times, the students drove the discussion, building off one another's contributions, as well as offering dissent and opposing approaches.

Before students can use databases effectively, they need to develop critical reading, writing and analysis skills. Instruction and assignments in weeks 2-4 focused on these goals. Students read papers outside of class and prepared vocabulary lists and summarized paragraphs to help them master content. Through these activities, students engaged in informal writing. We analyzed the content of the articles through in class discussion and helped them to transition to formal writing by having them collaboratively write article summaries. Since revision is such an important part of the writing process, we had students revise group summaries individually and gave them additional opportunities to revise their own writing. Students gained additional practice with writing fluently by writing papers on eight science seminars that students were required to attend.

By addressing reading, writing, and analysis skills early in the semester, the instructors believed that students would be less likely to use surface-level mechanical manipulation of databases to find literature. With this structure, students do not begin searching the literature until nearly halfway through the semester. The first time students formally used a research database to complete a task was week 7 (Table 1). By that time, students had practice identifying key ideas and determining how information in a paper relates to other papers. They were prepared to perform keyword searches and to understand why something was referenced or why a paper might be cited by others. The rest of the semester was devoted to developing expertise with specific databases (weeks 7, 9, and 10), improving searching techniques (weeks 7 and 9-13), and differentiating when to use different databases (weeks 12 and 13).

The next challenge in course design was to weave elements of data information literacy into the curriculum. Our goal was to introduce students to data management, reuse, and the research lifecycle. The focus on critical analysis early, and understanding of how science is communicated through the literature, helped set the stage for an in-depth session on data management. Data management is often associated with good laboratory practice and is most frequently taught in the curriculum through keeping notebooks in the teaching and research laboratories. However, students must also understand why it is important in the literature given the increase in data as a scholarly product, often as supplemental information. Lit&Sem provides a unique opportunity to introduce multiple concepts within the aforementioned data information literacy frame of *cultures of practice.* By delivering this content within the discipline, students can assimilate this information into other frameworks that have been built, such as ethics and information discovery. Throughout the course, students received information on the ethics, organization, discovery, and synthesis of information (usually in the form of journal articles, chemical structures, and other literature). Introducing the role of data in this ecosystem built upon that previous experience.

The instructors tried to find concrete representations of the abstract concept of research data, given that not all students participate in undergraduate research. The first effort, in 2012, used examples of personal photo collections or desktop file folders, which were too simplistic. Students rushed through the exercise and were not able to translate the naming protocols to the research environment (related to the *data management and organization* competency) when asked about it later *(51)*. In subsequent years, the instructors utilized a hands-on group exercise where the students performed a card sort based on experimental data. Students renamed and organized a series of given files to improve their ability to find and identify appropriate files in the future *(27)*. Part of the class period was also spent discussing media storage, archiving data, and file backup methods. It appeared that most undergraduates in the Lit&Sem classes had not thought about these ideas, but a passive lecture was not an ideal way to deliver abstract content. While the students could connect to the subject matter, the exercise was narrowly focused on file naming and file organization hierarchy. Upon assessment, some students noted “data management” as a skill that was learned, while others felt that it was busy work.

Learning from these prior experiences, the instructors opened the data management session of the redesigned Lit&Sem with the excellent YouTube animation from the NYU Health Sciences Libraries, “Data Sharing and Management Snafu in 3 Short Acts” *(66)*. This short video illustrates the difficulties of data sharing and management when one makes no plans to do so at the beginning of the research project. The humor and brevity of the video helped engage the students in a discussion of all of the roadblocks that the researcher encountered when trying to gain access to a dataset. In an attempt to build upon the deep reading and analysis work that occupied the first half of the semester, the instructors decided to adapt a graduate exercise from the Oregon Health and Science University called “The Gummi Bear Challenge” *(67)*. This was meant to be a hands-on, low content knowledge activity that would illustrate the many approaches to documenting and communicating data. Unfortunately, aspects of the exercise - that the data themselves were meaningless and that the methods of description was the real point - were too abstract for the students to feel comfortable during the session. Even though the inconsequential subject matter was supposed to reduce cognitive load, it actually created cognitive stress for the students since they were more accustomed to working with tangible, lab-produced data. This is an exercise where the autonomous and self-directed culture of graduate school is an asset and is not easily transferable to the undergraduate classroom.

