Many undergraduate and graduate students understand neither the process of scientific writing nor the significance of peer review. In response, some instructors have created writing assignments that teach or mimic parts of the scientific publishing process. However, none fully reproduced peer review and revision of papers together with the writing and publishing process from research to final, accepted draft. In addition, most have been instituted at the graduate rather than undergraduate level. We present a detailed method for teaching undergraduate students the full scientific publishing process, including anonymous peer review, during the process of writing a "term paper." The result is a review article in the format for submission to a major scientific journal. This method has been implemented in the course Cell and Molecular Biology for Engineers at the University of Virginia. Use of this method resulted in improved grades, much higher quality in the final manuscript, greater objectivity in grading, and improved understanding of the importance of peer review.

**Key words:** undergraduate; cell biology; molecular biology; referees; term paper; writing assignments

In addition, many students do not understand the process of scientific writing nor the significance of the peer review process. It has been reported that 92% of baccalaureate nursing students engaged in a major written assignment indicated that they did not know how to go about getting an article published (9). This has led faculty to create writing assignments that mimic or teach parts of the publishing process. Some were limited to teaching different strategies for peer review (3). Others required graduate students to write papers strictly according to the guidelines of a major journal (1). Some further required students to first write a "letter of inquiry" to inform the instructor of the subject matter (9). Still others included an open review of students’ papers by their peers (5). Each of...
these methods demonstrated surprisingly strong results as gauged by student evaluations and publication rates.

It has been reported that peer editing of papers among undergraduate students is a useful tool not only for improving student writing but for reducing instructor workload (7). Yet, these methods have most often been instituted at the graduate rather than undergraduate level. Furthermore, none fully reproduced single-blind peer review together with the publishing process from letter of inquiry to final, accepted draft.

We describe a detailed method for teaching students the full scientific publishing process, including anonymous peer review, during the process of writing a term paper. The result is a review article in the format for submission to a major scientific journal. This method has been implemented in a cell and molecular biology course for undergraduate engineering majors. It thus intervenes early in their postsecondary education. However, the method should be equally applicable to graduate education.

METHODS

Outline of the process. The flow and timeline of the method are illustrated in Fig. 1. Students prepare a “review article” as described in the guidelines for authors of a major biomedical journal. The students first select a subject that fits the topical requirements of the course and submit this as a letter of inquiry to the instructor, who serves as “Editor.” If the topic is acceptable, the student begins research and writing. The first draft of the paper is due midsemester and is given confidentially to two other students in the class for their critique. Within 2 wk, students return their critiques, and these are given back to the authors together with a summary from the instructor. Given the comments of their peers and the instructor, students write a final draft. Students are not graded on their first draft nor on the critiques they receive. Rather, their grade is based on their final draft and the quality of the critiques they write. The method thus parallels the actual process of writing and publishing.

This teaching method was first undertaken at the University of Virginia in BIOM 304, “Cell and Molec-
ular Biology for Engineers.” This course, together with a related course in human physiology, is designed for undergraduate engineering majors that are interested in entering the field of biomedical engineering. Consequently, students prepare their papers according to the guidelines for authors of the Annals of Biomedical Engineering.

Letter of inquiry. Guidelines were provided to students for the topics that are acceptable for papers. In the course described here, papers were required to reflect either 1) the use of engineering to solve a problem in cell physiology or 2) applications of cell physiology to advancing engineering. These guidelines were expressed both verbally and in the syllabus.

Once students had chosen a topic, they were required to write a letter of inquiry to the instructor expressing an interest in submitting a review article on their chosen topic. It was through this letter that students obtained permission to write on their chosen topic. The required components of the letter were 1) the subject about which they wished to write and 2) why the subject was appropriate for the specified journal. Students were allowed to work individually or in pairs. Submitting the letter of inquiry as “coauthors” committed them to working in pairs. Students were also informed that it is not the job of an Editor (in this case the instructor) to resolve differences of opinion or personality conflicts between authors.

Guidelines for authors. Students were provided modified guidelines for the Annals of Biomedical Engineering, although the journal should certainly be selected as appropriate for the course being taught. The guidelines for the journal were modified only to remove extraneous information and unnecessary details (e.g., guidelines for use of human subjects).

