Teaching with Technology

Improvements in Undergraduate Science Education Using Web-Based Instructional Modules: The Natural Science Pages

Anthony Carpi
Department of Sciences, John Jay College, CUNY, New York, NY 10019; *acarpi@jjay.cuny.edu*

In the decade since Tim Berners-Lee and CERN first released the hypertext program that has served as the foundation of the World Wide Web, the Internet has grown to become one of the most significant advancements in information distribution since the invention of the printing press (*1*). Over the past 5 years the number of registered Internet domains has grown from approximately 5 million to more than 93 million (*2*). The number of Internet users exceeded 400 million in 2000 and the number of Web pages available is expected to exceed 5 billion by the end of 2001 (*3, 4*). The proliferation of information openly available on the Web has catalyzed a major shift in educational paradigms. Instructors now cite Internet use as one of the most valuable aspects of computer technology for education, nearly half of all U.S. higher education institutions engage in online learning, and 50% of college students own personal computers (*5*). Many colleges now actively encourage (and some require) faculty to place course material on the Web (*6*).

The Web holds several advantages over traditional teaching resources for enhancing education. First, the ability of the Web to deliver interactive multimedia content overcomes the limitations of static resources such as textbooks in conveying complex and dynamic subject matter. Second, the proliferation of free educational content on the Web, including online news stories, library holdings, and virtual museums, represents an unprecedented opportunity for instructors to expand student access to educational material. Third, the capacity of the Web to allow the user to control the pace and order of the content presented creates an inquiry-based learning environment tailored to individual educational needs. Given these advantages, educators are increasingly recognizing the benefits of using the Web in traditional classroom instruction (*7*).

In 1998, I created a content-rich Web site, *The Natural Science Pages*, *http://web.jjay.cuny.edu/~acarpi/NSC/index.htm*, to leverage the strengths of the Web for enhancing pedagogy in an introductory science course (Introduction to Science in Society) at John Jay College. The site has proved popular with student users and has significantly increased interest and success in the target course. This paper details the pedagogical design of the course Web site and presents results from course exams and surveys administered one semester before and two semesters after the launch of the site.

Project Design

John Jay College is a senior college within the City University of New York. Located in the heart of Manhattan, John Jay draws widely on the inner-city, lower-income minority populations throughout all five boroughs of New York City and nearby suburbs. Introduction to Science in Society (NSC 107) is a non-major core requirement at John Jay

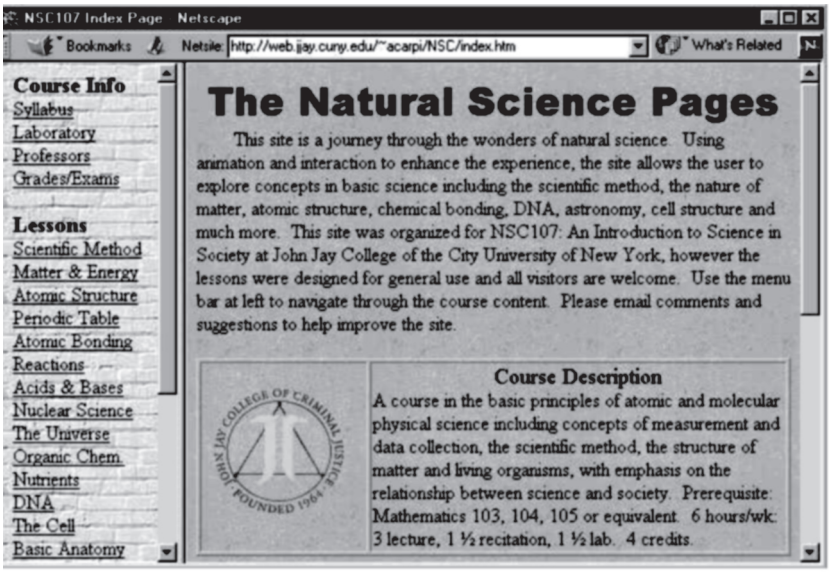

Figure 1. Home page of *The Natural Science Pages* course Web site.

