Development and Student Use of Web-Based Prelabs in Analytical Chemistry Courses

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Abstract

This paper describes the development and student use of Web-based prelabs in freshman-level Quantitative Analysis and senior-level Instrumental Analysis. The main goal of these prelabs is to help students prepare to do experiments or use instrumentation before they enter the lab. Typical Quantitative Analysis prelabs include a Beer's law tutorial and a tutorial and demonstration of a Spectronic 20 spectrophotometer. Spectroscopy prelabs in Instrumental Analysis include tutorials on the principles and instrumentation of atomic absorption, atomic emission, UV-Vis molecular absorption, and molecular fluorescence spectroscopy. The prelabs contain some or all of the following: textual descriptions, instrument schematics, graphical instrument tours, multiple-choice questions, slide shows, and video demonstrations. The programming tools used to deliver the prelabs include clickable-image maps, JavaScript, PERL scripts, and RealVideo streaming video. Student and instructor perceptions indicate that the prelab assignments help the students prepare for their lab work and help teach the principles of the experiments or instrumentation. The overall effectiveness of the prelabs is hindered by the difficulty in getting students to take greater responsibility for their own lab preparation and outcomes. Using these prelabs has made evident the challenge of teaching students to use all available learning aids effectively: lectures, textbook, lab work, and multimedia.

Introduction

Teaching spectroscopy in our analytical chemistry courses emphasizes laboratory work and measurement concepts. We continually reinforce basic analysis concepts such as accuracy, precision, and detection limits. We do not stress theory, but we do emphasize the connection between a measurable or observable to the relevant atomic or molecular-scale process. We especially try to avoid treating analytical instruments as "black boxes." Our philosophy is that conveying an understanding of a measurement provides students with the ability to reason through non-typical or difficult analyses.

This paper describes the development and student use of Web-based prelabs for teaching spectroscopic concepts and instrumentation in freshman-level Quantitative Analysis and senior-level Instrumental Analysis. Our initial motivation to implement computer and network technology in these courses was logistical, i.e., to make efficient use of instructor time when teaching multiple sections of the same course or when student groups rotate through a sequence of lab experiments. The prelab assignments would replace repetitive and time-inefficient lab lectures with interactive exercises to familiarize students with the laboratory experiments and instrumentation before their laboratory session.

The continued development and use of the on-line material has focussed on changing the pedagogy of our courses to shift more responsibility for lab preparation to the students. We treat the prelabs as one of many resources to accomplish a task. We think that this approach better simulates the work environment. There is also an implicit assumption that greater preparation will increase the learning effectiveness of the time students spend in the laboratory.

The logistics of large enrollment science courses can allow students to come to a laboratory with no preparation and follow a cookbook recipe to complete their required work. This practice avoids much of the thinking and reasoning that aid the learning process during laboratory work. It also does not help the students to understand the underlying concepts, i.e., lecture material, and requires lab time to explain simple things that are in an experiment handout. Prelab quizzes can get students to read an experiment handout, but they require lab time and do not necessarily help students who read the handout but do not understand the information in the handout. Adding hypermedia prelabs has the potential to be more effective than a text handout alone because it can incorporate remedial material, graphics, video, and self-evaluation questions. A text handout is still necessary as instructions and reference for the students during the laboratory.

Technical Details

Web page creation

The WWW was chosen as the delivery platform for the prelabs because of the ease of developing, modifying, and distributing hypermedia material over a network to PC or Mac clients.[1] The disadvantage of the WWW is that network bandwidth can limit the size and resolution of hypermedia material. Several years ago, video clips of approximately one minute or less required users to have Ethernet connections rather than modems. Current streaming video technology allows video to be a reasonable delivery mechanism over modem connections. Table 1 lists some of the programs that we use for development of Web-based hypermedia.[2,3] A major disadvantage of using multiple development programs is that it is very time consuming for one person to become an expert at any one of them.

Table 1

Web page creation	HTML editor - HomeSite™ - http://www1.allaire.com/products/homesite/ Search and replace utility - XReplace - http://www.vestris.com/software/xreplace/ Schematic and graphics creation - Freelance Graphics™, Microsoft PowerPoint™, or AutoDesk AutoSketch™ Images - Kodak™ DC40 digital camera Image editing - LView™ - http://www.lview.com/
Programming	JavaScript (no development software used) - Online JavaScript Reference Manual Image map creation - Map This! or MapEdit - http://www.boutell.com/mapedit/ PERL and CGI (no development software used) - http://www.perl.com/

Streaming Media

Videos were recorded with a standard Video Camcorder and were captured onto a 233 MHz Pentium II^{TM} computer using a MiroVideo DC 30+ video capture card (30 frames/sec with 10:1 compression). These captured AVI files were subsequently edited and audio added using Adobe Premier^{TM} (Version 4.2) software. The final edited files, typically 5 - 10 minutes long and approximately 10 MB in size were saved in the AVI format.

