Cell Biology Education
Vol. 4, 335–343, Winter 2005

Article

Information Literacy in Biology Education: An Example from an Advanced Cell Biology Course

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Received April 20, 2005; Accepted May 17, 2005
Monitoring Editor: Erin Dolan

Information literacy skills are critically important for the undergraduate biology student. The ability to find, understand, evaluate, and use information, whether from the scientific literature or from Web resources, is essential for a good understanding of a topic and for the conduct of research. A project in which students receive information literacy instruction and then proceed to select, update, and write about a current research topic in an upper-level cell biology course is described. Students research the chosen topic using paper and electronic resources, generate a list of relevant articles, prepare abstracts based on papers read, and, finally, prepare a ''state-of-the-art'' paper on the topic. This approach, which extends over most of one semester, has resulted in a number of well-researched and well-written papers that incorporate some of the latest research in cell biology. The steps in this project have also led to students who are prepared to address future projects on new and complex topics. The project is part of an undergraduate course in cell biology, but parts of the assignments can be modified to fit a variety of subject areas and levels.

Keywords: information literacy, undergraduate education, cell biology, computer databases

INTRODUCTION

An awareness of the current literature is as important to scientific research as the careful design of adequate controls. This is a lesson too often learned the hard way, and too often, the lesson is learned after the waste of valuable time. Virtually every active researcher has had a ''stroke of genius,'' only to find that the idea has been investigated by someone else before, and the results have been published. It is always better to discover that the work has already been done through a search of the literature than to discover this fact after weeks, months, or years of effort have been expended.

Unfortunately, students do not often realize the role that the literature plays in the scientific research process, and instructors do not always emphasize adequately the importance of the literature search. Even when aware of the literature, the students often find the papers difficult to understand and digest. In part, this is because the style of scientific papers is very different from that of most other reading, including textbooks. Journal articles can also be difficult because they are intended for those well versed in the topic, not for those who are largely ignorant of the methods, results, and implications of a particular line of research. It is important to introduce the scientific literature to students as early as possible. Greater understanding comes with greater familiarity; an awareness of how the research is done can assist in an understanding of the concepts found in texts and lectures.

In the old days, most biological and biochemical literature could be found through the cryptic and laborious searching of a few major print indices (e.g., *Biological Abstracts, Chemical Abstracts, Index Medicus, Biological and Agricultural Index, Science Citation Index*). Now, although some print sources are still available, there are a number of bibliographic databases available electronically, which make the searching more successful and less time-consuming. In order to be adequately aware of the literature available, it is equally important for students to be aware of the search methods. While it might be nice in theory to leave the searching to the bibliographic professional (librarian), this is not usual in current practice. End users are most often the ones doing the searching because they are more aware of the subtle variations on the theme of a particular research area and the synonymy in referring to that research. Such awareness is

DOI: 10.1187/cbe.04–12–0060
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critical for a completely successful search, at least until we have available truly context-oriented, natural language search engines for the databases.

Information literacy is the ability to locate, use, and evaluate information (Young and Harmony, 1999). The ready availability of information through bibliographic resources and the Internet, the latter often of questionable reliability, makes instruction on locating and evaluating the information resources a critical need in higher education. Information literacy instruction in biological science courses helps establish a pattern of lifelong learning and critical assessment that will serve students during and beyond their undergraduate education (Association of College and Research Libraries, 2000, 2001; Souchek and Meier, 1997). The demonstration of a cooperative approach to information access, involving both the researcher and the librarian, also models the kinds of behavior that the practicing biologist can use in the future to optimize individual search efforts.

Information literacy instruction is recognized as an essential part of an undergraduate education (Young and Harmony, 1999). At the same time, students seem ill-prepared to function in a world that has become increasingly dependent on the rapid acquisition and assessment of information. Maughan (2001) showed that an average of 60% of students in eight social science and humanities disciplines received poor or failing scores in an assessment of basic information literacy skills; there are few previous data that would allow a similar or different assessment for students in the basic sciences. Recently described information literacy projects in chemistry, pharmacy, the physical sciences, and a few other disciplines have appeared (Brown, 1999; Calderhead, 2000; Kirk *et al.*, 2000). The literature on information literacy in the biological sciences is still somewhat meager. Recent articles focus on the introductory level (Mulnix, 2003), while some older articles have become somewhat antiquated with the occurrence of dramatic changes in technology and the shift from a philosophy of bibliographic instruction to one of information literacy (Brundage and deFur, 1989; Jacobson and Wilson, 1991; Kinch, 1984; Nussbaum, 1991; Souchek and Meier, 1997).