College and is taught as a large lecture (typically 100 to 150 students) with smaller (<32) laboratory sections. The interdisciplinary course introduces nonscientists to a broad spectrum of scientific concepts and principles and serves as a foundation for a second core science requirement at the College. Because it is a non-major requirement, enrolled students have a wide range of science backgrounds. The large class size and diverse science backgrounds of students challenge course instruction by the need to teach concepts at a level that can be understood by all students yet in a manner that is engaging to students with more extensive science backgrounds. This problem is exacerbated by the inflexibility and inadequacy of traditional textbooks in conveying dynamic scientific concepts.

To address these issues, I created *The Natural Science Pages*. The site, pictured in frame format in Figure 1, provides access to course information and lessons written specifically for NSC 107. The Course Info section (Fig. 1, left frame, top) provides easy access to a syllabus, laboratory information, instructor contact information and grading data. The Lessons section (Fig. 1, left frame, bottom) provides enrichment modules that explain core scientific concepts and include explanatory animations and links to external sites to ground the lessons in research discoveries.

The *Natural Science Pages* site includes 20 original animations that help convey dynamic scientific concepts such as electron orbital theory, chemical bonding, and protein synthesis. Many modules also include interactive exercises to allow students the opportunity to learn by doing (*8*). All of the enrichment modules also include links to relevant external Web pages. These external links serve several purposes. First, links to external pages complement the lesson presented by giving those students struggling with the subject matter background readings to help further explain scientific principles. While relevant science lessons are prolific on the Web, this type of resource is difficult to make available to students off-line. External links also provide advanced readings that give those students who find a given lesson of particular interest an opportunity to explore the concept in further depth than is taught in class. For example, a module on the *Periodic Table* supplies a link to *The Particle Adventure*, a site detailing the history of subatomic particle discoveries from the Lawrence Berkeley National Laboratory (*9*). Finally, external links help to ground the lessons in historical and current research discoveries. A module on the structure of DNA, for example, links directly to James Watson and Francis Crick's pioneering paper "A Structure for Deoxyribose Nucleic Acid" (*10*).

Site Use and Pedagogical Value

Internet access and Web use were important considerations for this project given the large population of minority (29% Black and 37% Hispanic, Fall 1998 undergraduate enrollment) and lower-income students at John Jay College for whom Internet use is traditionally less widespread (*11*). Before the launch of the *Natural Science Pages* site, an anonymous survey was given to course students regarding their computer and Internet experience. Of the 172 students who responded, 98% stated that they had some computer experience and 77% had experience using the World Wide Web and Internet. Over 50% of students stated that they had access to the Internet at home, and over 60% stated that they had regular access to the Internet outside of college (at home or work).

Table 1. Mean Examination Scores before and after Launch of the Natural Science Pages Web Site

	Before Launch	After Launch			
Exam No.	Fall 1997 (n = 197)	Fall 1998 (n = 257)		Spring 1999 (n = 139)	
	Score ± 99% CI	Score ± 99% CI	p	Score ± 99% CI	p
1	56.3 ± 2.6	64.5 ± 2.2	.01	67.5 ± 2.8	.01
2	72.6 ± 2.5	70.7 ± 2.1	.14	67.7 ± 3.0	.09
3	70.0 ± 3.0	80.1 ± 1.9	.01	77.7 ± 2.5	.01

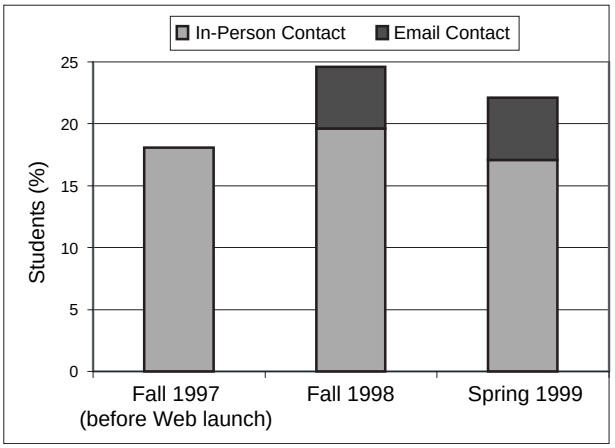

Figure 2. Student–instructor communication opportunities before and after launch of the course Web site.