Analysis of student gains

We have looked at student performance and gains using the JMU Chemistry Information Literacy Test (ILT), the Student Assessment of Learning Gains (SALG), and student course work. We looked at quantitative data from the ILT and SALG and qualitative data from the SALG and student assignments. Data were collected with protocols approved by the James Madison University Institutional Review Board. We found that students made gains in their reading, writing, analysis, and search skills as they progressed from their sophomore year to the end of this course sequence. In spite of our predictions that students would make greater gains in the new course format, no statistically significant differences were observed in the quantitative data that were collected over the last four years. Therefore, all data will be reported in aggregate from the past four years.

As part of the ILT, students were asked to self-assess their knowledge and comfort level with specific reference sources, databases, and information management tools using the following scale: 1 = never used this resource; 2 = used, but not comfortable; 3 = comfortable; 4 = expert. Prior to fall 2015, the

ILT was administered as a pre-test in Lit&Sem I (fall) and a post-test in Lit&Sem II (spring). Not all students completed the semester in sequence so data were stripped to remove students who were not enrolled in the sequence during a single academic year and non-consenting students. In the most recent iteration of the class, the pre- and post-tests were administered during the same semester. Students who dropped the course or did not consent to participate were dropped from the study.

Across all years, a pattern of improvement is seen in student comfort levels, with students reporting greater comfort at the post-test than the pre-test (N = 100: N = 26, Spring 2014; N = 35, Spring 2015; N = 39, Fall 2015). Data are arranged from the largest gains to the smallest gains (Table 3). It is not surprising, given the focus of the Lit&Sem coursework, that the greatest gains were observed from Refworks, Scopus, PubMed, SciFinder, and structure databases *(68)*. Online and printed handbooks, structure drawing programs, and MSDS are covered in earlier coursework, particularly the second year labs.

In the SALG, students self-report on the gains they make in understanding, skills, and attitude, and how elements of the class help their learning. Students select responses from a Likert Scale: 1 = no gains, 2 = a little gain, 3 = moderate gain, 4 = good gain, 5 = great gain. Across the four year average, students report making good or better gains in their understanding and skills. Areas where students reported a gain of 3.5 or better are presented in Tables 4 and 5. Questions that were asked for the first time in 2015 do not have mean data and are noted with “N/A.”

Despite the lack of statistically significant gains reflected in Tables 4 and 5, the authors observed a highly engaged and participatory classroom dynamic in the revised course. Students participated in thoughtful discussions on search strategies and were able to better analyze text as part of their group work. However, when asked to assess their own gains, these students generally underperformed when compared to previous years’ data/methods. Some of this was a result in the change of instructional focus; there was less of a focus on the second semester research paper which led to a decrease in the exploration of modern research in chemistry and less writing. It is possible that these students were more aware of their limitations and thus, did not value the gains that they did make as very great. It is also possible that when asked about applied skills in the abstract, students were not able to quantify the gains that they made. However, one would expect to see these limitations across cohorts. Although beyond the scope of this project, a potential area for research could be in determining if the gains that one could speculate were made because of the redesigned delivery (group work, hands-on activities, data management) were impactful enough to offset the areas where little growth was recorded.

Table 3. Self-reported Comfort Level with Resources (Means and Standard Deviations) of Chemistry Majors at the Post-test and Pre- to Post-test Changes.

	Post-test	**Gains from Pre-test to Post -test**
Refworks	3.11 ± 0.21	1.76 ± 0.20
Scopus	3.23 ± 0.15	1.47 ± 0.19
PubMed	2.65 ± 0.07	1.05 ± 0.11
Structure Databases	2.87 ± 0.04	0.91 ± 0.17
SciFinder	3.13 ± 0.05	0.81 ± 0.17
Google Scholar	2.71 ± 0.32	0.58 ± 0.13
Online Handbooks	2.62 ± 0.11	0.40 ± 0.26
Structure Drawing Programs	2.96 ± 0.20	0.31 ± 0.03
Printed Handbooks	2.52 ± 0.12	0.24 ± 0.24
MSDS	2.87 ± 0.09	0.14 ± 0.19

Table 4. Student Responses to the SALG Prompt, "As a result of your work in this class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following?"