This paper describes a series of assignments that have been developed and used in a college senior-level cell biology course. While information literacy can be taught in a stand-alone format (Donnelly, 2000), numerous experiences suggest that the material is better understood and is more relevant for the student if it is performed in the context of a specific, course-related task (Jacobson and Wilson, 1991; Souchek and Meier, 1997). The series of assignments are designed to take the student through the various stages of literature awareness and bibliographic searching. They yield, as well, an end product that illustrates the student's grasp of the subject matter and reinforces the research nature of this highly active field. These assignments also serve as a good example of the teaching collaboration that can occur between the science specialist (instructor) and the information specialist (librarian).

The assignments direct the students through the processes of topic selection and refinement, topic searching, reading, and understanding a subset of the papers identified as relevant; the preparation of abstracts; and the writing of a position paper on the content of the papers read (Table 1). While all of the activities should occur in the development of any student paper, students usually do not understand that process well. The assignments are therefore divided in focus and time to force the student to accumulate a literature base and understanding over the course of a semester. The result generally has been well-researched papers that demonstrate the student's true skills in handling complex information. These assignments also address many of the competency standards in the "Objectives for Information Literacy Instruction" (Association of College and Research Libraries, 2001).

Assignment 1. Topic Choice and the Literature Update

A number of sources can be used to generate a list of topics from which students can choose. One would be the instructor's knowledge of the field and personal interest in the subject. However, such topics should be checked for feasibility by constructing searches and ensuring that adequate literature "hits" are generated (Jacobson and Wilson, 1991). Low hit numbers are fine for Ph.D. candidates who want to ensure that an idea is novel, but poor yield is very frustrating to an undergraduate trying to understand a new topic.

I have used two major sources for a topic compilation. Originally, *Current Contents Life Sciences* (Institute for Scientific Information, Philadelphia, PA) was used for its Citation Classics section. These are papers chosen for a high number of citation references since their publication for the field or journal. These papers have an advantage for topic list generation in that there are a number of subsequent articles that refer to this original article, and so, presumably, the topic is one of active investigation. These articles also tend to be less than 5 yr old, so the topics are of current interest, rather than being a classic method.

More recently, a similar listing of articles occurred in *The Scientist* (Philadelphia, PA). These are referred to as Hot Papers and are, similarly, articles that have been frequently cited and are current areas of active research, and many are relevant to the topic of the course, cell biology. Over the course of the year, cell biological citations are collected from either source. If there is a particularly hot area of research (e.g., apoptosis, cancer, neurobiology), I am sure to list more than one paper from which the students can choose as long as there is a clear way to derive different topics from them. The articles are compiled into a topic choice list from which the students may each select one for further investigation. I encourage students to do some research in the field of the paper they have chosen before officially selecting it. Once students have chosen their papers, those papers are not available to others, and the students cannot change their minds about their choice. This is handled on a "first-come, first-served" basis with a specific time for the beginning of sign-ups. Since students are told that they may not get the paper of first choice and are encouraged to have at least one backup paper from the list, there have seldom been difficulties in the selection process. From the paper selected, a topic statement is formulated. The topic statement must be related in some way to the paper chosen, but it cannot be the title of the article verbatim. This ensures that the student is gaining an understanding of the area while the search process gets under way.

Each student receives instruction about print and electronic indexing sources for their searching. This instruction is provided by one or more members of the library faculty. As electronic sources have become more affordable and avail-

Table 1. Summary of the progression of topic development and writing

Task	Task title	Description	Graded
1	Selection of topic	The student tentatively chooses a topic paper from the list provided with one or more backup articles.	No
2	Preliminary search	A preliminary search is conducted using sources with which the student is familiar.	No
3	Information literacy instruction	The student receives formal instruction on bibliographic resources (electronic and paper).	No
4	Topic paper selection	The student makes the topic paper choice at the time assigned.	No
5	Preliminary topic choice	The student formulates the preliminary topic statement and performs the search once approved by the librarian.	No
6	Topic refinement	The topic statement is refined, and additional searches are performed using all of the available resources. If necessary, the student seeks guidance from the instructor on topic development.	No
7	Update list (assignment 1)	The student develops a list of 30–50 articles that updates the topic of the topic statement (assignment 1; due about midterm).	Yes
8	Preparation for abstracting	Five articles are chosen from the update list, and these are read for clear understanding.	No
9	Abstracts (assignment 2)	Abstracts are written for the five articles chosen (assignment 2; due 2–3 wk after assignment 1).	Yes
10	Outline of final paper	The student reads additional papers and formulates the outline of the final paper using the headings provided (“Background,” “Principal Approaches,” “Present Knowledge,” “Future Directions,” and “Conclusions”).	No
11	Final paper (assignment 3)	The student writes the final paper (assignment 3; due at the end of the semester). If necessary, the student seeks help in writing from the instructor (science understanding) or the Writing Center (grammar, syntax, and/or sentence structure).	Yes