The *Natural Science Pages* site was publicly launched on August 12, 1998, prior to the start of the Fall 1998 semester. To gauge interest and acceptance of the site, course students were given the site address (URL) on the first day of the Fall 1998 semester and they were informed of its contents; however, they were not required to use the site. Students were required to purchase an introductory textbook used in previous semesters for the course. In two independent surveys of the Fall 1998 classes, 63% of 148 registered students had used the site by the end of the first month of the semester and 82% had used it by the end of the semester. Of those students who had used the site by the end of the term, 92% stated that the course Web site helped them to better understand the material taught in the course (63% were strong affirmatives). Over 75% of students who had used the site stated that the course Web site was more helpful than the required introductory textbook.

Many students submitted written comments in an optional space provided on the survey instrument. Over 95% of written comments received were supportive of the course Web site. One student stated, "I am one of your NSC 107 students at John Jay and just wanted to thank you for the site. It is helping me a great deal. I wish more classes offered on line supplements." Another student submitted this statement comparing the course Web site and the required textbook, "I think that the Web site is an excellent idea. It should re-

place the book! I have the book, but I don't have a computer. However, I have visited the Web site more times than I have opened the book."

Many of the students who submitted written comments stated that the course Web site helped improve their performance in the course. One student stated, "I know that I will do twice as good as I had originally planned to do in this class." Another responded, "I got A's in this class and I believe it was largely due to the Web site." A third student summed up this sentiment, "The Web site definitely helped my grade." In fact, in a survey question designed to gauge the impact of the course Web site on the students' grades in the course, 74% of students enrolled in the course in the Fall 1998 semester and 66% of students in the Spring 1999 term stated that the course Web site helped improve their grade.

Results on course examinations support these student comments. Course performance is gauged by a series of three standard, multiple-choice examinations given over the course of the semester. In the two semesters after the launch of the course Web site, average scores on two of three exams were significantly higher than in the one semester prior to the launch of the course Web site (see Table 1).

Analysis using a two-way *t*-test confirmed that average scores on exams 1 and 3 were between 8 and 11 points higher (p = .01) after the launch of the Web site than exam scores prior to the site launch. To determine if average student ability differed in any of these semesters, cumulative GPA data were obtained for all students. There were no statistically significant differences; in fact, the mean student GPA was 2.7 in all three semesters. No significant differences were seen in exam scores in the two semesters following the site launch, supporting the hypothesis that the Web site was the causative factor for increased exam scores. No significant differences were apparent between test scores on the second examination. It is likely that the Web site had a greater effect on performance for exams 1 and 3 because these two exams cover more highly technical material.

All of the data sets tested positive for normality using the Kolmogorov–Smirnov test, meeting the assumption of the Student *t*-test. Three of the data sets, however, tested positive only at low confidence because of slightly extended tails at the low end of the grade range. While this slightly skewed distribution is expected, the analyses were repeated using the nonparametric Mann–Whitney test. The Mann–Whitney results confirmed all of the conclusions listed above.

Overall course performance also improved in the semesters following the launch of the course Web site. The number of students receiving a letter grade of C (satisfactory) or better increased from 68% in Fall 1997 before the launch of the site to 82% and 74% in the Fall 1998 and Spring 1999 semesters, respectively. Course failures decreased from 8.5% prior to the Web site launch to 4.2% and 5.0% in the two semesters following site launch.

The course Web site expanded communication and teaching opportunities in the course. In the semester prior to site launch, 18.1% of enrolled students sought outside help from the instructor by means of in-person office-hours meetings. Following the site launch, in-person office-hours appointments remained comparatively constant at 19.6% and 17.1% of enrolled students in the Fall 1998 and Spring 1999 semesters, respectively. However, in the two semesters following launch of the site, an additional 5% of enrolled students contacted the instructor via email to ask questions and seek extra tutoring (Fig. 2). The relatively anonymous nature of email communication appears to allow otherwise inhibited students to more actively participate in course discussions. In one particularly memorable email message a student inquired about the similarity between intercellular communication and cooperation and the population of "Borg" from the television program *Star Trek: The Next Generation*.

