Education

Weaving the Web into biology teaching

The World Wide Web has rapidly become part of the educational landscape. Students typically love it: it is new, it is fun to use, it is graphically and interactively rich, and it affords access to many types of information, academic and otherwise. Most of today's students arrive at college already having some experience with the Web, and some are adept at Web page design and construction. Many students turn to the Web rather than the library to search for information. On nearly every college campus, educators are incorporating one or more Web-based uses into their courses. Yet for several reasons, the Web has not yet become an integral part of the teaching process.

Among these reasons is that Web technology is too new, and too rapidly evolving, for most biologists to have had time to explore possible teaching applications. The time required to develop useful Web applications and procedures has proven a substantial barrier to many faculty members already stretched thin with time commitments. In addition, potentially useful educational material available on the Web, although abundant, is disorganized, generally short-lived, and often difficult to authenticate. Finally, it has taken some time for teachers who are "early adopters" of the Web to explore the landscape of possibilities and develop interesting models of possible applications. Many educators are still waiting to be convinced that the Web offers ways of significantly improving the teaching process beyond what they currently do.

Fortunately, most of these barriers to using the Web in teaching are diminishing or disappearing. Most academic institutions now have a substantial and growing investment in Internet-linked computers, for both faculty and student use. Many off-campus students have computers and Internet connections. The time and energy required to develop Web materials is considerably lessened by new software packages that provide tools for creating extensive Web sites. Biologically interesting teaching ideas and applications available on the Web are multiplying rapidly, and pioneering educators have demonstrated a number of pedagogically useful applications of the Web.

My goal in this article is twofold: to discuss current ways of using and producing documents on the Web, and to survey a variety of uses of the Web for teaching in the biological sciences. All citations from this article are listed on a Web page where citations are hypertext links (Terry 1999a).

The Web: What is it and how does one use it?

The Web is a collection of computer documents authored by individuals and institutions and made available on computer servers that are linked to the Internet 24 hours a day. A recent survey estimated that there are currently over 320 million Web pages, not counting the millions of Web pages hidden behind passwords or other barriers, and the number is growing rapidly (Treese 1998). The Web should not be confused with the Internet itself; the latter refers to the interconnected network of computers that are configured to exchange data by a common set of network protocols. The Web is just one format for such information, whose visual metaphor is a page with text, images, and links. Other common formats, such as e-mail, FTP (File Transfer Protocol), and Telnet, allow Internet transmission of information but do not produce Web pages.

The Web's page format is easy to use, and even computer-phobic students rapidly master basic techniques such as entering a URL (Uniform Resource Locator; the unique address for each Web page) and following hypertext links (highlighted text that transports the user to new Web pages when clicked). I introduce the Web during the first lecture of every new course with a short demonstration on how to type in a URL, how to recognize and navigate a hypertext link, how to bookmark a page, how to navigate forward and backward after a series of pages have been visited, and how to save or print Web pages. With rare exceptions, this 5-minute "crash course" is all the training students say they seem to need to become comfortable with basic Web usage, except for more complicated tasks, such as searching for information and creating Web pages.

Advantages and disadvantages of using the Web in education

The Web is the easiest and most platform independent medium for Internet communication; users of Windows, Macintosh, or Unix operating systems see essentially the same Web pages with similar multimedia effects, no matter which type of machine the pages were produced or served on. Web browsers and plug-ins (specialized software that extends browser capabilities) are free of cost for noncommercial users, as is much of the software that augments Web capabilities. Information, once posted, is immediately and globally available to anyone linked to the Internet, although in some cases a password is needed for access.

For educators, posting material on the Web eliminates many problems associated with producing, distributing, and archiving paper cop-
ies. For example, I post extensive Web documents, such as lecture notes or practice exams, that I would never undertake to print and distribute to a class of 300 students because of the expense and trouble involved. When I produce handout materials, I routinely convert them to Web documents for the benefit of absent students. If a student asks for a copy of last week’s handout, I reply, “It’s on the Web” instead of trying to find a paper copy. I no longer archive paper copies, except for copyrighted material that I can distribute in paper under “fair use” guidelines but cannot post on the Web.