able, much more of the instruction is computer based. At a minimum, each student is instructed about how to construct searches in *Biosis, MEDLINE, Agricola, FirstSearch,* and *Science Citation Index.* After the student receives both in- and out-of-class instruction on search structures, syntax, and search logic, each prepares a model search for librarian approval. This ensures that the student understands how to search the databases efficiently and is likely to obtain useful results. Prior to this instruction, many students are tempted to construct a search using the exact phrase of the topic statement (as initially conceived), without thinking about the probability of finding that exact phrase or being concerned with synonymy issues.

The students are required to produce a comprehensive update of the chosen topic for the past 2 yr. This is demonstrated through a listing of 30–50 articles, which are the products of their search effort. On the basis of the observations by the librarians and me, most students quickly learn what are good and what are bad topic statements. If the topic is too broad (“cancer” as the absurd example), the citation list is impossibly long. If the topic chosen is too narrow, the list is too short. If students are having difficulty formulating a topic statement, making the topic appropriate for the assignment, or interpreting the articles retrieved, I encourage them to see me for a discussion to resolve the difficulties.

I have chosen the range of 30–50 articles because this seems like a reasonable bibliography from which to start an understanding of a topic and would be about the point at which graduate students start as they begin research projects. The students are not required to read all of these papers, but they are required to read at least the abstracts to ensure that the articles fit the topic. The citation list is not limited by language; it is also not restricted by organism unless this is part of the topic statement. The students expand or constrict their topic statements as necessary to achieve the desired results. All bibliographic sources taught are used to ensure that the list is complete for the topic. I place great emphasis on a comprehensive update, so the searching effort has to be thorough and the topic well stated. The emphasis on a clear topic statement and the iterative refinement of the topic gives practice in careful work, clear thinking, and precise writing.

The list constitutes the first assignment. The students are assessed on the clarity of the topic statement, the applicability to the field of cell biology, and the thoroughness of the search. I construct searches based on the student’s topic statement and assess whether the lists are reasonably complete. If they are missing one or two articles that I find, this is not a problem because I am more skilled in constructing the searches. Points are deducted for additional missing articles. I can generally construct the search and assess the required elements of the list in less than 30-min per student citation list. It is not my intention in grading the assignment to construct the one “perfect” search that would yield all relevant articles. The search I construct is a sampling of the student’s topic that captures at least some of the articles the student should have found. I try to construct a search that yields at least 10 relevant articles and then determine how many of those 10 the student has also found. If I find fewer than 10 relevant articles, I construct another, related search to increase the number of articles found. Generally, several searches of multiple databases are required to construct the complete list; however, I feel that this is beyond the scope of the grading.

The students must also adhere to a prescribed bibliographic format. Although many acceptable formats are available, I specify one because it makes it easier for me to assess, and the students are given the idea that each journal specifies a format and is very strict about adherence. The format that I have used is given in Ambrose and Ambrose (2002); this handbook is also used for other aspects of the course. The topic article list is presented in the same format so that students have numerous examples of the reference format.

Occasionally, two students may choose very similar topics based on different, but related, papers. This becomes clear during the grading of assignment 1. However, there have always been enough differences in the specific focus of the topics and in the development that it is clear that each student is working independently. I allow this development of similar topics unless it is clear that there is too much overlap. This could be a greater problem with a much larger class size (>30).