First submission. Students submitted three copies of their paper by a due date near midsemester (Fig. 1). It was explained that two other students would see and read their paper (see Peer review). If there were particular classmates who the authors felt would have a conflict of interest in reviewing their paper, they had to be so listed in a cover letter submitted with their paper.
The first draft of the paper was required to be complete, with all the references and figures in place, of required length, and finished in every respect. This version of their paper, however, was not graded. The intent was to mimic the fact that the quality of a manuscript initially submitted to a journal does not necessarily determine whether it will eventually be published. Although the first draft was not graded, penalties were assessed for 1) late submission, five points per day; 2) incomplete papers, 25 points; 3) failure to comply with the Instructions for Authors, five points.

**Peer review.** One copy of the first draft was retained and read by the instructor, and two were distributed to other students in the class chosen according to similarity in the topics of their papers. The identity of the reviewers was strictly confidential. Students were provided review forms closely matching those used by major journals. They were also provided with guidelines for review that gave an impression of the expected content of the review. The guidelines for review are shown in Table 1.
Care must be taken in setting up a review so that papers are not lost and so that if reviews are not received, they may be easily tracked. The following method was used:

1) papers were numbered serially as they were received, and that number was recorded by the authors’ names on the grading sheet.

2) the papers were sorted into categories according to the subject matter (e.g., gene therapy, instrumentation, biomaterials, etc.).

3) for a given student, two papers were selected at random from within the category of the paper they wrote. Thus each student reviews papers with roughly similar topics to their own. Because some students worked in pairs, several students received only a single manuscript to review.

4) the numbers of the manuscripts reviewed by a given student were recorded on the grading sheet. Each student received the paper(s), review sheets, and guidelines for review.

Students were reminded repeatedly that they would be graded on the quality of their reviews, not on the reviews their papers received. Thus there was no advantage to being lenient in the review of a poorly written paper. Students were reminded that if they were too lenient, they would receive a low score for that review. Furthermore, the author would not get adequate feedback to enable him or her to improve the paper before its final submission.

Confidentiality and anonymity in the review process is critical to successful implementation of this method. Students are warned of “Honor Code” prosecution should they 1) inform another student in class of whose paper one is reviewing, 2) disclose the contents of that paper to another student, or 3) use the content of that paper to the betterment of one’s own manuscript (aside from references, which are a matter of public record). Penalties were assessed for late reviews at a rate of five points per day.

Revision and final submission. Students were not graded according to the reviews their papers received. Rather, students were permitted the opportunity to revise their papers based on the reviews from their peers and the instructor. The instructor’s review was in the form of a letter summarizing the comments of the reviewers and his/her personal opinion of the paper. Most often, revisions consisted of simple rewriting of sections for style or organization. However, some students found it necessary to conduct additional research to support their ideas. Near the end of the semester, students submitted a single copy of the final manuscript, along with a point-by-point response.

TABLE 1
Guidelines for review given to student

<table>
<thead>
<tr>
<th>Presentation</th>
<th>(Should Conform to Information for Authors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing</td>
<td>Is the writing clear, concise, and in proper English? Please point out frequent misspellings, unclear sentences, failures of logic, or poor sequencing of ideas.</td>
</tr>
<tr>
<td>References</td>
<td>Are more used than necessary? Are fewer used than necessary?</td>
</tr>
<tr>
<td>Tables and figures</td>
<td>Can they be simplified or condensed? Should any be omitted? Are they artistically appropriate and sharp in contrast? Are legends complete so that the meaning of the figure is clear?</td>
</tr>
<tr>
<td>Abstract</td>
<td>Does the abstract in one paragraph define the topic and state its importance in a clear and concise manner?</td>
</tr>
<tr>
<td>Format</td>
<td>Does the paper conform to the Instructions for Authors?</td>
</tr>
<tr>
<td>Content</td>
<td>(Should Conform to the Syllabus)</td>
</tr>
<tr>
<td>Topic</td>
<td>Does the subject of the article fit within the requirements in the syllabus?</td>
</tr>
<tr>
<td>References</td>
<td>Do the references reflect an adequate research effort?</td>
</tr>
<tr>
<td>Length</td>
<td>Was the paper of adequate or excessive length? Should the topic be expanded or narrowed in scope?</td>
</tr>
<tr>
<td>Intellectual content</td>
<td>Did the paper reflect understanding of the material on the author’s part? Did the information exceed that of the principle reference (if applicable), or was it a simple reiteration? Did you, as a reviewer, learn something from reading this paper or would your peers?</td>
</tr>
</tbody>
</table>

These guidelines are based on those for the *Annals of Biomedical Engineering*. 
to their reviews. The point-by-point response ensured that students had thoroughly examined their reviews and provided a convenient reference for the instructor so that papers did not need to be reread in detail to assign a final grade. Penalties were levied for late papers (10 points/day) and failure to submit a point-by-point response to reviews (10 points off).