Slide shows were generated similarly using Adobe Premier^{TM}. The slide-shows were typically prepared using Freelance Graphics^{TM} and/or Powerpoint^{TM} software. Individual slides were saved as JPEG files, imported into Premier, and arranged along the presentation timeline. Narration of each slide was added, and the duration of each slide was adjusted to match the narration. When complete, the slide show was saved in the AVI format.

The AVI files were converted to streaming video using Real Producer Plus G2^{TM}. The files, generated in the Surestream^{TM} file format, allow a single media file to be viewed efficiently over the Internet at a variety of connection speeds. This aspect is important in presenting video files over the Internet because video quality is a function of many factors that are impossible to know in advance (e.g. individual connection speeds, Internet congestion, etc.). The Surestream^{TM} file will scale the transmission bit rate dependent on the user's connection speed. The limitation of the Surestream^{TM} file is that the client computer must be running the RealPlayer G2^{TM} media player. Although RealPlayer G2^{TM} is available by free download, when we began using streaming video during Spring 1999 the G2 player had just been introduced and was not the default player bundled with most web browsers.

The completed media files are placed on a Real Video G2 Basic Server^{TM}. The computer used as the server is a 133 MHz Pentium computer running the Linux operating system (kernel version 2.2.6). The files could also be served by http using a standard web server (e.g. Apache). Http serving, however, limits the video transmission to a single bit rate, eliminating the advantage of the Surestream^{TM} file format. The Real Server G2^{TM} also provides a wealth of administrative features that are useful to an educational setting. It has a login feature, providing information regarding the usage of specific files. The administrator can limit the number of times files can be viewed. Files can have restricted availability based on IP number of connecting computer, by user login ID, by date, etc.

As an example of the utility of the streaming video format, the links below are to the same video file prepared in two different file formats: a standard AVI file, and a Real Media file.

AVI: http://www.chem.vt.edu/chem-dept/anderson/2124/indicator.avi
(requires Windows Media Player or equivalent)

RM: http://arg.chem.vt.edu:8080/ramgen/2124/indicator.rm
(requires Real Player G2 - http://www.real.com/welcome/index.html)

Each file is approximately 8 MB in size. Depending on connection speed, the time to begin playing these files can differ dramatically. When accessing by a 56K modem, for example, the AVI file requires more than 10 minutes to download and play. At the same connection speed, the RM file begins playing within approximately 1 minute. The difference lies in the requirements of the different media files. AVI files must download completely before playing. Streaming files, however, begin playing after only a portion of the file has downloaded to the client computer. The complexity of the media file (e.g. video, audio, slide-show, or some combination), as well as the connection speed, determines the amount of "pre-load" required before the file begins to play. As the file is playing, the remainder continues to download into a buffer on the client computer. Regardless of the intrinsic value of the video files, students will not watch files that require long download times prior to playing. With the AVI files, this limitation restricts the files to less than 30 seconds, hardly long enough to present a meaningful topic. Real Media files, however, of virtually any length will begin playing almost immediately after access.

A second advantage of the Real Video^{TM} files is the opportunity to assemble multiple files into a single presentation or to add interactivity to the video presentation. This is illustrated in the following example where hyperlinks appear during the video slide show that lead the viewer to more detailed information.

SMIL: http://arg.chem.vt.edu:8080/ramgen/2124/spec20smil.smi

This interactivity is accomplished using SMIL files. SMIL is a mark-up language, similar to HTML, except that it is for generating media files. In this example, text is added to a region below the video presentation. The appearance of the hyperlinked text is timed within the SMIL presentation to coincide with relevant discussion during the slideshow. As an education tool, the hyperlinked subtitles can be used to provide more detail, anticipate questions, or reinforce the concept presented in the video. The combination of the SMIL mark-up language with the streaming file formats offers a very powerful method for presenting laboratory concepts over the Internet.

Quantitative Analysis Laboratory (CHEM 2124)

We first used streaming videos in prelaboratory assignments during the spring 1999 semester for Chemistry 2124, Quantitative Analysis laboratory. This course is restricted to B. S. Chemistry and Chemical Engineering majors, and has a typical enrollment of 80 students. In general, this presentation of prelaboratory information was well received by the students. We plan on refining the prelaboratory materials and the server administration for the spring semester 2000.