In this first assignment, students are expected to read and understand a lead paper that will guide them in the formulation of a topic for investigation. They must then develop a topic statement, search that topic using the electronic and paper bibliographic sources, read abstracts, and determine whether the papers obtained are relevant to the topic; conduct additional searches; refine the topic; and finally prepare the bibliographic listing and chosen topic statement using a specified format. Some form of this project has been done in the undergraduate cell biology course since 1989. In the last 8 yr, 168 students have taken the course and completed this assignment. Of these, 49 (29%) have achieved a grade of "A" (90%+), and 57 (34%) have achieved a grade of "B" (80%+). This means that 63% of these students have accomplished the goals of this assignment, with the most usual problems being a failure to adhere strictly to the specified format and conducting a search that was partially incomplete. For this first assignment, 37 (22%) achieved a grade of "C" (70%+), 23 (14%) achieved a grade of "D" (60%+), and only seven students (4%) failed this assignment over this time period. This assignment is introduced in the first week of class and is generally due about the midpoint of the semester. It is given a weight of 50 points from a total for the course of about 625 points.

The size of the class has varied over the years, with more students taking the course now than 10 yr ago, but the class size has been in the range of 20–30 students over the past 6 yr. The students have satisfied a computer proficiency requirement in the first year of the curriculum, but this does not focus on information literacy skills. The literature and English courses similarly do not focus on science writing, but the students have generally read at least a few papers from the literature in several of the courses they have taken from the biology curriculum. Most of the students in the course are biology or microbiology majors, with smaller numbers of biochemistry students, for whom the course is required. The course is also required for the teacher certification students, who are generally also biology majors. There are also occasionally students from other majors, including pharmacology/toxicology, environmental science, chemistry, and pharmacy. The biochemistry students, generally less than 25% of each class, have taken one semester of Literature of Chemistry, which exposes them to the bibliographic skills required of practicing and researching chemists. Almost all of the students have had at least one semester of biochemistry prior to taking this course, and most have had biology courses with laboratory work above the level of the freshman sequence. Such courses include microbiology, anatomy and physiology, advanced microbiology, and genetics. At least some of these courses include reading, dissection, and analysis of papers from the recent literature. Practice in reading the literature is also introduced in the freshman biology sequence of courses.

Assignment 2. Abstracting

Some of the most difficult skills that students in science need to learn to do are to read, understand, and interpret the scientific literature. The second assignment in this series provides practice in assessing the content of papers related to the chosen topic. From the list of articles found in the first assignment, the student must choose five articles to read and understand. It would be unreasonable to expect a thorough understanding of all of the articles on the list, but each student should be able to grasp the content of at least a few of them. Since there are 30–50 articles from which to choose, five is a reasonable number.

The student reads the chosen articles and prepares a written abstract of the contents. The abstract must convey a sense of what was reported in the article and show, implicitly or explicitly, how the article relates to the chosen topic. Again, Ambrose and Ambrose (2002) provide guidance on how to construct abstracts. I offer a formula that will serve most purposes. The abstract consists of four to eight sentences: one to two sentences each for the Introduction, Methodology, Results, and Discussion/Conclusion sections. Clear, concise writing is the basis for any good abstract.

A significant challenge for the student in preparing the abstract is the temptation to plagiarize what has already been written. Each article typically contains an abstract written by the authors to summarize the work presented. I emphasize that the students cannot plagiarize; the ethical use of resources is one of the goals of information literacy instruction (Association of College and Research Libraries, 2001). Guidance is given on what is meant by plagiarism to include both direct copying and parallel plagiarism. I stress that plagiarism is a form of cheating and will be dealt with as such. The Writing Center provides much guidance on what does and does not constitute plagiarism (Gale, 2000). I do not feel that it is unreasonable to expect students to summarize, in their own words, the content of a few articles. I urge them to read the articles without referring to the abstract, write a summary of what they have read, and then go back to the published abstract to ensure that what they have written is not overly similar. The specific language of the topic is fine, especially for the Methods section, but the sentence construction and linking words should be unique.

In assessing the abstracts, emphasis is placed on scientific concepts and good writing. Can the content of the article be understood from what the student has written? Grammar and science logic are equally stressed. I do not generally find it necessary to read the articles that are abstracted. This is partly because I am generally familiar with the literature of cell biology. Also, the student is being assessed on whether the abstract makes sense. If the abstract is not logical or sensible, then the grade reflects this. After assessing the writing and content, I somewhat randomly pick one or two of the abstracts of each student to assess for plagiarism. This

can rather quickly be done by searching the article in one of the available databases. If one of those chosen is questionable, I check a second to see if this is a general pattern by this student. I always tell the students that I can generally distinguish a student abstract from one written by the original researchers. A high degree of sophistication in writing and an apparent understanding of the content are clues to plagiarism, but I am sometimes pleasantly surprised that a very good abstract has been written, and it is unique from the published one. On occasion, the student-generated abstract is better than the published one. I spend time emphasizing the importance of scientific integrity, stressing that I will check for plagiarism and that there are penalties for being found guilty of plagiarism. Since introducing these elements into the assignment description, I have had relatively few problems in this area.