	Mean Score (2012-2015)	Mean 2015
Finding chemical information from online databases	4.4	4.2
Conducting a thorough literature search	4.3	4.0
Reading papers from the peer reviewed literature	4.1	4.0
Finding information that can be found in handbooks and other resources	4.0	3.9
Understanding the broader field of chemistry	4.0	3.8
How studying this subject area helps people address real world issues	3.8	3.8
Evaluating / assessing chemical information	3.9	3.7
Scientific misconduct	3.8	3.7
Data management	3.5	3.7
Using citations	3.9	3.6
How ideas from this class relate to ideas encountered in other classes within chemistry	3.9	3.6
Writing about science	3.7	3.4
Impact factors	3.6	3.2

Table 5. Student Responses to the SALG Prompt, "HOW MUCH did each of the following aspects of the class HELP YOUR LEARNING?"

	Mean Score (2012-2015)	**Mean 2015**
Opportunities to use computers in class to explore databases, etc.	4.2	4.2
Doing hands-on classroom activities	3.8	4.0
Attending class sessions	3.7	3.8
Participating in group work during class	3.7	3.8
Listening to discussions during class	3.8	3.7
In class discussion of research papers	4.0	3.7
In class discussion of student writing (collaborative writing on MOFs [metal organic frameworks])	N/A	3.5
Collaborative group searching activities	N/A	3.5

The SALG also allowed for qualitative feedback from the students by allowing them to respond to a prompt about the class. We evaluated responses from several questions over the four years and coded them according to skills that were mentioned. Our classifications were searching the literature, reading the literature, the structure of the scientific literature, a broader view of chemistry, analysis skills (pull concepts from the literature or apply information learned to searching), organizing information, scientific communication, ethics, and grit (perseverance and effort). A comparison across years is detailed in Tables 6-8; only ideas seen in 10% or more of the responses are included.

Table 6. Student Responses to the SALG Prompt, "Please comment on HOW YOUR UNDERSTANDING OF THE SUBJECT HAS CHANGED as a result of this class."

	2012 (N = 27)	**2013 (N = 31)**	**2014 (N = 35)**	**2015 (N = 39)**	**Average**
searching the literature	52%	71%	40%	39%	50%
reading the literature	22%	32%	31%	21%	27%
structure of the scientific literature	19%	6%	14%	21%	15%
broader view of chemistry	22%	16%	17%	5%	14%
analysis skills	7%	6%	11%	18%	11%
organizing information	19%	10%	9%	5%	10%

Table 7. Student Responses to the SALG Question, "Please comment on what SKILLS you have gained as a result of this class."

	2012 (N = 27)	**2013 (N = 31)**	**2014 (N = 36)**	**2015 (N = 38)**	**Average**
searching the literature	59%	61%	72%	72%	67%
reading the literature	52%	42%	39%	14%	36%
analysis skills	30%	10%	19%	19%	19%
scientific communication	11%	16%	17%	3%	12%
organizing information	19%	6%	17%	0%	10%

Table 8. Student Responses to the SALG Question, "What will you CARRY WITH YOU into other classes or other aspects of your life?"

	2012 (N = 27)	**2013 (N = 31)**	**2014 (N = 35)**	**2015 (N = 38)**	**Average**
searching the literature	36%	48%	51%	60%	50%
analysis skills	48%	19%	40%	37%	36%
reading the literature	28%	23%	17%	17%	21%
organizing information	8%	19%	17%	17%	16%

The data were coded according to what the student mentioned in the comment. When we coded the responses we did not interpret what we thought students meant or what their intention may have been. The student must have used clear language in their response in order to receive the corresponding code. For example, "I know how to go about reading scientific literature, and finding this literature from different sources" was coded as "reading the literature" and "searching the literature." A general response along the lines of "I have learned a lot more, seeing as I knew next to nothing to begin with" was not coded and not included in the dataset. Some student responses generated no codes while others generated as many as four codes. Numbers in the table reflect the number of times that a codable response was provided, not the number of students who gave a codable comment. When the two authors disagreed on coding, they discussed their classification and came to agreement.