Another benefit of the Web is the ability to use color, which adds visual impact and interest to most documents in the form of either colored text or color graphics. Color pages or transparencies are expensive to produce, typically around a dollar per page for good-quality reproduction. By contrast, adding color to Web pages costs nothing and adds little to the electronic size of the page if the graphics are kept small. Relatively simple colored graphics can be produced in minutes and used to illustrate important concepts, or links can be set to relevant images from the enormous collections now available on the Web. The costs of obtaining printed copies of these ancillary materials are shifted from instructor to student. Although it may seem unfair for students to bear this expense, it is important to recognize that the information itself is being provided to students for free, and in greater quantity and quality than would be possible without the Web. Students have many inexpensive options to obtain such materials, including using the materials online, saving them to disk for use on their own computers, or printing them with a variety of print options ranging from inexpensive, low-quality black and white to high-resolution color.

A potential drawback of the Web is that it lacks the stability of print, in which documents cited do not change. This stability, of course, comes at a price: Upgrading information is expensive and time consuming, and many books and articles lose relevance and accuracy over time. By contrast, Web pages can be revised with such ease that citation of Web pages is often problematic. It is therefore good practice to list a revision date on every Web page. A related problem is that some Web resources disappear, usually without explanation. The owner may have discarded them to gain space for more recent materials, a file directory may have been reorganized for greater efficiency, or a server may have been replaced by a new one with a different Internet address. In those cases in which a Web page has been moved to a different location within the same server, it can often be located by trial and error after truncating the URL. As a fictitious example, imagine that the URL “http://www.bio.org/images/ecoli.html,” which formerly accessed a Web page about Escherichia coli, no longer worked. Deleting the last term would yield the URL “http://www.bio.org/images/,” and after pressing the “enter” key, the browser might reveal a directory of image files in which an additional folder called “bacteria” had been added. Clicking this term would yield a list of bacteria, including E. coli, and a new URL, “http://www.bio.org/images/bacteria/ecoli.html.” In other cases, the material may be available at a different URL entirely that can be found with a search engine.

Another disadvantage of the Web’s use in education is the occasional fallibility of all technological devices, including computers, Web servers, Internet access, and projection equipment. When any one of these devices fails, the entire Web or a particular Web site is at least temporarily unavailable, forcing unexpected alterations in delivery or study of course content. It is wise for teachers to arrive early for any class involving Web use so that the connection can be tested. If a problem is found, local support personnel may be able to fix the problem in short order, or there may be time to return to one’s office for transparencies, slides, or other, more traditional visual aids. Yet another disadvantage is that some users find it difficult to read text from a computer screen, preferring printed materials for extensive reading. Finally, using the Web is expensive, requiring computer and networking infrastructure as well as provisions for service and upgrades. Not all students have ready access to this infrastructure, and cost is a barrier to some. However, access is becoming less of a problem every year as computers and Internet connections become more affordable and as colleges and universities expand the number of Internet workstations.

Tools for producing Web documents

Web browsers are software products that interpret appropriate data to display Web pages. The major browsers today are Netscape Navigator and Microsoft’s Internet Explorer, both of which are free to educators and students (CNET 1999). Web pages are prepared in hypertext markup language (HTML), a relatively simple coding language in which tags are used to create Web page content. For example, inserting the <P> tag creates a paragraph break, and surrounding a word with the <I> and </I> tags creates italics. Most Web page creators will not need to learn HTML, however, because there are many commercial software packages that allow users to create HTML documents without having to learn the mechanics.

Some of these programs, such as Adobe PageMill, Claris HomePage, and Microsoft HomePage, offer WYSIWYG (“what you see is what you get”) interfaces similar to those of word processing software; the user arranges elements as desired on the page, and the software generates the corresponding HTML code on a separate page. A good Web source for all such software (including freeware, shareware, and demonstration versions of commercial software) is TuCows (1999), one of the most comprehensive Web sources of Internet-related software. Recent versions of Netscape and Microsoft browser software include tools for creating and editing Web pages, although they are not as fully featured as the programs described above.