In this second assignment, the students must choose papers that can be understood to the point that they can be summarized clearly. The emphasis is on good writing skills and a clear presentation of a summary of the background, methods, data, and conclusions. Over the past 8 yr, students have tended to do better with this assignment than with the citation list assignment. Of the 168 students reviewed, 86 (51%) achieved a grade of "A," 49 (29%) achieved a grade of "B," 17 (10%) achieved a grade of "C," 7 (4%) achieved a grade of "D," and 9 (5%) received a failing grade. Of the students with failing grades, only three have been found guilty of some form of plagiarism. The usual problems with this assignment included lack of clarity in the writing, poor sentence structure, lack of data or methodology, and an insufficient number of abstracts. This assignment is due 2–3 wk after the first assignment and, like it, also is given a weight of 50 points (10 points per abstract).

The better performance on this second assignment may reflect that students generally have had more practice with writing assignments prior to the college senior year than they have had with literature-searching assignments. It may also be true that the students better understand my expectations and grading following the first assignment. I always make sure that I give them the results and feedback on the first assignment prior to the due date of the second assignment (usually at least a week before); this gives the students some time to incorporate my comments into their preparation and revision of the second assignment. I grade this second assignment in less than 2 wk. This gives the students ample time to incorporate my comments on the writing and interpretations into the final paper.

Assignment 3. The Final Paper

Once the students have their bibliography and an understanding of the literature on the chosen topic, they put together a paper to demonstrate what they have learned. Rather than just a standard term paper, I have them write a **final,** "state-of-the-art" paper that addresses specific issues. The required sections of this paper are "Background," "Principal Approaches," "Present Knowledge," "Future Directions," and "Conclusions."

The "Background" section provides the reader with an introduction to the topic. What is the importance of this research area? What applications are currently available or foreseen? What are the implications of a maturation of this field of investigation? The student is also expected to state the major hypotheses that researchers in this area are currently investigating.

"Principal Approaches" is more or less a methodology section. However, because most methods writing by students at this point in their education has been the "so many mls of this and so many grams of that" variety typical of laboratory reports, I tell them that I want something very different. What are the "kinds" of experiments that people do? I want the major methods employed without all the detail of how a single experiment is performed step by step. For example, do all of the researchers use western blots after polyacrylamide gel electrophoresis? Is immunofluorescence microscopy with image analysis a major approach? Students often find this to be the most challenging section because they are tempted to give the experimental details paper by paper. I tell them to pick out the common features of the research area, state that these are the usual approaches, and then detail the major deviations or modifications seen in one or more laboratories. I also spend class time talking about what constitutes "kinds of experiments" compared with specific details of experiments. As is true for the other two assignments, students can also make individual appointments to discuss specific problems.

The "Present Knowledge" section outlines the information that is contained in the literature that the student has researched. This section answers the question, "What do we know?" The student presents the current state of knowledge for the chosen topic and the discoveries or experiments that have led to the present understanding; apparent contradictions in the research results are identified. This is somewhat analogous to a Results and Discussion section in that the student develops the relationship between the hypotheses presented in the "Background" section and the research data presented in the "Present Knowledge" section. I encourage them not to cover several papers sequentially but to synthesize a view of the results that have been obtained in various laboratories and show how they fit together into a cohesive picture, if such an assessment is, at present, possible. This is most often the most lengthy and detailed section of the paper.

The next section of the paper is "Future Directions." In this section, the students develop ideas from their understanding of the literature to answer the question, "What is (are) the logical next step(s)?" Authors will often suggest avenues for additional research that they may or may not be actively pursuing. It may also become clear that a new methodology or a new interpretation of data will open the field to more productive efforts. It may have become clear that further replication is necessary or that older interpretations need to be abandoned in the light of new findings. Pathways to the resolution of contradictions are discussed, including speculation about scenarios that may develop, depending on the outcome of proposed studies. It is in this section that the student should develop an awareness of the dynamic nature of science. Some students who are tempted to wait until "it is all known" to learn a field may come to an appreciation that science is an ongoing process that builds new information on known foundations.