When we look at responses to the questions about what students will carry with them (Table 8), we saw modest gains in searching the literature and little change in analysis skills, reading the literature, and organizing information. Of course, we have no data on prior knowledge about what students bring to the course. Students have different prior experiences and a well-prepared student (e.g. a student involved in undergraduate research) may be more likely to report smaller gains. However, the student comments highlight some interesting areas of growth in data management skills. Even though the majority of the students reported that the Gummi Bear exercise was the least helpful course activity, these same students provided the following comments:

> *The gummibear assignment felt like it was too different from all the other assignments. It does have its merits, but it seems like the only thing it teaches is how to make your research more easily available to other researchers.*
>
> *My computer files are becoming better organized by using data management techniques taught in this class.*
>
> *I have implemented a data management plan in my research.*
>
> *I also found the data management techniques helpful, because it makes a lot of sense to keep names of files, versions, etc. in such a way that others can easily track and understand what you have done.*

This cohort provided more data management specific feedback than previous cohorts and it indicates that students are adopting data management ideas. To us, this illustrates that data management is a valuable skill at the undergraduate level but that better delivery methods need to be developed.

The responses in Table 9 allow us to see an increase in positive responses to in-class assignments, group work, class discussion, and repetition of content. In 2014 and 2015, we asked students to "Please comment on how THE WAY THIS CLASS WAS TAUGHT helps you REMEMBER key ideas." Coding methodology was the same as to what was reported above, but student free responses were evaluated on the elements of the course: the in-class assignments, group work, in-class discussions, repetition of activities, and homework (outside of class). The data in Table 9 are consistent with the transition to more in-class activities and group work in the classroom.

Table 9. Student Responses to, "Please comment on how THE WAY THIS CLASS WAS TAUGHT helps you REMEMBER key ideas."

	2014 (N = 39)	**2015 (N = 37)**	**Average**
in class assignments	9%	60%	34%
group work	0%	43%	21%
homework outside of class	31%	3%	18%
in class discussions	9%	26%	17%
repetition of activities	6%	26%	15%

The elements that students highlighted in their free responses in 2015 were much more centered on in-class activities (in-class assignments, group work, and in-class discussions) compared to comments from 2014 (homework outside of class).

> *There was sort of a main idea every class, which was then carried over into the homework. This focus on one important topic each day, and the fact that the class built on previous knowledge, helped cement these key ideas.*
>
> *Key ideas were retained in this class by constantly needing to reuse them for the future assignments. This class does a good job building off of itself.*
>
> *I liked how each class typically had a lecture portion that was followed by time for working out problems and ideas with our groups. This allowed the ideas to really sink in.*

> *It was very applied and relevant. We used it as soon as we learned it and that helped me to retain it. It was also hands on and that made things work out very well.*
>
> *I liked the idea of splitting up groups in this class. It allowed room for discussion among group mates that led to more learning through asking more questions.*
>
> *I liked both the classroom and group setup, as well as the instructional style. The hands-on approach helped me to remember the information better and keep me focused during class.*

We also found some of the comments specific to *how* the class was taught to be especially interesting. One comment in particular illustrates the tension between the pedagogical conditioning that students have experienced up to this point and the team-based and active learning approaches that we tried to incorporate into Lit&Sem.

> *I was not the biggest fan of the teaching style of this class. I think that the powerpoints need to be more structured in terms of explicitly stating what we have learned as we go (eg. a bulleted list of what we should be learning). The exercises helped a lot in learning and, in my opinion, were more beneficial to learning than the actual lectures. However, I do not think this should be the case. Lectures should provide the foundation of learning and the exercises should supplement this and help to create a bank of experience from which students can remember objectives and other facts. In this class, the exercises had more of a 'sink or swim' approach where very little lecture proceeded and then we were thrown into the exercise and had to figure out most of it for ourselves.*

This student felt more comfortable with a highly structured, PowerPoint-driven lecture with exercises serving to supplement didactic delivery. Despite the fact that this student recognized the value of the activities, s/he did not think that this approach was an appropriate teaching strategy. This is consistent with prior observations of student resistance to active learning *(69-71)*.