The final submission was graded by the instructor alone, but using the same guidelines as when the paper was reviewed. In concept, how well students respond to their reviews should have a direct impact on their final grade.

Grading policies. The paper and peer review process constituted 30% of the final class grade. Overall grades on the papers were based on four elements: letter of inquiry, 0 points; first draft, 10 points; reviews, 25 points; final draft, 65 points.

Peer review grades were based on 1) how well and how thoroughly the student addressed all the points requested on the review sheet and 2) whether the instructor agreed with their assessment. Students were told that the instructor (i.e., the Editor) always has the final say on the quality of a review and often on subjective points, such as organization, relevance, importance, or clarity.

The final draft, as indicated above, was graded according to the same guidelines by which they were reviewed. This rendered the grading process somewhat more objective.

RESULTS

Statistics and anonymous feedback were collected from 35 or 36 (end and beginning of the semester, respectively) of 39 students enrolled in the class. The polled sample consisted of 1 first-year, 11 second-year, 23 third-year, and 6 fourth-year undergraduates. Students were asked six yes/no questions at the beginning and end of the semester to gauge their basic understanding of scientific publication and peer review. The questions and results are summarized in Table 2.

The most striking result is a dramatic increase in the professed level of understanding of the scientific publishing process (question 4), of peer review (question 5), and the decreased willingness to accept uniform resource locators (URLs) as references in papers.

<table>
<thead>
<tr>
<th>Question</th>
<th>% Answering “Yes”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Should you be allowed to include URLs (Internet addresses) as references in term papers?</td>
<td>92% 3%</td>
</tr>
<tr>
<td>2. Is there a difference in the reliability of information you receive in a scientific journal compared with the Internet?</td>
<td>75% 100%</td>
</tr>
<tr>
<td>3. Is there a difference in the reliability of information you receive in a scientific journal compared with magazines or newspapers?</td>
<td>70% 89%</td>
</tr>
<tr>
<td>4. If you wished to publish in a scientific or engineering journal, would you know how to go about doing so?</td>
<td>2% 91%</td>
</tr>
<tr>
<td>5. Do you understand the concept of “peer review” as it applies to scientific publishing?</td>
<td>39% 100%</td>
</tr>
<tr>
<td>6. Once a manuscript is submitted for publication in a scientific journal, is there ever an opportunity to revise it before publication?</td>
<td>31% 87%</td>
</tr>
</tbody>
</table>

Note the professed improvement in understanding of the scientific publishing process (question 4), of peer review (question 5), and the decreased willingness to accept uniform resource locators (URLs) as references in papers.

INNOVATIONS AND IDEAS
8) that the quality of their papers improved and that they would know how to go about writing a manuscript for publication as a result of this teaching method. Students also agreed (score 7.7) that as a result of this teaching method, they learned more about cell biology, will research papers and assess others’ work differently, and learned to write in a professional “style.” However, students agreed only slightly (score 6.5) that their writing skills improved or that they would change the way they write in the future.

The end of the semester survey also assessed students’ opinions of specific aspects of the review article/peer review method through written answers.

**In general, what did you think of the process of writing and revising your review article?** One hundred percent of the responses to this question were favorable. Students uniformly felt the experience was helpful and practical. A typical response to this question read “excellent—research was valuable, peer review was exceptionally helpful, and reading other papers was valuable too.”

**If you worked as a pair, how did you find the experience?** Ninety percent of students responding found the experience enjoyable and less work. Only one replied that the process left him/her feeling “distracted.”

**What did you think of the process of peer review?** Ninety-one percent of students responded favorably to peer review. Some students expressed disappointment that there was only time for one round of review before final submission. Seventeen percent of students complained that they had received either 1) one favorable and one unfavorable review or 2) one review that was poorly written. These students felt that the instructor should “enforce” the writing of good or uniform reviews beyond the assignment of a grade.