Once Web pages have been created, they need to be posted on a server, a computer equipped with special software to serve pages over the Internet. It is possible to use one’s own desktop computer as a server, but doing so requires leaving
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it turned on day and night and may result in some slowing of other work as external users access Web files. A more common scenario is to obtain an account on a college or university server, which usually provides a sizeable amount of storage space free of charge for course materials. Most institutions allow teachers to transfer files directly to their own server account, which makes it easy to update and add files on a day-by-day basis. Servers can usually be accessed over a campus network, and local computer support personnel should be able to answer questions about such connections. Files can also be transferred to server accounts by FTP software, available from TuCows (1999). It is advisable to maintain up-to-date copies of course files both on one’s own computer and on a server. Most commercial Web programs, such as those mentioned above, will automatically update server files whenever local files are updated, once Web authoring software has been configured with the appropriate server address.

Recently, a number of integrated “Web construction kits” have become commercially available, as have commercial services that handle all aspects of Website management. Such collections of software tools facilitate the creation of sophisticated Web-based educational environments by nontechnical users. Templates are available to create an entire online course, including quizzing features, bulletin boards, server accounts, lecture notes, course e-mail, and threaded discussions in which students can maintain an electronic dialogue on a topic. Instructors can select any set of materials as desired to supplement a course and can even develop entirely online courses. Such integrated software suites make the task of creating new Web course materials relatively easy, and a number of colleges and universities have purchased site licenses or provide other fee arrangements to allow widespread faculty use. Gray (1998) has recently reviewed and compared features for a number of these tools, such as Web Course in a Box (Mad Duck Technologies 1999) and Web Course Tools (WebCT 1999). Gray’s article contains complete URLs for all software reviewed.

For those who want to manipulate HTML code more directly or inexpensively, HTML editors such as HotDog for Windows or PageSpinner for Macintosh allow users to highlight text, choose items from a menu of selections, and let the software generate appropriate HTML code (TuCows 1999). Output from word processing software can be converted to HTML in a single operation. This is a convenient way to turn lecture notes, study guides, or other lengthy documents into Web documents, preserving formatting such as tables, headers, and even graphics. Word processing software such as Microsoft Word and WordPerfect include HTML export options. An alternative is to first save a document as Rich Text Format (RTF) and then use the shareware product RTF-to-HTML Converter to turn this into HTML (RTF 1999). This converter offers many options and often produces results superior to saving a word processing file as HTML directly. In either case, results of HTML conversions are not always what one wants, and it is sometimes necessary to “tweak” the resulting document to improve appearance. For example, a common problem is too much or too little “white space,” resulting in text that is too separated from other text or too crammed together. The paragraph tag produces one blank line, but repeated paragraph tags are ignored, as are extra blank spaces entered with space or return keys from a computer keyboard. Extra blank lines can be added by repeating the line break tag; for example, \texttt{<BR>} produces three blank lines. If these commands are insufficient, other HTML tags can be learned easily from a number of free Web-based HTML tutorials (Yahoo! 1999a).

It is also possible to borrow HTML formatting from any page on the Web by using the browser’s “View” menu to open “Document Source” (Netscape Navigator) or “Source” (Internet Explorer). This action will open a document containing complete HTML tags and text. It is often possible to find tags that create a certain effect one would like to duplicate, such as the use of color in certain lines of a table or tags that automatically update a page’s revision date. These tags and their embedded text can be copied, pasted into one’s own document, and modified to suit individual needs. As long as such borrowing is limited to reproducing the tags needed to achieve a certain format and does not involve reproduction of text or graphics authored by another, it is acceptable and common practice and not a violation of copyright.

Some strategies for using the Web in biology education

Instructors will find many ways to use the Web in biology teaching. Students can be provided with Web-based resources created or selected by the instructor for use outside of class. If appropriate computer and projection facilities are available, Web materials can be presented in class or laboratory settings. Some instructors have developed distance education courses entirely on the Web. My own Web usage began with the limited goal of providing a few supplementary materials to help students study and has grown steadily every semester. I now use the Web to provide a rich variety of assigned and supplementary materials as well as to present certain materials directly in the classroom. I describe some of these activities below. Instructors who use the Web will undoubtedly discover other applications.