The availability of text, graphics, and video allows an efficient presentation of the focal point of individual laboratory exercises over the web. Until recently, however, transmission of video files over the Internet has been slow and of poor quality. Within approximately the last 12 months, software technology has improved to the point that full-motion video may be viewed over the Internet with sufficient resolution and fast enough download times to be useful for demonstrating laboratory procedures. Streaming audio/video files can begin to play on the student computer almost immediately. With streaming video, the Internet provides a useful platform for demonstrating new laboratory procedures.

For example, an experiment early in the Quantitative Analysis laboratory requires the use of bromocresol green indicator for an acid-base titration. Unfortunately, this laboratory comes prior to the discussion of acid-base indicators in the lecture portion of the class. The use of a streaming slide show provides a mini-lecture (approximately 6 minutes in duration) on the behavior of acid-base indicators and shows the colors to expect with the bromocresol green indicator.

RM: http://arg.chem.vt.edu:8080/ramgen/2124/indicator.rm
(requires Real Player G2 - http://www.real.com/welcome/index.html)

Unlike a typical in-class lecture, the streamed video slide-show provides the opportunity to view the material again should a student not understand the presented concept. Unfortunately, when using the web-based presentation the students cannot ask questions of the lecturer. During the videos, however, hyperlinks may appear which direct the students to additional information on the topics being discussed should it be needed. The use of the streaming video, we feel, provides a consistent presentation to all of the students in the different laboratory sections of the course.

While the acid-base indicator illustrates the usage of web-based streaming video, the real value of this presentation style lies in demonstrating the use of unfamiliar instrumentation to the students. Frequently, this course is the students' first hands-on experience with many instrumental measurements (e.g. pH meters, spectrometers, analytical balances), and the student performance (hence, grade) depends on proper use of this equipment. The challenge is to instruct the student on the proper usage of unfamiliar instruments, while not turning the instrument into a black-box. Teaching spectroscopy is especially challenging at the Freshman/Sophomore level because students typically have limited exposure to atomic/molecular energies. Presentation in a laboratory lecture would require too much time, and runs the risk of becoming a "how-to-run" the instrument presentation. Streaming videos provided over the Internet provides an opportunity to integrate the theoretical background with a description of the instrument used in the laboratory.

Prelaboratory: http://www.chem.vt.edu/chem-dept/anderson/2124/2124-experiment11.html
(opens in new window)

Student Use and Perception

The challenge is to insure that the students make use of the available material. During the spring semester of 1999, on-line pre-laboratory quizzes were used as a formal check that students were using the available resources. While forcing the students to log onto the web-site, the on-line quizzes do not require the students to take full advantage of the material. The server log files provide anecdotal evidence of student usage. During the spring semester 1999 (the first semester that the streaming videos were used in the 2124 laboratory course), the access log file was monitored weekly. Video streams were accessed, on average, a number of times equivalent to approximately 80% of the course enrollment. This number should be contrasted with the nearly 100% completion of the on-line pre-lab quiz (completion of the pre-lab quiz was required for admission into the laboratory every week). Although not an exhaustive study, the log files suggest that not all students were using the material.

Student feedback concerning the videos was generally positive. Some students, however, had difficulties when accessing the materials over a slow Internet connection (e.g. poor video quality, disruption of the video stream due to net traffic, etc.). An unanticipated problem was in configuring the video player software on client computers (e.g. student's personal computers or computers in University laboratories). RealPlayer software is freely distributed, but technology in this area changed dramatically during the semester when the videos were first used. The server used was the RealServer G2 Basic Server. This server uses a dynamically calculated bit rate to stream the data at the optimal value for individual connection speeds. This greatly simplifies the production of the audio/video streams because only one stream is required to efficiently serve all connections speeds. Prior to the G2 server, the audio/video content was generated either (i) to meet the slowest common connection speed, or (ii) the audio/video files were compiled separately to match the connection speed. Unfortunately, the G2 compatible streams that we produced were not backward compatible with the previous generation RealPlayer. This problem should disappear as new production software allows the Audio/Video streams to be compiled so that they are backward compatible.

Instrumental Analysis (CHEM 4114)

We have used Web-based prelabs in Instrumental Analysis since the fall of 1995. This course typically has an enrollment of 20-30 students and consists of three hours of lecture and a three-hour laboratory. The students are senior B.S. chemistry majors and approximately half of the students go on to graduate or professional school and half go into industry.

There are two or three lab sections with a maximum of 12 students per section. The students work in groups of 2 or 3 and cycle through three or four different lab experiments during four-week time periods (see Table 1). The course web page (http://www.chem.vt.edu/chem-dept/tissue/4114/index.html) has the typical material for students, including a syllabus, a question-and-answer page, a page of announcements and textbook assignments, downloadable exam solutions, final project instructions and resources, and the interactive prelab assignments.

Table 2. Sequence of laboratory experiments in Instrumental Analysis (Fall 1999).