Finally, students were given the opportunity to write undirected comments. Seventeen percent of students indicated that writing the paper and engaging in peer review were their favorite aspects of the course. In contrast, when the term paper approach was used, none of the students listed the writing of the paper as their favorite aspect of the course.

Although it is admittedly a poor measure for comparison, the mean score on the final draft (neglecting late penalties or the other graded portions) using this method was 93.1% (±7.2 SD, n = 34) compared with 85.9% (±24.6 SD, n = 16) the previous year using the traditional “term paper” approach.

**DISCUSSION**

Requiring students to proceed through peer review and writing according to journal guidelines results in higher quality papers, an understanding of the significance of peer-reviewed journals, and knowledge of the scientific publishing process itself. By requiring the format of a scientific journal, students are given much clearer information about the purpose and expectations of a paper, as has been recommended by others (8). As a result, grading is rendered much more

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**TABLE 3**

Numerical scoring of statements given to students on the last day of class

<table>
<thead>
<tr>
<th>Statement “as a result of this project, . . . ”</th>
<th>Mean Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I learned more about cell biology</td>
<td>7.5</td>
</tr>
<tr>
<td>2. I sharpened my editing skills</td>
<td>7.4</td>
</tr>
<tr>
<td>3. My paper was improved</td>
<td>8.5</td>
</tr>
<tr>
<td>4. My writing skills improved</td>
<td>6.5</td>
</tr>
<tr>
<td>5. I will change the way I write</td>
<td>6.8</td>
</tr>
<tr>
<td>6. I will change the way I research papers</td>
<td>7.5</td>
</tr>
<tr>
<td>7. I learned to review and assess other people’s work</td>
<td>7.7</td>
</tr>
<tr>
<td>8. I would know how to write a manuscript for publication</td>
<td>8.2</td>
</tr>
<tr>
<td>9. I learned how to write in a professional “style”</td>
<td>7.9</td>
</tr>
</tbody>
</table>

**Other questions**

10. Before completing this project, I understood the process of scientific publishing. 3.3
11. Before completing this project, I understood the relative reliability of information in scientific journals, magazines, newspapers, and the Internet. 6.9
12. I was able to comment on the scientific content of the paper(s) I reviewed. 6.9

Respondents responded with integer values ranging from 1 to 10, with 1 indicating “strongly disagree” and 10 indicating “strongly agree.”

>8) that the quality of their papers improved and that they would know how to go about writing a manuscript for publication as a result of this teaching method. Students also agreed (score >7) that as a result of this teaching method, they learned more about cell biology, will research papers and assess others’ work differently, and learned to write in a professional “style.” However, students agreed only slightly (score >6) that their writing skills improved or that they would change the way they write in the future.

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objectively, and the instructor receives fewer complaints and petitions for grade changes. Finally, the students leave the class with useful technical skill-writing for publication. If applied at the graduate level, use of this method would certainly result in publication-quality manuscripts.

Use of this method has many benefits for both the instructor and the student compared with traditional term paper approaches. First, students learn more in specific areas:

1) students learn the scientific and technical publishing process up to manuscript acceptance.

2) students learn the value of peer review. Through experience, they come to understand why peer-reviewed journals are considered more reliable as references than newspapers, magazines, encyclopedias, and the Internet.

3) Students learn to write in a style and according to guidelines that have practical relevance to their careers.

This method also has other tangible benefits for the instructor and the student. First, the penalties for tardiness are sufficiently heavy, the result being that few items were ever turned in more than 1 day late. In fact, many students appreciated the extra incentive to complete the assignments. Furthermore, the necessity of strict guidelines is obvious to the student when presented within the context of peer review and paper revision. If guidelines are not strictly enforced, one’s classmates are directly affected.

Second, grading the final draft according to the guidelines used for review rendered the grading process itself relatively objective and eliminated grade challenges by the students. In the previous year, 25% of students petitioned for changes to the grade they received on their paper. With the use of this method, there were no petitions.

As a consequence of grading the final draft according to the guidelines used for review, responding to all of the points in the reviews virtually guaranteed that the paper would meet the criteria for a good grade. The quality, consistency, and grades of the final papers were markedly improved over the previous academic year of the same course, when the assignment consisted of a term paper.