The "Conclusions" portion of the paper summarizes the previous sections and gives the "take-home message." The main ideas, hypotheses, approaches, findings, and interpretations are restated, along with the most likely or potentially most productive future studies.

In the introduction to the final paper assignment, the students are instructed to make use of electronic resources, especially Web pages and e-mail, to ''update their update.'' In other words, they have already used the current literature to update the topic for the previous 2 yr (the literature list from assignment 1). They are reminded that it takes anywhere from 1 to 3 yr to get research data information into print after it has been obtained in the laboratory. Even recent reviews will give a somewhat distorted view, because they will contain the same recent literature supplemented with whatever recent data the author may have. The only way to become even more current in the topic is to be in contact directly with the researchers working in that field. The only effective way for an undergraduate student to do that is to make use of the direct communication forms of electronic resources, such as e-mail and laboratory Web pages. The students are encouraged to e-mail principal researchers in their chosen field, but only after the students have become rather knowledgeable about the available literature. A few years ago, e-mail was very effective for getting reasoned responses from research directors or their immediate coworkers. I was sometimes very surprised at the amount of detailed data that postdoctoral or graduate students would send out, sometimes from experiments run just the day before. More recently, the number of responses has sharply declined, probably because the novelty of e-mail is gone, as researchers have become more accustomed to it as a very normal route of research communication. Also, many researchers may have simply run out of time to reply to every inquiry. For instance, hardly a day goes by that I do not receive an inquiry from a prospective postdoctoral or graduate student. At the same time, the number of laboratory Web pages has increased enormously. Students can get current hypotheses, current research approaches, some recent data, theoretical overviews, and, sometimes, even preprints of literature not yet published.

It is in the ''Present Knowledge'' and the ''Future Directions'' sections of the paper that the students make use of this new information. These updated ''references'' have to be interpreted more cautiously, because they have not gone through the peer-review process, but such sources can be very valuable for ideas about where the research is heading, what work has been abandoned or modified, and what avenues are proving to be most productive. In fact, so much good information is now available in laboratory Web pages that I have had to limit the number of references to unreviewed, electronic resources to about 10% of the total number of references.

Often, term papers written by undergraduate students are based on only one or a very few original articles, if not largely based on a single review article. To encourage the synthesis of ideas and content, I require that the students use at least one-half of the articles listed in the bibliographic list generated in assignment 1. I also encourage them to use additional articles found in subsequent searches, older reviews, and key papers and a minimum of two electronic sources. It is common for a student paper to have 20 or more references.

The paper is graded much as a major paper would be. Not only are the science and interpretation evaluated, but also the construction and adherence to grammatical norms. I developed a grading rubric (Table 2) and make this available to the students well before the paper due date. It usually takes between 30 min and 1 h to grade a typical paper, but it is some of the most enjoyable reading that I have had in my teaching career. Two examples of unedited student papers are available at http//is.usip.edu/bs461/samples.html. Because the students have been forced to become thoroughly conversant with the chosen topic, even the weakest paper is well above the quality of the typical term paper. The students have had the opportunity to develop science acumen and to develop writing skills at a critical point in their education. The expertise developed during these assignments has often led the students to be offered positions readily in first-choice graduate programs or technical positions.

This final assignment of the semester-long project is generally due in the last week of classes. This schedule gives the student maximum time to develop the thinking behind the paper and construction of the writing. It does not, however, allow time for constructive feedback. I do encourage students to make use of the Writing Center to resolve problems of sentence construction, clarity, grammar, and organization. And, feedback on the previous two assignments does give each student an idea of my expectations and specific criticisms on formatting, grammar, data interpretation, and formulation of conclusions. It does not, however, give feedback on data presentation (figures and tables), which is notably weaker for many students in the final paper than other aspects. This is an area for future development of the assignment.

This third assignment is given a weight of 150 points in the 625-point course total. Analysis of the students doing this assignment from 1997 to 2004 shows that 57 (34%) achieved a grade of ''A,'' 67 (40%) achieved a grade of ''B,'' 28 (17%) achieved a grade of ''C,'' 6 (4%) achieved a grade of ''D,'' and 10 (6%) failed. Further analysis of this failing group shows that three committed plagiarism and that five failed to turn in the assignment at all. This assignment requires a thorough understanding of the topic chosen, an appropriate selection of articles to include in the review, a clear presentation of methods and data, an interpretation of those data, and an ability to write clearly. The very high success rate, 74% with a grade of ''A'' or ''B,'' suggests that the students develop these skills much better than is true for a typical ''term paper'' assignment. If these grades appear rather high, it should be noted that this is typically taken by senior-level students, so that very weak students are no longer in the curriculum.