Assign students to visit Web sites chosen by the instructor. The simplest way to add Internet materials to biology teaching is to find useful Web sites and assign students the task of visiting them. There are thousands of sites with interesting and appropriate materials to supplement courses, including image collections of organisms, ranging from viruses to plants and animals; sequenced genomes; databases of biomolecular structures, ranging from small molecules to proteins and nucleic acids; course materials posted by other instructors; online scientific publications, ranging from \textit{Discovery} and \textit{Scientific American} to professional journals; and much more. One way to find such sites is by topic searches, using some of the Web sites listed in Table 1 as starting points or using keyword searches for specific topics.

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Another way is to look at materials that other instructors are using. The World Lecture Hall contains links to pages created by faculty worldwide who are using the Web in their teaching and whose materials are not blocked by password or domain protection (WLH 1999).

Some Web sites promote interactive experiences. For example, the "Virtual Fly Lab" directs students to breed pairs of mutant fruit flies of their choosing, observe statistically large populations of virtual F1 and F2 generation offspring, and attempt to identify the genotypes of parental strains (Desharnais 1997). The "Virtual Immunology Lab" allows students to simulate an ELISA assay exactly as it is carried out in lab, including animated pipetting, centrifugation, and incubation steps (HHMI 1999). The "JavaScript SEM" allows students to simulate operating a scanning electron microscope, selecting from a variety of samples, changing magnifications, and even activating a simulated vacuum pump (Kunkel 1997).

Students' experiences with the Web can be enhanced by creating a list of questions to be answered. For example, when I assign students to visit the Web site of The Institute for Genome Research (TIGR 1999), a database containing many genome sequences, I provide a handout with the URL of the Web page for *Mycoplasma genitalium*, the bacterium with the smallest known genome. Students must explore the genome to find such items as the smallest and largest gene, the total number of genes, the number of genes involved in protein biosynthesis, and the DNA and polypeptide sequence for a given gene. Such tasks involve students in a process of exploration and discovery and give them some basic familiarity with the contents of a genome database. Students often come back from such assignments with questions that show a new awareness of issues related to genomes. Similar kinds of handouts could be used for visits to many instructor-selected Web sites. In fact, some biology textbooks have associated Web sites with practice questions that can be e-mailed directly to the instructor as proof of visit. Such feedback is helpful to measure student activity and work on the Web.

Because producing a quality Web site is expensive, it is not surprising that some Web sites charge fees to cover their costs, raising difficulties with access while making higher quality materials possible. Some online journals, such as *Science* and *Nature*, are available only by subscription at rates that are too high for the average student. Some commercial Web sites, such as The Biology Place, are oriented specifically toward introductory biology students, providing an extensive and growing collection of interactive exercises with well-designed content and graphics (TBP 1999). Student subscriptions to The Biology Place are often bundled with the purchase of certain textbooks or are inexpensively priced for semester use. Free access is available for a week's use, allowing biology educators to explore this collection of resources at no charge. Despite the cost, certain subscription sites may be valuable enough to include as required or supplementary resources for biology courses.

Assign students to search the Web for specific information. As the Web grows in content, variety, and popularity, students increasingly attempt to use it as a research tool. The temptation is obvious: Search engines seem to hold the promise of immediate access to limitless information simply by typing a topic into the search window. All too frequently, however, such searches generate thousands of references to information that is useless for the standards of an academic assignment. I have seen more frustration from students assigned to research a topic on the Web than from any other academic assignment, usually because the student had little or no training in either good search techniques or the evaluation of relevance and quality. It is possible, with a few carefully chosen training exercises, to reduce this frustration and to create useful and interesting activities in which students search for biological information on the Web.