Both the quotes and quantitative data illustrate the importance of group work in the class. We were encouraged that nearly half of the students mentioned group work; previous groups of students did not comment on group activities. An unstated goal for this course was to provide students with team experiences, and they responded (unprompted) that group work contributed positively to their experience. All but three of the student respondents thought that the group work was a positive aspect of this course. Students frequently commented that working in groups was valuable because of the discussion. A few students even remarked that group work helped them improve their collaboration and team-work skills. Negative responses were from students who prefer to do things by themselves, do not like that the grade is dependent on group members, or had a group with poor dynamics. Students were frustrated when they perceived unequal contributions from group members. Of course, we know that as students transition to professional careers, they will work in many group environments and will need to develop the skills to navigate these situations.

Discussion

On the whole, the redesigned Lit&Sem sequence resulted in positive gains across our learning objectives, although some were not as great as we would have hoped. Although the increased curricular time is a benefit, it is still a challenge to meet our objectives in the time allowed. In the past, we closely aligned the two Lit&Sem courses, expecting students in the first course, in the fall, to have selected the topic that they would write about in the spring semester before the fall semester concluded. With the redesign, we decoupled the content and gave more emphasis to reading and searching in the fall semester and shifted the emphasis on communication and writing to the spring. Students recognize that part of the picture is missing, and commented on the SALG that they want more writing and reading practice. This is a structural element that we need to consider in the Department of Chemistry and Biochemistry and recognize that this will inform curriculum delivery.

The unstructured lecture approach, with active engagement intermixed throughout, allowed for organic discussion and connections throughout the semester. A key element that we did not realize that we were introducing was the emphasis we placed on *why* we teach and discuss the material. Through class participation, we made connections to careers, graduate study, and undergraduate research. The clearest evidence for this occurred after the final exam when a student came up afterwards to tell us that she had not known about a particular area of research before learning about it through the reading assignment *(72)* on our final exam and that she was excited to go discuss this with her family since she thought it would be relevant to her family's farm. The translation of research from an article to a student's personal life may not have been an explicit goal for the course, but it was an extremely gratifying moment.

Some of the cognitive roadblocks we have observed require more attention than a one-credit, one-semester course can give. While students recognize the value of specialized research databases, they have yet to fully incorporate them into their workflows, nor can they articulate the quality or selectivity of the resource. It is difficult to retrain a lifelong habit of using Google, which has been good enough for the majority of their information needs, in a single semester. The ability to evaluate authority and determine trust are critical skills that are difficult to develop in a culture where there are "two sides" to the scientific treatment of topics like evolution and climate change. In spite of these challenges, the repetitive assignments we incorporated into our most recent iteration of the course have resulted in students using research databases more frequently to complete the final search assignment of Lit&Sem I. More research on student search strategies, and the instructional methods that produce change to more expert practices are needed.

Both the library and chemistry faculty members have benefitted from the close collaboration that has resulted from this course. Each brings a disciplinary focus - chemistry and data information - to this course. Only as a team are we able to identify the skills that our students need in an evolving information landscape, without overwhelming our students with the information that only experts need to know. We are able to put chemical information literacy standards into the broader landscape of data information literacy, provide a broader perspective on understanding and applying criteria for evaluating the authority and appropriateness of a document or information source, and demonstrating critical thinking by evaluating information and following a logical path of inquiry *(2)*, while developing an ability to manage ever increasing amounts of information. Our assessment program helps us to inform instruction (content and methods) and appropriately target interventions to achieve these goals.

Information has many forms. Traditionally, information literacy for chemists has referred to chemical properties and literature. Increasingly, data management and reuse are critical skills for all researchers, including students. As data take on a more prominent role as a primary source of information, and good data management becomes more important to the reuse of data, the ways in which researchers and librarians engage with the data information literacy competencies will evolve with the research environment. We have taken the first step towards addressing the ever-broadening landscape of information literacy in our course and we look forward to seeing how the community responds to these changes and how it affects teaching information literacy across the undergraduate chemistry curriculum.

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