It is interesting that the topics chosen by students often mesh very well with the material covered in the lectures. This is not actually surprising, since the class focuses more on the current activity in the cell biology field than in the more classic structure-function topics, although some of this is also covered. It is also interesting when a student chooses a topic that is quite different from the lecture material. The students have the course outline and topics at the time that they are making paper topic choices, so it would be easy to decide whether additional material on the topic will be coming in the course and approximately when that content will be delivered. Students can often add to the discussion of a topic on the basis of their own reading.

Concluding Remarks

This series of assignments (with modifications in the depth, number, and kind of electronic and bibliographic resources available and the nature of the final product) has been used every year in a senior-level cell biology course since 1986.

Table 2. Grading rubrics for the writing assignments

A. Bibliographic update (assignment 1)

Grade	Criteria
"A"	A total of 30–50 articles; no more than one to two missing articles compared with the instructor's search; articles clearly related to topic statement; topic statement clear; citation format followed exactly; spelling correct; bibliographic list clearly meets the intent of the exercise
"B"	One or two articles fewer than 30 in list; three to four missing articles that are relevant to the topic; some articles not clearly related to the topic; topic statement wordy, ambiguous, or unclear; citation format generally followed but is not exact or consistent throughout; spelling mostly correct
"C"	Fewer than 28 articles in list; five to six relevant articles missing; some articles not related to topic; topic statement general or unclear; citation format inconsistent or frequently not as specified; frequent spelling errors
"D"	Fewer than 28 articles in list; seven to nine relevant articles missing; reason for inclusion of several articles unclear or clearly expands topic beyond the statement scope; topic statement overly general, superficial, or contrived; citation format very variable, inconsistent, and not as specified; spelling poor
"F"	At least 10 relevant articles missing compared with instructor's search; articles not formatted or compiled into a clear list; topic statement missing or uninterpretable; citations compiled merely by cutting and pasting without formatting; spelling poor

B. Abstracts of selected papers (assignment 2)

Grade	Criteria
"A"	Five abstracts; abstracted papers clearly relevant to the topic; abstracts clearly constructed, contain all elements of paper; data and methodology presented; grammatically correct; precise, clear wording; spelling correct; abstracts, paper choice, and construction clearly meet the stated goals of the exercise
"B"	Four to five abstracts; one or two of the abstracted papers are not clearly relevant to the topic; abstracts are mostly clear and well constructed, but one or two lack paper elements (usually Methods or Results); inclusion of quotation when not necessary; some grammatical or spelling problems, but generally correct
"C"	Four to five abstracts; more than two abstracted papers not relevant to the topic; topic statement missing; some abstracts not clear, or organization is mixed or incomplete; some to most of the abstracts lack Methods, Results, or DIscussion; frequent quotation of sentences or passages; several grammatical and spelling problems
"D"	Three to four abstracts; more than three abstract papers not relevant to the topic; topic statement missing; abstracts unclear, confusing, incomplete; all or nearly all of the abstracts lack required elements; quotation used excessively; frequent grammatical and spelling errors
"F"	Fewer than three abstracts; none of the papers abstracted seem to be related to the topic, or no clear topic discernible from paper selection (if topic statement missing); no adherence to format of an abstract; excessive grammatical and spelling errors; plagiarism

C. "State-of-the-art" paper (assignment 3)

Grade	Criteria
"A"	Arguments clear and complete; content accurate, thorough, complete, concise, and coherent; sentence structure complete, clear, and grammatically correct; quotation infrequent and only when essential; spelling accurate; paper format followed precisely; references always used when needed; reference style in text and "References" section consistent, correct; figures and/or tables used when appropriate; paper goes well beyond minimum expectations
"B"	Arguments complete but not entirely clear; content accurate, concise, and coherent but incompletely cover the topic; quotation occasional but not always necessary; sentence structure mostly correct, with occasional errors; spelling mostly accurate; paper format followed precisely or very nearly so; references seldom missing when needed; reference style mostly correct but lacks consistency, or there are occasional errors; figures and/or tables not used when they would help clarify the argument, somewhat confusing or inappropriate, or somewhat sloppy
"C"	Arguments nearly complete or lack clarity; content inaccurate, wordy, illogical, or incomplete; paper contains several quotations that could have been easily paraphrased by the student; sentence structure and spelling show regular errors; paper format nearly correct but not followed precisely; references missing; reference style inconsistent, incorrect, or with several errors; figures and/or table missing, poorly incorporated, inappropriate, or significantly sloppy
"D"	Arguments and content incomplete, poorly worded, unclear, and illogical; paper lacks focus; frequent quotations that take place of the student developing the sentences and ideas; many spelling and grammatical errors; paper format mostly not followed; many missing references; reference style very inconsistent, mostly inaccurate, or misleading or references rarely used; very sloppy figures and/or tables; paper generally lacking in coherence or style or is a paraphrased "cut-and-paste" attempt
"F"	Plagiarism; paper very sloppy, incomplete, inaccurate, unclear; no attention to any formatting requirements; incomplete paper; no references used; no real attempt to construct a worthy paper