In addition to its utility in the target course, the *Natural Science Pages* site has generated widespread interest outside of John Jay College. In its first semester of use, the site received more than 9,000 visits; as of Jan 23, 2001, it had logged more than 55,000 visits and the site had been accessed from more than 67 countries (*12*). One external visitor commented, "Your course home page is terrific. Makes me want to enroll in your course."

Project Evaluation

As a means of evaluating and improving the conceptual design of the site, the project solicited feedback from NSC 107 students and external users through in-class surveys, email comments, and student interviews. This feedback has helped clarify strengths and identify needed modifications for the project's continuation.

The modular design of the lessons has been identified as a significant strength of the site because, as intended, it helps to focus users on a given topic and allows them to progress through the content at their own pace. During extensive interviews with site users, it was discovered that many students were printing the lessons, reading them at their leisure, and then returning to the site (usually via the high-speed connection available at the College) to view the animations and links connected to the lessons. This was especially the case for students who had no or inadequate Internet access from their home. It was therefore recognized that modifying the lesson format to facilitate printing would significantly enhance the utility of the material to minority and underprivileged populations that have less access to computer technology.

User comments have been overwhelmingly supportive of the animations that illustrate many of the modules; however, the practice of placing animations directly on the lesson page has been identified as problematic. Users find the background motion distracting when they are trying to read the lessons and embedded animations are cumbersome when a user tries to print lesson material. Also, because animations tend to have large file sizes, placing them directly on the lesson pages slows loading times. Users have suggested that separating animations from the main module window would improve the site design.

Site users have been strongly supportive of the external links placed on the module pages. Many have commented that external links would be more helpful if categorically arranged to differentiate background reading from advanced sites that allow study beyond the scope of the course. Users have also expressed a desire for additional links to interactive problem-solving exercises on the modules.

Feedback submitted via email has suggested that a large number of instructors outside of John Jay College have found the site helpful in classrooms other than the target course.

Because the site was originally designed for a single class, external instructors cannot customize the lesson order or Course Info links. This feedback suggests that a dynamic interface that allows some degree of customization would permit the site to be more effectively used by external instructors with different curricular objectives.

As a result of the widespread success of the *Natural Science Pages* site and to incorporate the enhancements identified above, I recently launched a public science education portal entitled Visionlearning. The Visionlearning project (*http://www.visionlearning.com*) provides modular, interdisciplinary science lessons that are formatted to optimize printing, load concept animations in separate windows, and have extensive categorically arranged links to existing Web content to enhance the learning environment. These links incorporate relevant educational material such as current news stories, interactive experiments, biographies of key scientific figures, and "further exploration" pages to enhance the experience. In addition, the site features a dynamic interface that allows external instructors to customize lesson order and incorporate links to individual course home pages, syllabi, and other personal resources. Development of Visionlearning is being funded in part by the National Science Foundation's Educational Materials Development program.

Discussion

Despite the proliferation of educational and classroom material on the Internet, few published studies document the strengths or weaknesses of using the World Wide Web as a teaching tool. Classroom Web content can significantly extend traditional teaching resources by providing interactive multimedia material not available with static printed pages and by leveraging the wealth of existing Web content to provide a rich learning environment. Student surveys, test scores, and course performance data from this study all suggest that properly designed Web-based course supplements can increase student interest and success in science education.

Given the potential advantages of Web-based teaching resources, more instructors need access to Web-based course materials. Several barriers currently prevent the widespread use of the Internet in science classrooms. Web page construction remains a technical activity that requires some understanding of HTML programming and file transfer protocols (despite the proliferation of Web programming software). High-quality page design requires training and experience to ensure that pages are understandable and easily navigable and convey the intended message. Maintaining a Web-based classroom requires time, technical experience, and vigilance to update old or broken page links, as the open nature of Web publishing means that pages range in accuracy, load at different speeds, and can be removed at any time. Unfortunately, most instructors lack the technology training and time necessary to develop content-rich course supplements, and institutions are failing to address these needs (*13*). To truly leverage the advantages of the Web in education, instructors need access to high-quality, consistent educational content in an easily customizable format and education-technology training to help them incorporate Web resources into the classroom.

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