Statistics	Introduction to Statistics (spreadsheet exercise)
Spectroscopy Sequence	Flame and Graphite-Furnace Atomic Absorption (metals in soil) Flame Atomic Emission (calcium in water) UV-Vis Absorption (caffeine and acetylsalicylic acid in analgesic tablet) Fluorimetry (quinine in tonic water)
Chromatography Sequence	Quantitative Gas Chromatography (organic solvents) Supercritical Fluid Extraction (fat in potato chips) High-Performance Liquid Chromatography (parabens in lotions) Size-Exclusion Chromatography (polystyrene standards, styrofoam cup)
Electrochemistry Sequence	Fluoride Ion-Selective Electrode (mouthwash) Cyclic Voltammetry (Fe(CN)63-) Inorganic and Organic Polarography (Cd, maleic and fumaric acid)

The on-line statistics lab contained instructions, data, and hyperlinks to reference formulas. Data could be cut out of the browser window and pasted into a spreadsheet. The instructions told the students to write formulas and plot the data and then tape printouts of their work into their lab notebooks to be graded. The main purpose of this lab was to ensure that all students were proficient using a spreadsheet. It also gave them a set of formulas to use for data analysis in their later lab write-ups. In past years we've also used a similar mass spectrometry dry lab. A web page contained links to tutorial documents, mass spectral data in JCAMP-DX format, graphics files, and instructions. The students read the tutorials, downloaded data, and answered questions that were taped into their lab notebooks for grading.

Prelab Exercises

During Fall 1999, the prelab assignments are worth 5% of the final grade and must be completed prior to lab for credit. The value and late policy differed in earlier years. Each prelab instructed the student to read the experimental handout before doing the prelab and provided relevant text reading. A prelab exercise consisted of a web page that had one or more links to descriptive hypermedia about the experimental set-up and instrumentation, an instrument tour, and links to multiple-choice questions. The following link shows an example of one of the prelab assignments.

Prelab Example: Atomic Absorption Spectroscopy
(opens in a new window).

The instrument tours use clickable-image maps and JavaScript. The multiple-choice questions are generated by a PERL script that runs via the common-gateway interface (CGI). The PERL script generates the question page that is displayed, evaluates the answer selected by the student, returns a response page, and logs the student credit to a data file. Usually at least one questions asks about something contained in the experiment handout.

Student Use and Perception

The use and student perception of the hypermedia prelabs were assessed from the student log file and from student responses to an instructor-designed feedback form that was collected at the end of the semester.[4] The log file for the multiple-choice questions showed that on-time completion during 1997 and 1998 was 80-90%. Some students would do all of the prelabs at the beginning of a four-week lab sequence so that they would not forget the prelab and miss the deadline. This approach is less effective than doing the prelabs shortly before lab. A few students would also redo the multiple-choice questions before an exam. From the 1998 survey, approximately 2/3 of the students did the prelabs from home and approximately 1/3 did them from computers in the chemistry department. Prior to 1997 most prelabs were done from on-campus computers. The following figures summarize survey results from 1997 and 1998. Some results of earlier surveys are published elsewhere.[5,6]

Figures 1 and 2 show student perception of the prelabs during 1997 and 1998. The responses suggest that the prelab exercises helped the students to understand the underlying concepts and to prepare for the laboratory experiments.

Figures 3 and 4 show that the students are neutral to having more prelabs to prepare for lab. They are positive about having computer-based material to help learn the lecture material. On the surface, this response would indicate that the students value the on-line material. Unfortunately, it also highlights that the students are not recognizing that the prelabs are the same material as covered in the course lectures.

Figures 5 and 6 show the student-reported time-on-task at doing the prelabs. The difference between 1997 and 1998 highlights the change in grading. During 1997 full credit was given for the on-time prelabs regardless of the student's answer. Approximately half of the class clicked through the prelab questions too quickly to obtain any benefit. In response to student feedback, the script was changed and in 1998 full credit was given for correct answers, half credit for wrong answers, and zero credit for late prelabs. During 1998 the students took the prelabs more seriously and spent more time reading and answering the questions.

Comments on the survey forms indicate that the instrument tours are useful. In the current implementation, there is no logging of completion to know if everyone looks at them. Another common comment is that the students like the flexibility of doing the prelabs at their convenience.

Summary

We think that the on-line prelabs are effective in helping students to learn spectroscopy and to make lab time more effective. The overall effectiveness of the prelabs is hindered by the difficulty in getting students to take greater responsibility for their own lab preparation and outcomes. Using these prelabs has made evident the challenge of teaching students to use all available learning aids effectively: lectures, textbook, lab work, and multimedia. A major consideration in developing this type of material is that learning the programming tools and developing and maintaining the on-line material requires substantial time and effort.

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