One helpful practice is to develop short training exercises in Web search strategies. The first task I often as-

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**Table 1. Selected Web pages for searches by subject.**

<table>
<thead>
<tr>
<th>Page name (reference to URL)</th>
<th>Content</th>
<th>Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological Sciences Resources</td>
<td>Extensive links</td>
<td>Maintained by William D. Graziadei, State University of New York at Plattsburgh, Plattsburgh, NY</td>
</tr>
<tr>
<td>CSU BioWeb (Wolf 1999)</td>
<td>Extensive links in many subject areas</td>
<td>Maintained by Steven J. Wolf, California State University–Stanislaus, Stanislaus, CA</td>
</tr>
<tr>
<td>Estrella Mountain Community College Biology Internet Resources (Farabee 1997)</td>
<td>Useful links for general biology</td>
<td>Compiled by M. J. Farabee and students at Estrella Mountain Community College, Avondale, AZ</td>
</tr>
<tr>
<td>Britannica (Encyclopedia Britannica, Inc. 1999)</td>
<td>Links (found by navigating to &quot;Science,&quot; then &quot;Biology&quot;) are carefully selected and reviewed for accuracy, relevance, and currency</td>
<td>Commercial site</td>
</tr>
<tr>
<td>SciCentral (SciCentral 1999)</td>
<td>Links to over 50,000 sites</td>
<td>Commercial site, maintained by scientists</td>
</tr>
<tr>
<td>Science Web Sites (Science NetLinks 1999)</td>
<td>Ranks selected science Web sites as &quot;Super sites&quot; or &quot;Approved sites&quot;; links each site with a one-page review</td>
<td>Sponsored by MCI WorldCom and the American Association for the Advancement of Science</td>
</tr>
<tr>
<td>Yahoo! Biology (Yahoo! 1999c)</td>
<td>Links selected for accuracy and high quality; frequently updated</td>
<td>Commercial site</td>
</tr>
</tbody>
</table>

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sign my students is to go to Yahoo! (1999b) and find, within the Yahoo! site, a link to a tutorial on how to conduct a Web search. Yahoo! presents information in a hierarchically structured manner, and I suggest to students that they follow the following path: main index—Computers & Internet—Internet—Searching the Net—World Wide Web—How to Search the Web. This path leads the students to a Web page with many tutorials to choose from and also gives them firsthand experience in using a hierarchical search as an alternative to a keyword search. They must then submit a one-page report including the URL and their own summary of what they learned by reading the tutorial. Once they have submitted their report, they are given a second task, to use a search engine to find five good Web resources for a specific topic, such as food poisoning by Campylobacter or global incidence of filariasis. Students compare their search results and problems encountered during the next class. These tasks help develop useful search skills and lead to more productive use of the Web for subsequent biology searches.

Along with developing good search skills, students also need training in how to evaluate the quality of Web information. Many good Web tutorials (often written by librarians) provide ideas for how to assess quality. For example, Grassian (1998) provides a number of important questions that focus attention on quality, such as identifying the audience, assessing the accuracy and completeness of the information and links provided, comparing the Web site to other resources, and assessing the date(s) of material covered. Once students are engaged in Web searches, I require them to read an article on assessing quality and to write a short “quality assessment” for each Web reference they cite. It may also be useful to limit allowable Web citations to those published by periodicals or journals, scientific organizations, college or university collections, or other reputable sources. Other resources that evaluate the quality of Web information include Good (1997), Steggall (1997), Tillman (1997), and Grassian (1998).

Once students have acquired some basic skills in searching and evaluating the quality of information on the Web, they can pursue a variety of interesting assignments using Web resources. For example, one semester I assigned student teams the task of researching different aspects of tuberculosis (TB). Among other projects, one team explored the pathogenesis of lung infections and another explored the global epidemiology of TB. Each team was required to cite at least three print references and at least three relevant Web references. The pathogenesis team found an excellent collection of images showing many stages of lung pathology—including images of TB far superior to those in any of our textbooks—at a medical school Web site. The global epidemiology team explored the World Health Organization’s Web pages and was able to find current statistics of TB prevalence in different parts of the world. Feedback on this exercise was very positive, and many students commented on the high interest level of finding and using such authoritative resources. Instructors should have no difficulty choosing research topics in any area of biology for which Web resources can enhance and stimulate interest and learning.

Creating one’s own course materials. Most instructors who use the Web will want to create some of their own Web materials, even if only a page of links. I list a number of Web course materials below; for example, see one or more of my online courses (Terry 1999b).