The actual improvement in writing and research skills when using this method is difficult to gauge. Writing styles and skills must be assessed subjectively. Because the method was implemented in a single-section course, we are not able to make completely objective side-by-side comparisons of this method to a traditional term paper approach. Grading standards for the paper were greatly elevated when this method was instituted. Yet, students scored somewhat better on the paper than in previous offerings of the course, professed enjoyment of the project, and showed marked improvements in the final written product as judged by the instructor. These are strong subjective indicators of improved student performance. Results from student surveys also support an improvement in understanding of peer review (Tables 2 and 3). Particularly telling in this regard was dramatic decrease in the percentage of students who believed URLs should be acceptable references in term papers (93% to 3%) before and after engaging in peer review.

Students agreed only marginally that their writing skills had improved and that engaging in this process would change the way they write papers in the future (Table 3). This suggests that it is the feedback from peers and the highly structured nature of the assignment that led to an improvement in the final manuscript and not the experience of writing. This is somewhat surprising given the small number of writing assignments given undergraduate engineering majors. Nonetheless, it does support the notion that clear written guidelines for writing assignments are central to student performance (8).

Pitfalls and limitations. This method is not without difficulties. First and foremost is the increased workload for the instructor. This is in contrast to a previously reported implementation of peer review that resulted in a decrease in the time required for grading (7). However, reading each of the student papers as the Editor, grading the reviews themselves, writing a summary of the reviews, setting up the review process, and assigning grades to the final draft take a
great deal of time. Faculty interested in implementing this method should make use of graduate teaching assistants whenever possible.

Two other mechanisms may be used to limit the instructor workload. The first and most obvious is simply to leave the review of the first submission to the student peers. For the most part, however, this simply shifts the instructor workload from midsemester to the end of the semester. Another approach is to simply require students to work in pairs. Indeed, in the current offering of the author’s undergraduate course, implementing this requirement has cut the number of manuscripts by ~30%.

Students ranked themselves on the statement “I could comment on the scientific content of the papers I reviewed” and returned a mean score of 6.9 (Table 3). However, a detailed assessment of the reviews showed that authors writing on closely related topics (e.g., 2 papers on DNA-based computing) were the only students who actually commented on the scientific content and accuracy of each other’s manuscripts. In an effort to correct this deficiency, students are currently given a selection of six narrow topics on which to write. The intent is to force some overlap of scientific knowledge and thereby enhance the review process.

The importance of example manuscripts and letters of inquiry cannot be underestimated. The format, content, and intellectual level of these items is completely unknown to the average student, and examples were the most frequently requested piece of information by students. They are now made available to students on the class website (2).

Some students may have difficulty being critical of their peers’ manuscripts while wishing to support those other students. Four measures help remove this barrier to a successful review: 1) severe punishment is enforced for breaking the confidentiality of peer review, 2) students may decline to review a manuscript based on conflict of interest, 3) the reviews themselves are graded, and 4) students are lectured on the importance of critical reviews to generating a final manuscript that can receive a high grade. Together, these measures have promoted in-depth reviews ranging qualitatively from polite to scathing.

Several variations on this method may be envisioned that would further enhance the experience of writing or expand the work to fill a stand-alone undergraduate or graduate course.

**Multiple rounds of review.** Some students suggested that we engage in multiple rounds of review to better represent the actual publishing process and allow them to further hone their manuscripts. Due to time constraints, this is not practical in a typical one-semester class or where the paper is only a fraction of the grade.

**Production of a “journal.”** Some students suggested that all or some of the review articles be compiled into a journal that class members could keep. The complexity of this step could range from simply spiral binding photocopies of the final drafts to enlisting the aid of a desktop publisher to produce galleys for student inspection before final printing. Clearly, this is not appropriate for anything but a class dedicated to teaching scientific writing.

**Steering toward publication.** In higher-level classes, the authors of especially well-researched papers might be encouraged to refine and submit manuscripts to existing scientific journals. Indeed, this approach has been taken in at least one graduate nursing course (1).

**Inclusion in the senior thesis process.** Finally, many universities, including the University of Virginia, require a senior thesis to be written to receive a baccalaureate degree. Standards for the writing and format of senior theses vary. However, requiring students to write their senior thesis according to the guidelines of a few select journals and engaging in peer review of one another’s work would add a new dimension to this process and provide additional opportunities for publication.

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