Over that time, the final outcome has varied from a brief position paper, a summary of e-mail responses from researchers (abandoned when the response rate became too low to be meaningful), additional abstracting, a grant proposal, and the current state-of-the-art paper. Of all of these, the grant proposal was the most intimidating to the students, to the point that it became destructive to the learning process. Most students did not feel adequately prepared in the methodology to propose reasonable experiments and research approaches. The current product has been the most rewarding to me as an instructor, results in a reasonable paper even from weaker students, and is often fun to read. It has been gratifying the number of times that students have returned to tell me that the knowledge they learned in the project was instrumental in securing them the graduate program or work position that they wanted. Many students have also commented that the bibliographic skills gained have allowed them to impress employers and mentors as they are required to provide recent literature overviews for a new or continuing area of work.

An added benefit of these assignments is that computer phobia, which, however surprising, still persists among a significant proportion of students, is reduced. These students' fears of causing harm to the computer or of being made to appear stupid by the computer decrease as they gain experience with the computers as a work and information tool.

The entire group of assignments as described here is probably most appropriate for relatively small, upper-level courses. However, an assignment similar to one or more of the specific assignments described here could be incorporated easily into a wide variety of courses. For example, picking the main theme or topic of a paper, or formulating new topics from an assigned paper, would also be a valuable class exercise that could be applied to classes of any size as either individual or group assignments. With an appropriate selection of topic papers, the bibliographic list, perhaps with added annotations and less emphasis on ''completeness,'' could be developed as an assignment for almost any scientific field. Practice in abstracting, whether from a researched topic or a single, assigned paper, could augment the science-writing practice in courses at any level of instruction. This entire project could also be adopted, over the course of one or more years, as an integral part of a senior thesis or student research course.

The term paper is an often-used element of many courses. However, all too often, little instruction is given other than general format, length, and topic. While most researchers and educators would recognize that any well-researched term paper should include all of the steps described for this series of assignments, breaking the assignment specifically into those steps has helped the students realize the importance of formulating an appropriate, well-defined, and clearly circumscribed topic; developing the information base on which to base the writing; and formatting the writing in a clear, organized, and logical manner.

Whether the biology student plans to pursue a higher degree through graduate studies, teach, or pursue technical positions in industry, the ability to find, read, and interpret the scientific literature is crucial. Protocols from the literature must be evaluated and followed, and familiarity with the literature makes that task more readily achievable. Teachers can quickly update themselves with knowledge of a new field for the classroom. Medical students also gain in that they can find and interpret papers relevant to diseases under study; they can also find and read the basic science literature that underpins the medical interpretation. The series of assignments described here provides each student with a strong information literacy skill set using a variety of sources. This better prepares them to be more quickly productive as they continue beyond their undergraduate education.

A logical, progressive, content-oriented approach to information literacy instruction in biological science courses is a rewarding experience, both for the immediate product produced and for the skills that each student obtains in the process. All persons who are interested in pursuing these ideas for their own classes are encouraged to view the detailed assignment instructions, topic list, and library certification documents at the course Web page (http://is.usip.edu/bs461/).

ACKNOWLEDGMENTS

I gratefully acknowledge the financial support of the National Science Foundation (NSF DUE-9650207), which allowed the purchase of computers that students use in completing these and related assignments. I also thank Mignon Adams, director of Library and Information Services, J.W. England Library, for a critical review of the manuscript and her unfailing support. I am indebted to the several librarians who have assisted in these assignments, but I especially thank Leslie Bowman, Judith Hesp, and Sue Brizuela for their skillful assistance and encouragement.

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