A “home page.” This term is frequently misused to refer to an entire Web site consisting of many pages; a better term for the entry-level Web page is “index page.” Although this page can be a long, scrolling document, it is better kept short, with a list of links, an image map, or frames that allow students to navigate to desired pages within the instructor’s Web site or to important pages outside the site. Actual content should be restricted to other Web pages, which might include any or all of the following materials.

Basic course handouts. It is easy to turn syllabi, study guides, lecture and laboratory schedules, and other standard handouts into HTML documents by the methods already described and to include links to these documents from an index page. This approach obviates the need to find extra copies of handouts later in the semester for occasional students who missed class or lost a copy. This approach also makes it possible to update a lecture syllabus that often deviates from the version printed at the beginning of the semester and to add new material, such as links to interesting Web sites that were not known when the syllabus was printed.

An announcement page. Information about exams, makeup exams, review sessions, special lectures, and similar matters is usually written on the board at the beginning of class and often erased, and it is therefore frequently missed by latecomers or absentees. Once students learn that this information is always available on the Web, most will use it. It is also possible to update information outside of class time, such as, for example, when an instructor announces a special review or class session but has not yet reserved the room.

Practice quizzes or exams. One of many factors contributing to poor student performance is insufficient preparation for the appropriate level of exam questions. It is easy to convert an old exam into a Web document, or, better still, to convert a practice exam into an interactive format so that students can select answers and be graded instantly by the computer. Integrated Web software suites typically include such features (Gray 1998). Alternatively, university computer centers often have student or staff workers who can be asked to create an interactive exam format with instructions for Web users (see DePalma 1999). Figure 1 provides an example of an interactive Web quiz (Terry 1998). The “X” tells the student immediately that one answer was incorrect, but it does not reveal the correct answer, thus inviting further thought rather than the mechanical copying of an answer key. In my experience, student reaction to such interactive practice tests is overwhelmingly positive.

Instructor’s lecture notes or outlines. There are many good reasons for making these notes available to students. One of the goals of biology instructors is to convey relevant, up-
20) One of the major functions of rough endoplasmic reticulum is
- a. synthesis of phospholipids
- b. synthesis of steroids
- c. synthesis of secretory proteins
- d. synthesis of cytoplasmic proteins
- e. all of the above

21) In eucaryotes, ribosomes are synthesized in/on:
- a. the nucleolus
- b. the cytosol
- c. rough endoplasmic reticulum
- d. smooth endoplasmic reticulum
- e. mitochondria

This quiz had 27 question(s).
You answered 2 question(s).
You correctly answered 1 of 2 computer-correctable question(s), scoring 50% correct.

Figure 1. Sample questions from a computer-scored interactive practice exam used in introductory biology (Terry 1998). The instructor creates a text file that assigns values to different variables. The source code is a perl script, which creates a quiz when the Web page is opened by the user (DePalma 1999).

to-date information with appropriate examples and organization. In their notes, students commonly fail to transcribe accurate or even modestly complete information. Even the best students miss an occasional class due to excusable circumstances—why should we not ensure that they have the best-quality information, instead of relying on questionable notes from other students? Many students have commented to me that having lecture notes available on the Web allowed them to pay more attention to lectures without worrying about the need to transcribe every detail, and this feature is always rated highly in student evaluations.

Nevertheless, the concept of posting lecture notes excites more controversy than any other use of the Web in teaching. Many instructors wonder why students would continue to come to class if they could obtain lecture notes on the Web, and in truth some students do abuse the availability of posted lecture notes. In my experience, most biology majors and more mature students rarely miss a class, whereas a substantial number of nonmajors and freshmen are likely to decrease their frequency of attendance when Web notes are posted. Much depends on the way an instructor uses a lecture period. If the instructor reads lecture notes in class word for word, the incentive to attend class will indeed be reduced. If the class includes a variety of activities and materials not available on the Web, however, attendance is less likely to suffer. Or, instructors might post only outlines, leaving at least some of the specific content to be filled in during class as an incentive for attendance.

Graphic supplements. Many graphic images are available for classroom presentation, including slides, transparencies, CD-ROM images, laserdisks, and videos. One disadvantage to these materials is that, once the presentation is over, they are not usually available for students to review. The Web is becoming richly endowed with collections of biologically useful images in a variety of forms: electron micrographs, color photographs, line drawings, and animations or short digital videos. It is often possible to find Web-based graphics that are as appropriate for classroom use as the traditional media, with the added advantage that students can access them as desired for further study.

Any Web image can be downloaded by holding the mouse button down (right button in Windows) and selecting “Save this image” from the pop-up menu that appears. To use such images on a local Web site, permission should be obtained from the copyright holder. Many image owners will allow posting of their images on educational sites, usually in return for setting a link or an acknowledgment. Alternatively, images can simply be linked from one’s own Web pages. This practice is especially useful for lecture notes, which most students will print for use in studying, and to which images add significantly to printing time and cost.

Instructors should also consider constructing their own graphics, using one of the many commercial graphics programs. With a little practice, colored images can be quickly and easily developed to illustrate many biological concepts. Photographs can be digitized by scanning, by commercial processors, or by using a digital camera. Graphics posted on the Web need to be compressed in GIF format (used for drawings with limited numbers of colors) or JPEG format (used for photographs and images with continuous variation). If a graphics program does not save directly to these formats, freely available conversion programs will create them easily (TuCows 1999). If permission is granted to use images from a CD-ROM or another source on the Web for local, but not global, use, local computer personnel should be able to set up a Web site with password restriction or local domain limitation to avoid copyright violation.

Animations. Understanding of many biological processes can be enhanced by simple animations. The simplest type of animations, animated GIFs, can be created using free software such as GIFBuilder (Macintosh) or shareware such as GIF Movie Gear (Windows), which con-
vert a series of images into a single animated file (TuCows 1999). This software makes it possible to change the interframe delay for each frame, cause the animation to loop back to the beginning or end after one or a few cycles, and much more. Showing such animations does not require additional software; most Web browsers support the GIF89a format that makes these animations visible. Anyone with even modest abilities to work with simple graphics can create such animations. I have found it relatively easy to create animations to illustrate, for example, how electrons pass along the mitochondrial membrane while protons are translocated across the membrane during cell respiration, as shown in Figure 2 (Terry 1997).

More complicated animations, with smoother transitions, sound effects, and even interactivity can be created using commercial programs such as Macromedia Director, a multimedia animation program for creating animated movies and presentations (Macromedia 1999a). These animations can be exported as Shockwave animations, which are visible on the Web once the free Shockwave plug-in is installed in the browser’s plug-in folder (Macromedia 1999b). A good example of a sophisticated Shockwave animation is “Polymerase Chain Reaction (All Cycles)” produced by the DNA Learning Center (1999).

Links to short videos. A short movie is one of the surest ways to capture student interest. Unfortunately, the Web is not an ideal format for movies because even small movies require significant download time, especially with a modem connection. Streaming video technology, in which initial segments of a movie are displayed while later segments are still being transmitted, makes access much faster, although the quality of images often suffers at modern transmission speeds. Plug-ins such as the free QuickTime plug-in (TuCows 1999) and the VivoActive plug-in (Vivo Software, Inc. 1999) are required to display video and streaming video, respectively, on a Web browser. A number of short movies are available in many areas of biology, and these can add interest to both lecture presentations and student study. Some examples are listed in Table 2.

Use of Chime to view molecular data files. Chime is a free Web browser plug-in that allows users to view molecular data files as interactive images (MDL Information Systems, Inc. 1999). Users can rotate these images in space, expand or shrink them, and view them in different ways (e.g., as space-filling models or wire frame views). Among the images that can be viewed in this way are those in the National Institutes of Health’s “PDB at a glance” database, which allows convenient access to protein database (PDB) files for many proteins, nucleic acids, and other large molecules (NIH 1999b). Hundreds of PDB files for smaller molecules are available from Klotho (1999). Students are often excited and intrigued by the ability to interact with such data files. Instructors can create virtual activities that allow students to interact with selected Chime graphics to deepen understanding of molecular structure and function. Eric Martz, at the University of Massachusetts, Amherst, maintains a Chime Resource site with several useful Chime tutorials in biology (Martz 1999).

Student work. Students can be assigned a project involving not only researching a topic in biology but also converting such information into a Web page and adding links to other related sites and graphics. For example, a number of students in my microbiology class worked in groups of three or four to write Web pages dealing with TB, creating a class resource called “Project TB” (Terry 1996). Their first task was to write and revise appropriate text, a task comparable to a term paper assignment. They then had to collaborate in producing a Web page, searching for links to related sites, finding or creating appropriate graphics, and, finally, reading and evaluating the Web pages published by their peers. The quality of writing was better than that of typical term papers, and students commented that they wanted their work to be especially good “because it was going to be on the Web.” Some reported with pride that they had showed their Web site to parents or friends. Web pages were clearly identified as student projects so that people searching the Web would not be misled as to their authority. Many students evaluated this project as one of the more chal-

![Figure 2. One frame from a 24-frame animation of electron transport in mitochondria (Terry 1997). Images for such animations can be created in any graphics program. To create this animation, all background elements were grouped as a single image, and movable elements were dragged to slightly different positions to create different frames. Each frame was then copied to GIFBuilder, free software that merges many single images into an animation (available from TuCows 1999). Such animations take little time to prepare and are effective in teaching dynamic biological processes.](https://academic.oup.com/bioscience/article-abstract/49/9/733/246952/999k)

Table 2. Examples of Web-based videos useful in teaching biology.

<table>
<thead>
<tr>
<th>Title (file size)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>The National Library of Medicine’s Visible Human Project™ (752 Kb)</td>
<td>NIH 1999a</td>
</tr>
<tr>
<td>Bacterial Growth: E. coli (728 Kb)</td>
<td>Sullivan 1999a</td>
</tr>
<tr>
<td>Chemotaxis of Human Neutrophils (556 Kb)</td>
<td>Sullivan 1999b</td>
</tr>
</tbody>
</table>
ling and interesting experiences in their undergraduate studies.

Other applications. A variety of other useful information that could be posted on educational Web sites includes answer keys, posted immediately after exams; grades (password protected for privacy); handouts and study guides; laboratory information, including photos of laboratory instructors and candid photos of students at work (with permission); a forms page that allows students to type in a question and automatically e-mail it to the instructor; student questions, along with the instructor's answer, so that the whole class can benefit; a FAQ ("frequently asked questions") page with answers to such recurrent questions as "how can I get involved in undergraduate research?"; samples of exemplary student papers or lab reports to serve as models; a link to the instructor's personal page, where students can find more information about their instructor; current news items related to course topic; and summaries of student feedback and comments. Once templates are set up for such pages, they are easy to maintain and update.

In courses in which I have provided some or all of the features described above, feedback has been very positive (Terry 1999c). Many students express the wish that all instructors would provide these types of resources, and the majority of students believe that their performance improves as a result. I am in the process of collecting statistical data to examine whether such improvement can be objectively measured.

What lies ahead?

Web technology and usage continues to evolve rapidly. If current trends continue, the following outcomes seem likely:

- Most college students will own or have ready access to a computer and to the Internet. Computer literacy will become one of the expected outcomes of a college education, and graduates lacking such skills will suffer in the job market; therefore, university instructors will be expected to provide relevant computer-based instruction.
- The quality and quantity of educationally useful materials on the Web will continue to improve. For example, the American Society for Microbiology (ASM) is in the process of collecting and editing an extensive Web-based resource collection for use in microbiology education, including images, animations, videos, and laboratory and classroom activities written by microbiology educators (ASM 1999). This collection will be maintained on ASM's Web site, and users will be able to add comments and feedback to many of the activities. Other societies in the biological sciences are likely to adopt similar stratagems.
- More and more faculty will use the Web to supplement and enrich course content. One major university (University of California–Los Angeles) has already instituted a policy that all courses must have a Web site and provided resources to support this requirement. Many higher education institutions provide some support for faculty using the Web, and this support should become more extensive. An increasing number of college courses will include Web materials as substantial and useful course components.

References cited


1997. Animation of electron trans-


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